CAEPIPE™

Code Compliance Manual

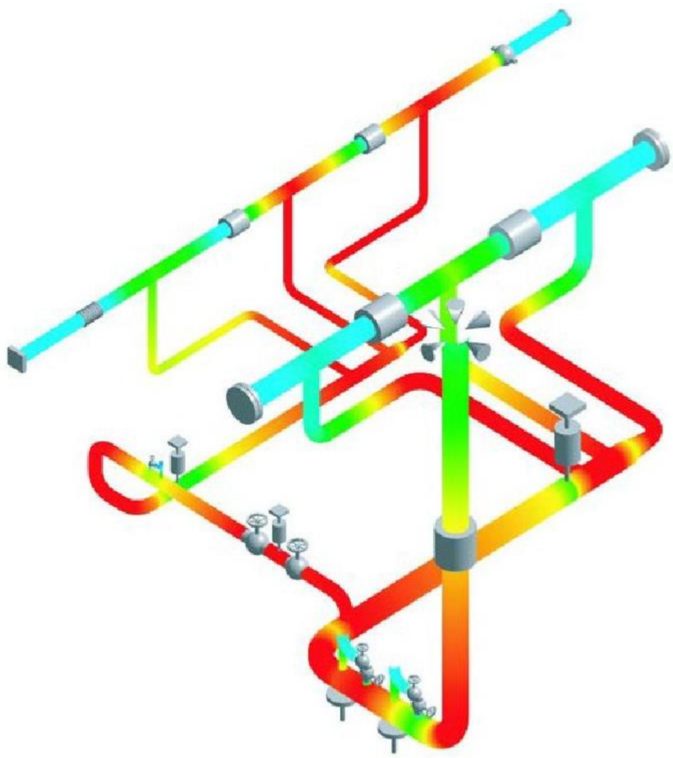

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Table of Contents

Table of Contents

Table of Contents

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Code Compliance Summary

Table given below lists the Piping Codes that are built into CAEPIPE Version 12.20 or later for Code Compliance checks with their piping type and analysis type covered.

Sl. No.	Piping Code and Description	Metallic / Nonmetallic Piping	Above Ground	Buried Piping
1	ASME B31.1 (2022) - Power Piping	Metallic	Yes	---
2	ASME B31.1 (1967) - Power Piping	Metallic	Yes	---
3	ASME B31.1 (1973) - Power Piping	Metallic	Yes	---
4	ASME B31.1 (1977) - Power Piping	Metallic	Yes	---
5	ASME B31.1 (1980) - Power Piping	Metallic	Yes	---
6	ASME B31.3 (2022) - Process Piping	Metallic	Yes	---
7	ASME B31.4 (2022) - Pipeline Transportation Systems for Liquids and Slurries	Metallic	Yes	Yes
8	ASME B31.5 (2022) - Refrigeration Piping and Heat Transfer Components	Metallic	Yes	---
9	ASME B31.8 (2022) - Gas Transmission and Distribution Piping Systems	Metallic	Yes	Yes
10	ASME B31.9 (2020) - Building Services Piping	Metallic	Yes	---
11	ASME B31.12 IP (2019) - Hydrogen Piping	Metallic	Yes	---
12	ASME B31.12 PL (2019) - Hydrogen Pipelines	Metallic	Yes	Yes
13	ASME NM.1 (2022) - Thermoplastic Piping Systems	Nonmetallic	Yes	---
14	ASME NM.2 (2022) - Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems (GRP/FRP)	Nonmetallic	Yes	---
15	ASME Class 2 (1980) - ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
16	ASME Class 2 (1986) - ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
17	ASME Class 2 (1992) - ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
18	ASME Class 2 (2015) - ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
19	ASME Class 2 (2017) ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
20	ASME Class 2 (2021) - ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
21	ASME Class 2 (2023) - ASME Section III, Subsection NC - Class 2	Metallic	Yes	---
22	ASME Class 3 (2017) - ASME Section III, Subsection ND - Class 3	Metallic	Yes	---
23	ASME Class 3 (2021) - ASME Section III, Subsection ND - Class 3	Metallic	Yes	---
24	ASME Class 3 (2023) - ASME Section III, Subsection ND - Class 3	Metallic	Yes	---
25	ISO 14692-3 (2017) - Petroleum and Natural Gas Industries - Glass Reinforced Plastics (GRP/FRP) Piping	Nonmetallic	Yes	Yes
26	EN 13480 (2020) - Metallic industrial piping	Metallic	Yes	Yes

Code Compliance Summary

Sl. No.	Piping Code and Description	Metallic / Nonmetallic Piping	Above Ground	Buried Piping
27	EN 13941 (2019) - District heating pipes	Metallic	No	Yes
28	BS 806 (1986) - Construction of Ferrous Piping Installations for and in Connection with Land Boilers (British)	Metallic	Yes	---
29	DNV-ST-F101 – Submarine pipeline systems	Metallic	Yes	---
30	IGEM (2012) - Institution of Gas Engineers and Managers (IGEM) IGE/TD/12 Edition 2 (UK)	Metallic	Yes	---
31	Norwegian (1983) - Process design	Metallic	Yes	---
32	Norwegian (1990) - Process design	Metallic	Yes	---
33	RCC-M (1985) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Metallic	Yes	---
34	RCC-M (2018) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Metallic	Yes	---
35	RCC-M (2020) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Metallic	Yes	---
36	RCC-M (2022) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Metallic	Yes	---
37	CODETI (2013) - CODE DE CONSTRUCTION DES TUYAUTERIES INDUSTRIELLES (French)	Metallic	Yes	---
38	Stoomwezen (1989) - Dutch Power piping code	Metallic	Yes	---
39	Swedish (1978) – Swedish piping code	Metallic	Yes	---
40	Z183 (1990) - Oil Pipeline Systems (Canadian)	Metallic	Yes	---
41	Z184 (1992) - Gas Pipeline Systems (Canadian)	Metallic	Yes	---
42	Z662 (2019) - Oil & Gas Pipeline Systems (Canadian)	Metallic	Yes	Yes
43	NONE (for AWWA M11 applications, and for applications in aircraft, aerospace & defence industries)	Metallic	Yes	Yes

Allowable Pressure

At this time, there is no provision in CAEPIPE to specify the type of pipe manufacturing process, i.e., whether the pipe is a seamless or longitudinal welded or spiral welded. Accordingly, irrespective of the type of pipe manufacturing process, for straight pipes and bends, CAEPIPE calculates allowable pressure using Eq. (9) of para.104.1.2 and Eqs. (3) & (5) of para. 102.4.5 (b).

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)} . \left(\frac{W}{I}\right)$$

where

P_a= allowable pressure

SE = maximum allowable stress for the material inclusive of weld joint efficiency factor E (or casting quality factor F) at the design temperature (i.e., at T_{design} input into CAEPIPE). The values of SE and SF are given in Mandatory Appendix A of ASME B31.1 (2024) Code.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

d = inside diameter of pipe

I = 1.0 for straight pipes and at the side wall on the bend / elbow centerline

Values for coefficient Y are as per Table 104.1.2-1. Refer to the Table listed at the end of this section for details on coefficient 'Y' implemented in CAEPIPE.

W = weld strength reduction factor as per Table 102.4.7-1. Refer to the Table listed at the end of this section for details on weld strength reduction factors implemented in CAEPIPE.

ASME B31.1 Code does not provide any explicit equation to compute Allowable Pressure for closely spaced and widely spaced miter bends. Hence, for ASME B31.1 Code, CAEPIPE computes the allowable pressure for miter bends using the explicit equations given in ASME B31.3 (2022) [see para. 304.2.3], as listed below.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a(R - r)}{r(R - r/2)}$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 0.643\tan\theta\sqrt{rt_a})}$$

For widely spaced miter bends with θ > 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 1.25\tan\theta\sqrt{rt_a})}$$

where

r = mean radius of pipe = $(D_o - t_n)/2$

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\dfrac{1.0}{\left(\dfrac{2R}{r} - 1.0\right)}\right)$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. 15 of para.104.8.1

$$S_L = \sqrt{\left[I_a\left|S_{lp} + \frac{F_a}{A_p}\right| + \frac{\sqrt{(I_i M_{iA})^2 + (I_o M_{oA})^2}}{Z}\right]^2 + \left(\frac{I_t M_{tA}}{Z}\right)^2} \le S_h$$

where

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE pressures P1 through P10

S_{lp} = longitudinal pressure stress as defined in para. 102.3.2(a)(3) = $\frac{PD_o}{4t_n}$ *or* $\frac{Pd_n^2}{D_o^2 - d_n^2}$

t_n= nominal wall thickness

D_o = nominal outside diameter

d_n = nominal inside diameter = $D_o - 2t_n$

F_a= longitudinal force due to weight and other sustained mechanical loads (excluding pressure)

I_a= sustained longitudinal force index = 1.00

I_i = sustained in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = sustained out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = sustained torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iA}, M_{oA}, M_{tA} = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads

Z = nominal section modulus = un-corroded section modulus

A_p= un-corroded nominal cross sectional area

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

S_L = stress due to pressure, weight and other sustained mechanical loads

Occasional Stress

The stress (S_O) due to sustained and occasional loads is calculated from Eq. 16 of para. 104.8.2 as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind. Wind and earthquake are not considered to act concurrently as per para. 101.5.2 and para. 101.5.3.

$$S_O = \sqrt{\left[I_a\left|S_{lpo} + \frac{F_b}{A_p}\right| + \frac{\sqrt{(I_iM_{iB})^2 + (I_oM_{oB})^2}}{Z}\right]^2 + \left(\frac{I_tM_{tB}}{Z}\right)^2} \leq kS_h$$

where

F_b = longitudinal force due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

S_{lpo} = longitudinal peak pressure stress = $\frac{P_oD_o}{4t_n}$ or $\frac{P_od_n^2}{D_o^2-d_n^2}$

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

t_n= nominal wall thickness

D_o = nominal outside diameter

d_n = nominal inside diameter = $D_o - 2t_n$

I_a= occasional longitudinal force index = 1.00

I_i = occasional in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = occasional out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = occasional torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iB}, M_{oB}, M_{tB} = in-plane, out-of-plane and torsional moment respectively due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

S_O = stress due to pressure, weight, other sustained mechanical loads and occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake, wind etc.

k = 1.2 for occasional loads acting for no more than 1 hr at any one time and no more than 80 hr/yr.

All other terms such as P, D_o, Z, etc. are as defined under Sustained Stress.

For Unsigned occasional load cases such as Earthquake, etc. the forces and moments are combined as given below.

$$I_a\left|S_{lpo}+\frac{F_b}{A_p}\right| = max\left[I_a\left(\left|S_{lpo}+\frac{F_{b(sust)}}{A_p}\right|+\left|\frac{F_{b(occa)}}{A_p}\right|\right), I_a\left(\left|S_{lpo}+\frac{I_aF_{b(sust)}}{A_p}\right|-\left|\frac{F_{b(occa)}}{A_p}\right|\right)\right]$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}\right|+\left|M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}\right|+\left|M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}\right|+\left|M_{tB(occa)}\right|\right]^2$$

For Signed occasional load cases such as Wind, etc. the forces and moments are combined as given below.

$$I_a\left|S_{lpo}+\frac{F_b}{A_p}\right| = I_a\left|S_{lpo}+\frac{F_{b(sust)}}{A_p}+\frac{F_{b(occa)}}{A_p}\right|$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}+M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}+M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}+M_{tB(occa)}\right|\right]^2$$

where

$M_{iB(sust)}$, $M_{oB(sust)}$, $M_{tB(sust)}$ = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads (excluding pressure).

$M_{iB(occa)}$, $M_{oB(occa)}$, $M_{tB(occa)}$ = in-plane, out-of-plane and torsional moment respectively due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

$F_{b(sust)}$ = longitudinal force due to weight, other sustained mechanical loads (excluding pressure)

$F_{b(occa)}$ = longitudinal force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

Expansion Stress Range (i.e., Stress due to Displacement Load Range)

The stress range (S_E) due to thermal expansion is calculated from Eq. 17 of para.104.8.3.

$$S_E = \sqrt{\left[\left|\frac{i_a F_c}{A_p}\right| + \frac{\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tC}}{Z}\right)^2} \leq S_A$$

where

F_c = axial force <u>range</u> due to reference displacement load range

A_p= un-corroded nominal cross sectional area

i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

M_{iC}, M_{oC}, M_{tC} = in-plane, out-of-plane and torsional moment <u>range</u> respectively due to the reference displacement load range

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

Z = nominal section modulus = un-corroded section modulus

$S_A = f(1.25S_C + 0.25S_h)$, from Eq. (1A) of para. 102.3.2 (b)

f = cyclic stress range reduction factor from Eq. (1C) of para. 102.3.2 (b),

$f = 6/N^{0.2}$ <= 1.0 and f >= 0.15 with N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping

S_C = basic allowable stress at minimum metal temperature expected during the displacement stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement stress range under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, from Eq. (1B) of para. 102.3.2 (b).

This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 2** below)

This is specified as an analysis option: "Use liberal allowable stresses", in the menu Options->Analysis on the Code tab of CAEPIPE.

Note:

1. Refer to the end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
2. As per Note 2 of para. 102.3.2 (b) (1) of ASME B31.1 (2024), "For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1A) and (1B) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_L) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1A) of para. 102.3.2.

Settlement Stress

The stress range (S_S) due to single, noncyclic displacement stress range (e.g., predicted settlement or uplift or movement of pipe support structures such as buildings, pipe racks, anchors, etc.) is calculated from Eq. 17 of Figure 104.8-1 as given below in accordance with para. 102.3.2 (b)(2).

$$S_S = \sqrt{\left[\left|\frac{i_a F_D}{A_p}\right| + \frac{\sqrt{(i_i M_{iD})^2 + (i_o M_{oD})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tD}}{Z}\right)^2} \leq 3S_C$$

where
i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

F_D = axial force range due to any single noncyclic anchor movement (e.g., predicted building settlement)

Ap= un-corroded nominal cross sectional area

M_{iD}, M_{oD}, M_{tD} = in-plane, out-of-plane and torsional moment range respectively due to any single noncyclic anchor movement (e.g., predicted building settlement)

Z = nominal section modulus = un-corroded section modulus

S_c = allowable stress at the Reference Temperature in CAEPIPE

Hydrotest Stress

The sum of longitudinal stress (S_L) due to test pressure, live and dead loads at the time of hydrotest shall not exceed 90% of yield strength at test temperature as per para. 102.3.3 (b).

$$S_{LT} = \sqrt{\left[I_a\left|\frac{PD_o}{4t_n}+\frac{F_a}{A_p}\right|+\frac{\sqrt{(I_iM_{iH})^2+(I_oM_{oH})^2}}{Z}\right]^2+\left(\frac{I_tM_{tH}}{Z}\right)^2} \leq 0.9S_y$$

where

P = The hydrostatic test pressure at any point in the piping system shall not be less than 1.5 times the design pressure as per para. 137.4.5.
D_o = nominal outside diameter

t_n= nominal wall thickness

F_a= longitudinal force due to hydrotest loads (excluding pressure)

I_a= longitudinal force index = 1.00

I_i = in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iH}, M_{oH}, M_{tH} = in-plane, out-of-plane and torsional moment respectively due to hydrotest

Z = nominal section modulus = un-corroded section modulus

A_p= un-corroded nominal cross sectional area

S_y = yield strength at test temperature [i.e., at Tref in CAEPIPE)]

S_{LT} = stress due to hydrotest loads

ASME B31.1 (2024) – Nonmetallic piping as per Chapter N-II

The Piping Code ASME NM.1 (2020) titled "Thermoplastic Piping Systems" provides methods to evaluate Nonmetallic piping such as PVC, CPVC, HDPE, etc. Code Compliance as per ASME NM.1 is built into CAEPIPE Version 12.00 or later. Hence, for Nonmetallic Piping Analysis, ASME NM.1 can be selected in CAEPIPE for Code Compliance checks.

Material Properties for PVC, CPVC, etc. are provided in "Chapter N-II" titled "Design" of ASME B31.1 (2024). These properties are already included in the material library for Plastics (B311-2024_N-II.mat) in CAEPIPE. In addition, Allowable Pressure calculation for Non-metallic pipe and pipe fittings as per Chapter N-II is already included into CAEPIPE as given below.

So, if you still wish to perform Nonmetallic piping analysis as per ASME B31.1 (2024), then the material properties for Nonmetallic piping can be selected from the material library (B311-2024_N-II.mat) supplied with CAEPIPE.

Allowable Pressure

From ASME B31.1 (2024) Chapter N-II, Allowable Pressure for Nonmetallic (thermoplastics) pipe and pipe fittings are computed using Eq. (2) of para. N-104.1.2(a)(1).

$$P_a = \frac{2S_a}{\left(\frac{D_o}{t_a} - 1\right)}$$

where

P_a= allowable pressure

S_a = hydrostatic design stress from Table N-102.2.1-1 of ASME B31.1 (2024) code (input into CAEPIPE material property for thermoplastics)

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE as per para. N-104.1.1)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

Coefficient 'Y' used in CAEPIPE to compute components Allowable Design Pressure
(extracted from Table 104.1.2-1 of ASME B31.1 – 2024)

S. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloy UNS No. N06690 (NA)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
4.	Other Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
5.	Cast Iron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	Material Types other than those stated from Sl. Nos. 1 to 5.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

1. If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y as

$$Y = \frac{d}{d + D_o}$$

Weld Strength Reduction Factors (W) used in CAEPIPE to calculate components Allowable Design Pressure (extracted from Table 102.4.7-1 of ASME B31.1-2024)

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)
1	Carbon Steel (CS) [see Note (a)]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
4	Material Description that contains a string “CrMo”	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64
5	Material Types other than those stated in Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

(a) Based on Note 7 of Table 102.4.7-1 of ASME B31.1 (2024) code, W = 1.0 for Carbon Steel (CS).

(b) For Austenitic Steels (including 800H and 800 HT), values up to 1500 deg F are as follows:

Temperature, deg F	Temperature, deg C	Weld Strength Reduction Factor
1250	677	0.73
1300	704	0.68
1350	732	0.64
1400	760	0.59
1450	788	0.55
1500	816	0.50

Allowable Pressure

At this time, there is no provision in CAEPIPE to specify the type of pipe manufacturing process, i.e., whether the pipe is a seamless or longitudinal welded or spiral welded. Accordingly, irrespective of the type of pipe manufacturing process, for straight pipes and bends, CAEPIPE calculates allowable pressure using Eq. (9) of para.104.1.2 and Eqs. (3) & (5) of para. 102.4.5 (b).

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)} \cdot \left(\frac{W}{I}\right)$$

where

P_a= allowable pressure

SE = maximum allowable stress for the material inclusive of weld joint efficiency factor E (or casting quality factor F) at the design temperature (i.e., at T_{design} input into CAEPIPE). The values of SE and SF are given in Mandatory Appendix A of ASME B31.1 (2022) Code.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

d = inside diameter of pipe

I = 1.0 for straight pipes and at the side wall on the bend / elbow centerline

Values for coefficient Y are as per Table 104.1.2-1. Refer to the Table listed at the end of this section for details on coefficient 'Y' implemented in CAEPIPE.

W = weld strength reduction factor as per Table 102.4.7-1. Refer to the Table listed at the end of this section for details on weld strength reduction factors implemented in CAEPIPE.

ASME B31.1 Code does not provide any explicit equation to compute Allowable Pressure for closely spaced and widely spaced miter bends. Hence, for ASME B31.1 Code, CAEPIPE computes the allowable pressure for miter bends using the explicit equations given in ASME B31.3 (2020) [see para. 304.2.3], as listed below.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a(R-r)}{r(R-r/2)}$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 0.643\tan\theta\sqrt{rt_a})}$$

For widely spaced miter bends with $\theta >$ 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 1.25\tan\theta\sqrt{rt_a})}$$

where

r = mean radius of pipe = (D_o - t_n)/2

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r} - 1.0\right)}\right)$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. 15 of para.104.8.1

$$S_L = \sqrt{\left[I_a\left|\frac{PD_o}{4t_n} + \frac{F_a}{A_p}\right| + \frac{\sqrt{(I_iM_{iA})^2 + (I_oM_{oA})^2}}{Z}\right]^2 + \left(\frac{I_tM_{tA}}{Z}\right)^2} \leq S_h$$

where

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE pressures P1 through P10

D_o = nominal outside diameter

t_n= nominal wall thickness

F_a= longitudinal force due to weight and other sustained mechanical loads (excluding pressure)

I_a= sustained longitudinal force index = 1.00

I_i = sustained in-plane moment index. I_i is taken as the greater of 0.75i_i and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = sustained out-of-plane moment index. I_o is taken as the greater of 0.75i_o and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = sustained torsional moment index. I_t is taken as the greater of 0.75i_t and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iA}, M_{oA}, M_{tA} = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads

Z = nominal section modulus = un-corroded section modulus

A_p= un-corroded nominal cross sectional area

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

S_L = stress due to pressure, weight and other sustained mechanical loads

Occasional Stress

The stress (S_O) due to sustained and occasional loads is calculated from Eq. 16 of para. 104.8.2 as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind. Wind and earthquake are not considered to act concurrently as per para. 101.5.2 and para. 101.5.3.

$$S_O = \sqrt{\left[I_a\left|\frac{P_oD_o}{4t_n}+\frac{F_b}{A_p}\right|+\frac{\sqrt{(I_iM_{iB})^2+(I_oM_{oB})^2}}{Z}\right]^2+\left(\frac{I_tM_{tB}}{Z}\right)^2} \le kS_h$$

where

F_b = longitudinal force due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.
I_a= occasional longitudinal force index = 1.00

I_i = occasional in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = occasional out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = occasional torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iB}, M_{oB}, M_{tB} = in-plane, out-of-plane and torsional moment respectively due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

S_O = stress due to pressure, weight, other sustained mechanical loads and occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake, wind etc.

k = 1.2 for occasional loads acting for no more than 1 hr at any one time and no more than 80 hr/yr.

All other terms such as P, A_p, Z, etc. are as defined under Sustained Stress.

For Unsigned occasional load cases such as Earthquake, etc. the forces and moments are combined as given below.

$$I_a\left|\frac{P_oD_o}{4t_n}+\frac{F_b}{A_p}\right| = max\left[I_a\left(\left|\frac{P_oD_o}{4t_n}+\frac{F_{b(sust)}}{A_p}\right|+\left|\frac{F_{b(occa)}}{A_p}\right|\right), I_a\left(\left|\frac{P_oD_o}{4t_n}+\frac{I_aF_{b(sust)}}{A_p}\right|-\left|\frac{F_{b(occa)}}{A_p}\right|\right)\right]$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}\right|+\left|M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}\right|+\left|M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}\right|+\left|M_{tB(occa)}\right|\right]^2$$

For Signed occasional load cases such as Wind, etc. the forces and moments are combined as given below.

$$I_a\left|\frac{P_oD_o}{4t_n}+\frac{F_b}{A_p}\right| = I_a\left|\frac{P_oD_o}{4t_n}+\frac{F_{b(sust)}}{A_p}+\frac{F_{b(occa)}}{A_p}\right|$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}+M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}+M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}+M_{tB(occa)}\right|\right]^2$$

where

$M_{iB(sust)}$, $M_{oB(sust)}$, $M_{tB(sust)}$ = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads (excluding pressure).

$M_{iB(occa)}$, $M_{oB(occa)}$, $M_{tB(occa)}$ = in-plane, out-of-plane and torsional moment respectively due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

$F_{b(sust)}$ = longitudinal force due to weight, other sustained mechanical loads (excluding pressure)

$F_{b(occa)}$ = longitudinal force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

Expansion Stress Range (i.e., Stress due to Displacement Load Range)

The stress range (S_E) due to thermal expansion is calculated from Eq. 17 of para.104.8.3.

$$S_E = \sqrt{\left[\left|\frac{i_a F_c}{A_p}\right| + \frac{\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tC}}{Z}\right)^2} \le S_A$$

where

F_c = axial force range due to reference displacement load range

A_p= un-corroded nominal cross sectional area

i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

M_{iC}, M_{oC}, M_{tC} = in-plane, out-of-plane and torsional moment range respectively due to the reference displacement load range

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

Z = nominal section modulus = un-corroded section modulus

$S_A = f(1.25S_C + 0.25S_h)$, from Eq. (1A) of para. 102.3.2 (b)

f = cyclic stress range reduction factor from Eq. (1C) of para. 102.3.2 (b),

$f = 6/N^{0.2}$ <= 1.0 and f >= 0.15 with N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping

S_C = basic allowable stress at minimum metal temperature expected during the displacement stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement stress range under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, from Eq. (1B) of para. 102.3.2 (b).

This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 2** below)

This is specified as an analysis option: “Use liberal allowable stresses”, in the menu Options->Analysis on the Code tab of CAEPIPE.

Note:

3. Refer to the end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

4. As per Note 2 of para. 102.3.2 (b) (1) of ASME B31.1 (2022), "For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1A) and (1B) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_L) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1A) of para. 102.3.2.

Settlement Stress

The stress range (S_S) due to single, noncyclic displacement stress range (e.g., predicted settlement or uplift or movement of pipe support structures such as buildings, pipe racks, anchors, etc.) is calculated from Eq. 17 of Figure 104.8-1 as given below in accordance with para. 102.3.2 (b)(2).

$$S_S = \sqrt{\left[\left|\frac{i_a F_D}{A_p}\right| + \frac{\sqrt{(i_i M_{iD})^2 + (i_o M_{oD})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tD}}{Z}\right)^2} \leq 3S_C$$

where
i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

F_D = axial force range due to any single noncyclic anchor movement (e.g., predicted building settlement)

Ap= un-corroded nominal cross sectional area

M_{iD}, M_{oD}, M_{tD} = in-plane, out-of-plane and torsional moment range respectively due to any single noncyclic anchor movement (e.g., predicted building settlement)

Z = nominal section modulus = un-corroded section modulus

S_c = allowable stress at the Reference Temperature in CAEPIPE

Hydrotest Stress

The sum of longitudinal stress (S_L) due to test pressure, live and dead loads at the time of hydrotest shall not exceed 90% of yield strength at test temperature as per para. 102.3.3 (b).

$$S_{LT} = \sqrt{\left[I_a\left|\frac{PD_o}{4t_n}+\frac{F_a}{A_p}\right|+\frac{\sqrt{(I_iM_{iH})^2+(I_oM_{oH})^2}}{Z}\right]^2+\left(\frac{I_tM_{tH}}{Z}\right)^2} \leq 0.9S_y$$

where

P = The hydrostatic test pressure at any point in the piping system shall not be less than 1.5 times the design pressure as per para. 137.4.5.
D_o = nominal outside diameter

t_n= nominal wall thickness

F_a= longitudinal force due to hydrotest loads (excluding pressure)

I_a= longitudinal force index = 1.00

I_i = in-plane moment index. I_i is taken as the greater of 0.75i_i and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = out-of-plane moment index. I_o is taken as the greater of 0.75i_o and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = torsional moment index. I_t is taken as the greater of 0.75i_t and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iH}, M_{oH}, M_{tH} = in-plane, out-of-plane and torsional moment respectively due to hydrotest

Z = nominal section modulus = un-corroded section modulus

A_p= un-corroded nominal cross sectional area

Sy = yield strength at test temperature [i.e., at Tref in CAEPIPE)]

S_{LT} = stress due to hydrotest loads

ASME B31.1 (2022) – Nonmetallic piping as per Chapter N-II

The Piping Code ASME NM.1 (2020) titled "Thermoplastic Piping Systems" provides methods to evaluate Nonmetallic piping such as PVC, CPVC, HDPE, etc. Code Compliance as per ASME NM.1 is built into CAEPIPE Version 12.00 or later. Hence, for Nonmetallic Piping Analysis, ASME NM.1 can be selected in CAEPIPE for Code Compliance checks.

Material Properties for PVC, CPVC, etc. are provided in "Chapter N-II" titled "Design" of ASME B31.1 (2022). These properties are already included in the material library for Plastics (B311-2022_N-II.mat) in CAEPIPE. In addition, Allowable Pressure calculation for Non-metallic pipe and pipe fittings as per Chapter N-II is already included into CAEPIPE as given below.

So, if you still wish to perform Nonmetallic piping analysis as per ASME B31.1 (2022), then the material properties for Nonmetallic piping can be selected from the material library (B311-2022_N-II.mat) supplied with CAEPIPE.

Allowable Pressure

From ASME B31.1 (2022) Chapter N-II, Allowable Pressure for Nonmetallic (thermoplastics) pipe and pipe fittings are computed using Eq. (2) of para. N-104.1.2(a)(1).

$$P_a = \frac{2S_a}{\left(\frac{D_o}{t_a} - 1\right)}$$

where

P_a= allowable pressure

S_a = hydrostatic design stress from Table N-102.2.1-1 of ASME B31.1 (2022) code (input into CAEPIPE material property for thermoplastics)

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE as per para. N-104.1.1)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 104.1.2-1 of ASME B31.1 – 2022)

S. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloy UNS No. N06690 (NA)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
4.	Other Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
5.	Cast Iron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	Material Types other than those stated from Sl. Nos. 1 to 5.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

2. If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y as

$$Y = \frac{d}{d + D_o}$$

Weld Strength Reduction Factors (W) used in CAEPIPE to calculate the Allowable Design Pressure of components (extracted from Table 102.4.7-1 of ASME B31.1-2022)

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)
1	Carbon Steel (CS) [see Note (a)]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
4	Material Description that contains a string "CrMo"	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64
5	Material Types other than those stated in Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

(c) Based on Note 7 of Table 102.4.7-1 of ASME B31.1 (2022) code, W = 1.0 for Carbon Steel (CS).

(d) For Austenitic Steels (including 800H and 800 HT), values up to 1500 deg F are as follows:

Temperature, deg F	Temperature, deg C	Weld Strength Reduction Factor
1250	677	0.73
1300	704	0.68
1350	732	0.64
1400	760	0.59
1450	788	0.55
1500	816	0.50

Allowable Pressure

At this time, there is no provision in CAEPIPE to specify the type of pipe manufacturing process, i.e., whether the pipe is a seamless or longitudinal welded or spiral welded. Accordingly, irrespective of the type of pipe manufacturing process, for straight pipes and bends, CAEPIPE calculates allowable pressure using Eq. (9) of para.104.1.2 and Eqs. (3) & (5) of para. 102.4.5 (b).

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)} \cdot \left(\frac{W}{I}\right)$$

where

P_a= allowable pressure

SE = maximum allowable stress for the material inclusive of weld joint efficiency factor E (or casting quality factor F) at the design temperature (i.e., at T_{design} input into CAEPIPE). The values of SE/SF are given in Mandatory Appendix A of B31.1 (2020) Code.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

d = inside diameter of pipe

I = 1.0 for straight pipes and at the side wall on the bend / elbow centerline

Values for coefficient Y are as per Table 104.1.2-1. Refer to the Table listed at the end of this section for details on coefficient 'Y' implemented in CAEPIPE.

W = weld strength reduction factor as per Table 102.4.7-1. Refer to the Table listed at the end of this section for details on weld strength reduction factors implemented in CAEPIPE.

ASME B31.1 Code does not provide any explicit equation to compute Allowable Pressure for closely spaced and widely spaced miter bends. Hence, for ASME B31.1 Code, CAEPIPE computes the allowable pressure for miter bends using the explicit equations given in ASME B31.3 (2018) [see para. 304.2.3], as listed below.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a(R-r)}{r(R-r/2)}$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 0.643\tan\theta\sqrt{rt_a})}$$

For widely spaced miter bends with $\theta >$ 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 1.25\tan\theta\sqrt{rt_a})}$$

where

r = mean radius of pipe = $(D_o - t_n)/2$

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r} - 1.0\right)}\right)$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. 15 of para.104.8.1

$$S_L = \sqrt{\left[\left|\frac{PD_o}{4t_n} + \frac{I_aF_a}{A_p}\right| + \frac{\sqrt{(I_iM_{iA})^2 + (I_oM_{oA})^2}}{Z}\right]^2 + \left(\frac{I_tM_{tA}}{Z}\right)^2} \le S_h$$

where

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE pressures P1 through P10

D_o = nominal outside diameter

t_n= nominal wall thickness

F_a= longitudinal force due to weight and other sustained mechanical loads (excluding pressure)

I_a= sustained longitudinal force index = 1.00

I_i = sustained in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = sustained out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = sustained torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iA}, M_{oA}, M_{tA} = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads

Z = nominal section modulus = un-corroded section modulus

A_p= un-corroded nominal cross sectional area

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

S_L = stress due to pressure, weight and other sustained mechanical loads

Note:

When the option "Pressure stress" is selected as "Pd^2/(D^2-d^2)" through CAEPIPE Layout Window > Options > Analysis > Pressure; then CAEPIPE will replace the term "PD/4t" with the term "Pd^2/(D^2 – d^2)", where, d = nominal inside diameter

Occasional Stress

The stress (S_O) due to sustained and occasional loads is calculated from Eq. 16 of para. 104.8.2 as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind. Wind and earthquake are not considered to act concurrently as per para. 101.5.2 and para. 101.5.3.

$$S_O = \sqrt{\left[\left|\frac{P_o D_o}{4t_n} + \frac{I_a F_b}{A_p}\right| + \frac{\sqrt{(I_i M_{iB})^2 + (I_o M_{oB})^2}}{Z}\right]^2 + \left(\frac{I_t M_{tB}}{Z}\right)^2} \leq kS_h$$

where

F_b = longitudinal force due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.
I_a= occasional longitudinal force index = 1.00

I_i = occasional in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = occasional out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = occasional torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iB}, M_{oB}, M_{tB} = in-plane, out-of-plane and torsional moment respectively due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

S_O = stress due to pressure, weight, other sustained mechanical loads and occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake, wind etc.

k = 1.2 for occasional loads acting for no more than 1 hr at any one time and no more than 80 hr/yr.

All other terms such as P, A_p, Z, etc. are as defined under Sustained Stress.

For Unsigned occasional load cases such as Earthquake, etc. the forces and moments are combined as given below.

$$\left|\frac{P_oD_o}{4t_n}+\frac{I_aF_b}{A_p}\right| = max\left[\left|\frac{P_oD_o}{4t_n}+\frac{I_aF_{b(sust)}}{A_p}\right|+\left|\frac{I_aF_{b(occa)}}{A_p}\right|, \left|\frac{P_oD_o}{4t_n}+\frac{I_aF_{b(sust)}}{A_p}\right|-\left|\frac{I_aF_{b(occa)}}{A_p}\right|\right]$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}\right|+\left|M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}\right|+\left|M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}\right|+\left|M_{tB(occa)}\right|\right]^2$$

For Signed occasional load cases such as Wind, etc. the forces and moments are combined as given below.

$$\left|\frac{P_oD_o}{4t_n}+\frac{I_aF_b}{A_p}\right| = \left|\frac{P_oD_o}{4t_n}+\frac{I_aF_{b(sust)}}{A_p}+\frac{I_aF_{b(occa)}}{A_p}\right|$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}+M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}+M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}+M_{tB(occa)}\right|\right]^2$$

where

$M_{iB(sust)}$, $M_{oB(sust)}$, $M_{tB(sust)}$ = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads (excluding pressure).

$M_{iB(occa)}$, $M_{oB(occa)}$, $M_{tB(occa)}$ = in-plane, out-of-plane and torsional moment respectively due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

$F_{b(sust)}$ = longitudinal force due to weight, other sustained mechanical loads (excluding pressure)

$F_{b(occa)}$ = longitudinal force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

Note:

When the option "Pressure stress" is selected as "Pd^2/(D^2-d^2)" through CAEPIPE Layout Window > Options > Analysis > Pressure; then CAEPIPE will replace the term "P_oD/4t" with the term "P_od^2/(D^2 – d^2)", where, d = nominal inside diameter

Expansion Stress Range (i.e., Stress due to Displacement Load Range)

The stress range (S_E) due to thermal expansion is calculated from Eq. 17 of para.104.8.3.

$$S_E = \sqrt{\left[\left|\frac{i_a F_c}{A_p}\right| + \frac{\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tC}}{Z}\right)^2} \le S_A$$

where

F_c = axial force range due to reference displacement load range

A_p= un-corroded nominal cross sectional area

i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

M_{iC}, M_{oC}, M_{tC} = in-plane, out-of-plane and torsional moment range respectively due to the reference displacement load range

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

Z = nominal section modulus = un-corroded section modulus

$S_A = f(1.25S_C + 0.25S_h)$, from Eq. (1A) of para. 102.3.2 (b)

f = cyclic stress range reduction factor from Eq. (1C) of para. 102.3.2 (b),

$f = 6/N^{0.2}$ <= 1.0 and f >= 0.15 with N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping

S_C = basic allowable stress at minimum metal temperature expected during the displacement stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement stress range under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, from Eq. (1B) of para. 102.3.2 (b).

This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 2** below)

This is specified as an analysis option: "Use liberal allowable stresses", in the menu Options->Analysis on the Code tab of CAEPIPE.

Note:

1. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
2. As per Note 2 of para. 102.3.2 (b) (1) of ASME B31.1 (2020), "For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1A) and (1B) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_L) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1A).

Settlement Stress

The stress range (S_S) due to single, noncyclic displacement stress range (e.g., predicted settlement or uplift or movement of pipe support structures such as buildings, pipe racks, anchors, etc.) is calculated from Eq. 17 of Figure 104.8-1 as given below in accordance with para. 102.3.2 (b)(2).

$$S_S = \sqrt{\left[\left|\frac{i_a F_D}{A_p}\right| + \frac{\sqrt{(i_i M_{iD})^2 + (i_o M_{oD})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tD}}{Z}\right)^2} \leq 3S_C$$

where
i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

F_D = axial force range due to any single noncyclic anchor movement (e.g., predicted building settlement)

Ap= un-corroded nominal cross sectional area

M_{iD}, M_{oD}, M_{tD} = in-plane, out-of-plane and torsional moment range respectively due to any single noncyclic anchor movement (e.g., predicted building settlement)

Z = nominal section modulus = un-corroded section modulus

S_c = allowable stress at the Reference Temperature in CAEPIPE

ASME B31.1 (2020) – Non-metallic piping as per Chapter N-II

The Chapter N-II titled "Design" of ASME B31.1 (2020) provides methods to evaluate Non-metallic piping such as PVC, CPVC etc. This Chapter presents equations and references for

1. Pressure Design (Allowable Pressure calculation) of Non-metallic Pipe and Pipe Fittings, and
2. Code Compliance checks (such as Sustained Stress, Expansion Stress and Occasional Stress) for Non-Metallic piping .

From ASME B31.1 (2020) Chapter N-II, it was observed that the equations for Allowable Pressure for Non-metallic piping and pipe fittings are different from those provided for Metallic piping and pipe fittings. On the other hand, equations provided for Code Compliance checks for Metallic piping are also applicable for Non-metallic piping. Refer to Code Compliance equations for Metallic piping as per ASME B31.1 (2020) given above.

In view of the above, CAEPIPE can be used for analyzing Plastic Piping (such as PVC, CPVC etc.) using ASME B31.1 (2020) code to obtain results for displacements, element forces and moments, stresses, support loads and support load summary; however, the Allowable Pressure results given in Column 2 of Code Compliance Results should be ignored. Allowable pressures for Plastic Pipe and Pipe Fittings have to be computed manually as per Chapter N-II of ASME B31.1 (2020) outside of CAEPIPE.

Material Properties for PVC, CPVC, etc. are provided in "Chapter N-II" titled "Design" of ASME B31.1 (2020). These properties are already included in the material library for Plastics starting CAEPIPE Version 11.00.

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 104.1.2-1 of ASME B31.1 – 2020)

S. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloy UNS No. N06690 (NA)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
4.	Other Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
5.	Cast Iron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	Material Types other than those stated from Sl. Nos. 1 to 5.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

3. If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y as

$$Y = \frac{d}{d + D_o}$$

Weld Strength Reduction Factors (W) used in CAEPIPE to calculate the Allowable Design Pressure of components (extracted from Table 102.4.7-1 of ASME B31.1-2020)

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)
1	Carbon Steel (CS) [see Note (a)]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
4	Material Description that contains a string “CrMo”	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64
5	Material Types other than those stated in Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

(e) Based on Note 7 of Table 102.4.7-1 of ASME B31.1 (2020) code, W = 1.0 for Carbon Steel (CS).

(f) For Austenitic Steels (including 800H and 800 HT), values up to 1500 deg F are as follows:

Temperature, deg F	Temperature, deg C	Weld Strength Reduction Factor
1250	677	0.73
1300	704	0.68
1350	732	0.64
1400	760	0.59
1450	788	0.55
1500	816	0.50

Allowable Pressure

At this time, there is no provision in CAEPIPE to specify the type of pipe construction, i.e., whether the pipe is a seamless or longitudinal welded or spiral welded. Accordingly, irrespective of the type of pipe construction, CAEPIPE calculates allowable pressure as follows.

For straight pipes and bends with seamless construction or designed for sustained operation below the creep range, Eq. (9) of para.104.1.2 is used as given below to compute allowable pressure.

$$P_a = \frac{2SEWt_a}{D_o - 2Yt_a}$$

where

P_a= allowable pressure

SE = maximum allowable stress in material due to internal pressure and joint efficiency (or casting quality factor) at the design temperature. The values of SE are given in Mandatory Appendix A of B31.1 (2018) Code

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

d = inside diameter of pipe

The coefficient Y is implemented as per Table 104.1.2-1. Refer to the Table listed at the end of this section for details on 'Y' factor implemented in CAEPIPE.

W = weld strength reduction factor as per Table 102.4.7-1. Refer to the Table listed at the end of this section for details on Weld strength reduction factor implemented in CAEPIPE.

ASME B31.1 Code does not provide any explicit equation to compute Allowable Pressure for closely spaced and widely spaced miter bends. Hence, for ASME B31.1 Code, CAEPIPE computes the allowable pressure for miter bends using the explicit equations given in ASME B31.3 (2018) [see para. 304.2.3] as listed below.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a(R-r)}{r(R-r/2)}$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 0.643\tan\theta\sqrt{rt_a})}$$

For widely spaced miter bends with θ > 22.5 deg, the allowable pressure is calculated in CAEPIPE as

$$P_a = \frac{SEWt_a^2}{r(t_a + 1.25\tan\theta\sqrt{rt_a})}$$

where

r = mean radius of pipe = (D_o - t_n)/2

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r} - 1.0\right)}\right)$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. 15 of para.104.8.1

$$S_L = \frac{PD_o}{4t_n} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum of CAEPIPE pressures P1 through P10

D_o = outside diameter

t_n = nominal wall thickness

i = stress intensification factor. The product 0.75i shall not be less than 1.0.

M_A = resultant bending moment due to weight and other sustained loads

Z = un-corroded section modulus; for reduced outlets, effective section modulus as per para. 104.8.4

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

Occasional Stress

The stress (S_{LO}) due to occasional loads is calculated from Eq. 16 of para.104.8.2 as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_o) such as earthquake or wind. Wind and earthquake are not considered concurrently.

$$S_{Lo} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75 i M_A}{Z} + \frac{0.75 i M_B}{Z} \le 1.2 S_h$$

where

M_B = resultant bending moment on the cross-section due to occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake, wind etc.

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P

Expansion Stress Range (i.e., Stress due to Displacement Load Range)

The stress (S_E) due to thermal expansion is calculated from Eq. 17 of para.104.8.3.

$$S_E = \frac{i M_C}{Z} \le S_A$$

where

M_C = resultant moment due to thermal expansion

$S_A = f(1.25 S_C + 0.25 S_h)$, from Eq. (1A) of para. 102.3.2 (b)

f = cyclic stress range reduction factor from Eq.(1C) of para. 102.3.2(b),

$f = 6/N^{0.2} <= 1.0$ and $f >= 0.15$ with N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping

S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, from Eq. (1B) of para. 102.3.2 (b)

This is specified as an analysis option: "Use liberal allowable stresses", in the menu Options->Analysis on the Code tab of CAEPIPE.

Note:

Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Table D-1 Flexibility and Stress Intensification Factors

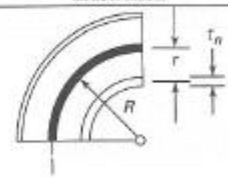
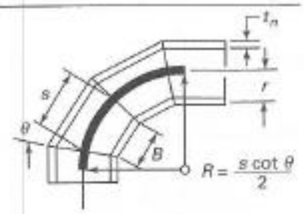
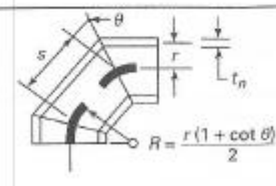
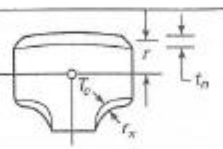
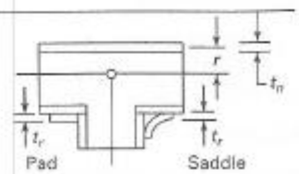
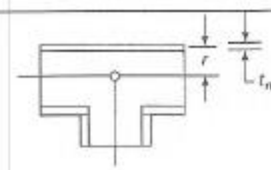
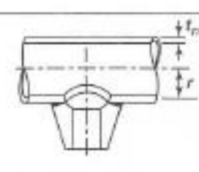
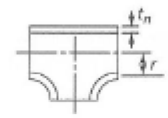
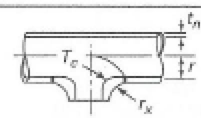
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r[1 + \tan\theta]$ $B \geq 6t_n$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (5), (6)] $s \geq r[1 + \tan\theta]$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Notes (1), (2), (7)]	$\frac{3.1t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (8), (9)]	$\frac{\left(t_n + \frac{t_r}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]	$\frac{3.3t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Extruded outlet meeting the requirements of para. 104.3.1(g) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert [Notes (1), (2), (7)]	$\frac{3.1t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

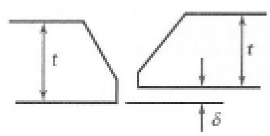
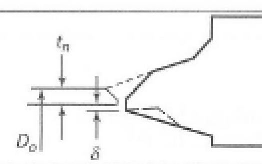
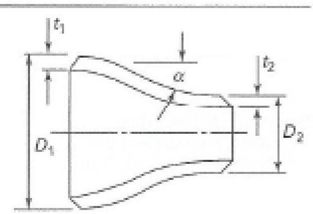
Description	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Figure D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/8$ in., and δ_{avg}/t = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/t)]$, but not less than 1.0 [Note (11)]	
Butt weld [Note (1)] $t < 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.33$	1		
Fillet welds	1	1.3 [Note (12)]	See Figures 127.4.4-1, 127.4.4-2, and 127.4.4-3
Tapered transition per para. 127.4.2(b) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$	
Concentric reducer per ASME B16.9 [Notes (1), (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Threaded pipe joint or threaded flange	1	2.3	...
Corrugated straight pipe, or corrugated or creased bend [Note (14)]	5	2.5	...

GENERAL NOTES:

(a) The validity of the stress intensification and flexibility factor data in Table D-1 has been demonstrated for $D_o/t_n \le 100$.

(b) The designer may use the stress intensification and flexibility factors from ASME B31J instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of the in-plane (i_i), out-plane (i_o), and torsional (i_t) stress intensification factors shall be used in calculating stresses in accordance with para. 104.8. Alternatively, stress intensification factors may be developed using ASME B31J, Nonmandatory Appendix A.

NOTES:

(1) The following nomenclature applies to Table D-1:
- B = length of miter segment at crotch, in. (mm)
- D_1 = outside diameter of reducer on large end, in. (mm)
- D_2 = outside diameter of reducer on small end, in. (mm)
- D_o = outside diameter, in. (mm)
- D_{ob} = outside diameter of branch, in. (mm)
- R = bend radius of elbow or pipe bend, in. (mm)
- r = mean radius of pipe, in. (mm) (matching pipe for tees)
- r_x = external crotch radius of welded-in contour inserts and welding tees, in. (mm)
- s = miter spacing at centerline, in. (mm)
- T_c = crotch thickness of welded-in contour inserts and welding tees, in. (mm)
- t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
- t_r = reinforcement pad or saddle thickness, in. (mm)
- α = reducer cone angle, deg
- δ = mismatch, in. (mm)
- θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factors, k, and stress intensification factors, i, in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Figure D-2 by entering with the characteristic, h, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor, c, given below, which can be read directly from Figure D-3, entering with the computed h: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i. Values from the Table may be corrected by dividing k by

$$\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}\right]$$

and dividing i by

$$\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}\right]$$

(6) Also includes single miter joints.

(7) If $r_x \ge D_{ob}/8$ and $T_c \ge 1.5t_n$, a flexibility characteristic, h, of $4.4t_n/r$ may be used.

(8) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

(9) The stress intensification factors in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

(10) The equation applies only if the following conditions are met:
- (a) The reinforcement area requirements of para. 104.3 are met.
- (b) The axis of the branch pipe is normal to the surface of run pipe wall.

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.

(d) The inside corner radius r_1 (see Figure D-1) is between 10% and 50% of t_{nh}.

(e) The outer radius, r_2 [see Figure D-1], is not less than the larger of $T_b/2$, $(T_b + y)/2$ [shown in Figure D-1 illustration (c)], or $t_{nh}/2$.

(f) The outer radius, r_3 (see Figure D-1), is not less than the larger of

(1) $0.002\theta d_o$

(2) $2(\sin\theta)^3$ times the offset for the configurations shown in Figure D-1 illustrations (a) and (b)

(g) $R_m/t_{nh} \le 50$ and $r'_m/R_m \le 0.5$.

(11) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875t$ and $1.10t$ for an axial distance of $\sqrt{D_o t}$. D_o and t are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a full weld is made between the pipe and fitting as shown in Figure 127.4.4-3. For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Figure 127.4.4-2 and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Figure 127.4.4-1, illustrations (b) and (d), has been shown to improve the fatigue performance of the weld.

(13) The equation applies only if the following conditions are met:

(a) Cone angle, α, does not exceed 60 deg, and the reducer is concentric.

(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(14) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Figure D-2 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

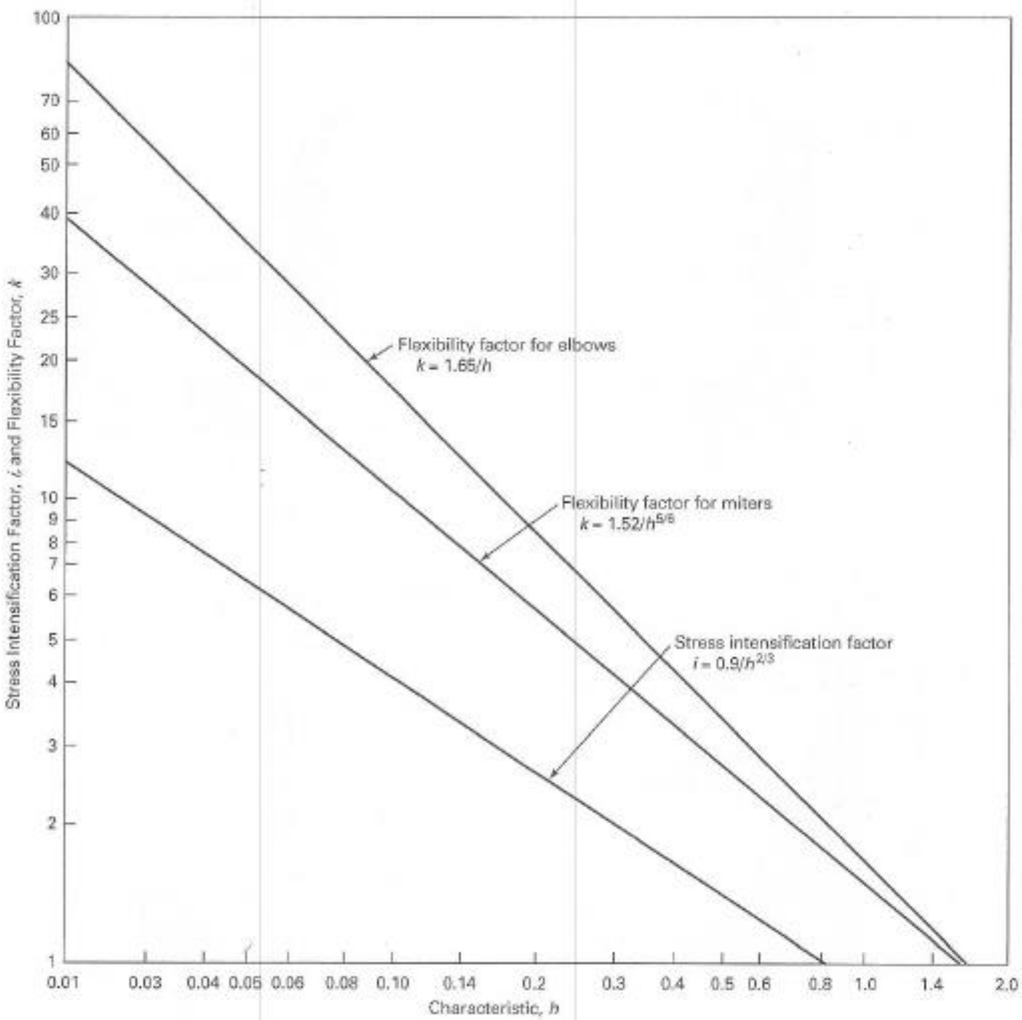
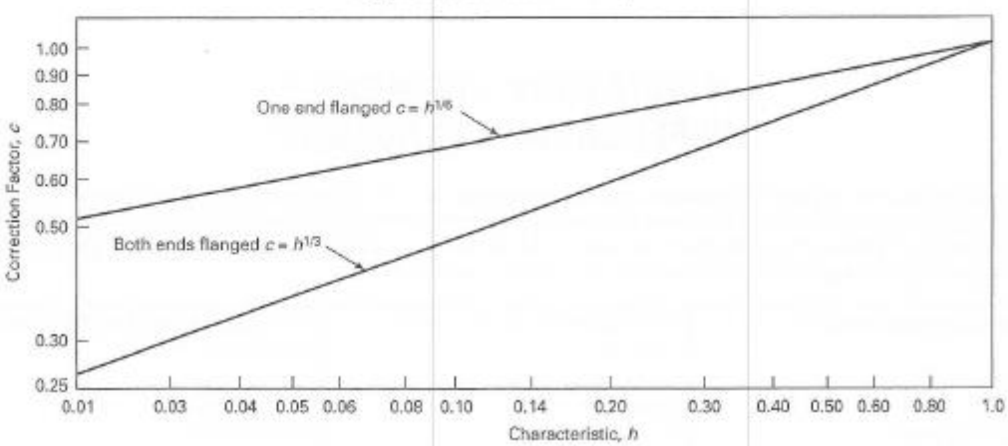


Figure D-3 Correction Factor, *c*



Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 104.1.2-1 of ASME B31.1 – 2018)

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloy UNS No. N06690 (NA)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
4.	Other Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
5.	Cast Iron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	Material Types other than those stated from Sl. Nos. 1 to 5.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

4. If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y as

$$Y = \frac{d}{d + D_o}$$

Weld Strength Reduction Factors used in CAEPIPE to calculate the Allowable Design Pressure of components (extracted from Table 102.4.7-1 of ASME B31.1-2018)

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)
1	Carbon Steel (CS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
4	Material Description that contains a string "CrMo"	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64
5	Material Types other than those stated in Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

For Austenitic Steels (including 800H and 800 HT) the values upto 1500 deg F are as follows:

Temperature, deg F	Temperature, deg C	Weld Strength Reduction Factor
1250	677	0.73
1300	704	0.68
1350	732	0.64
1400	760	0.59
1450	788	0.55
1500	816	0.50

Allowable Pressure

At this time, there is no provision in CAEPIPE to specify the type of pipe construction, i.e., whether the pipe is a seamless or longitudinal welded or spiral welded. Accordingly, irrespective of the type of pipe construction, CAEPIPE calculates allowable pressure as follows.

For straight pipes and bends with seamless construction or designed for sustained operation below the creep range, Eq. (9) of para.104.1.2 is used as given below to compute allowable pressure.

$$P_a = \frac{2SEt_a}{D_o - 2Yt_a}$$

For straight pipes and bends designed for sustained operation within the creep range, Eq. (11) of para.104.1.4 is used as given below to calculate allowable pressure.

$$P_a = \frac{2SEWt_a}{D_o - 2Yt_a}$$

where

P_a= allowable pressure

SE = allowable stress as given in Appendix A of B31.1 (2016) Code, where

E = weld joint efficiency factor or casting quality factor as given in Table 102.4.3

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= outside diameter of pipe

d = inside diameter of pipe

The Pressure coefficient Y is implemented as per Table 104.1.2 (A). Refer to the Table listed at the end of this section for details on 'Y' factor implemented in CAEPIPE

W = weld strength reduction factor as per Table 102.4.7. Refer to the Table listed at the end of this section for details on Weld strength reduction factor implemented in CAEPIPE.

For closely spaced miter bends, the allowable pressure is calculated from Eq. (C.3.1) of para.104.3.3.

$$P_a = \frac{SEt_a(R-r)}{r(R-r/2)}$$

where

r = mean radius of pipe = $(D_o - t_n)/2$

R = equivalent bend radius of the miter

For widely spaced miter bends, the allowable pressure is calculated from Eq. (C.3.2) of para. 104.3.3.

$$P_a = \frac{SEt_a^2}{r(t_a + 1.25\tan\theta\sqrt{rt_a})}$$

Where, θ = miter half angle

Sustained Stress

The stress (SL) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. 15 of para.104.8.1

$$S_L = \frac{PD_o}{4t_n} + \frac{0.75iM_A}{Z} \le S_h$$

where

P = maximum of CAEPIPE pressures P1 through P10

D_o = outside diameter

t_n= nominal wall thickness

i = stress intensification factor. The product 0.75i shall not be less than 1.0.

M_A = resultant bending moment due to weight and other sustained loads

Z = un-corroded section modulus; for reduced outlets, effective section modulus as per para. 104.8.4

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

Occasional Stress

The stress (SLo) due to occasional loads is calculated from Eq. 16 of para.104.8.2 as the sum of stress due to sustained loads (SL) and stress due to occasional loads (So) such as earthquake or wind. Wind and earthquake are not considered concurrently.

$$S_{Lo} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75 i M_A}{Z} + \frac{0.75 i M_B}{Z} \leq 1.2 S_h$$

where

M_B = resultant bending moment on the cross-section due to occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake, wind etc.

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P

Expansion Stress Range (i.e., Stress due to Displacement Load Range)

The stress (S_E) due to thermal expansion is calculated from Eq. 17 of para.104.8.3.

$$S_E = \frac{i M_C}{Z} \leq S_A$$

where

M_C = resultant moment due to thermal expansion

$S_A = f(1.25 S_C + 0.25 S_h)$, from Eq. (1A) of para. 102.3.2 (B)

$f =$ cyclicstress range reduction factor from Eq.(1C) of para. 102.3.2(B),

$f =$ $6/N^{0.2}$ <= 1.0 and f >= 0.15 with N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping

S_C = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, from Eq. (1B) of para. 102.3.2 (B)

This is specified as an analysis option: "Use liberal allowable stresses", in the menu Options->Analysis on the Code tab of CAEPIPE.

Note:

Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

MANDATORY APPENDIX D

Table D-1 Flexibility and Stress Intensification Factors

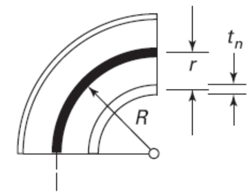
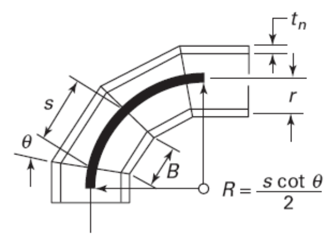
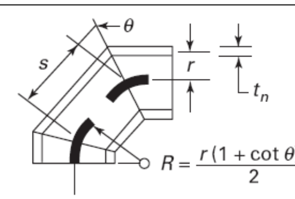
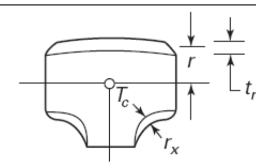
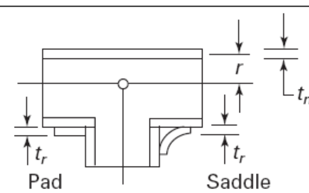
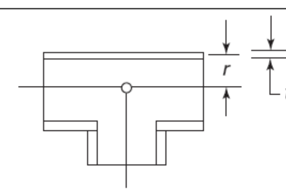
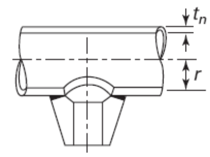
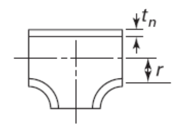
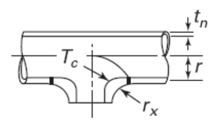
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r(1 + \tan \theta)$ $B \geq 6\ t_n$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{s t_n \cot \theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (5), (6)] $s \geq r(1 + \tan \theta)$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{t_n (1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Notes (1), (2), (7)]	$\frac{3.1 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (8), (9)]	$\frac{\left(t_n + \frac{t_r}{2}\right)^{5/2}}{r (t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]	$\frac{3.3t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Extruded outlet meeting the requirements of para. 104.3.1(G) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert [Notes (1), (2), (7)]	$3.1\,\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

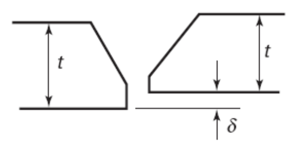
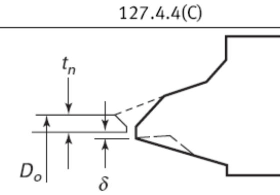
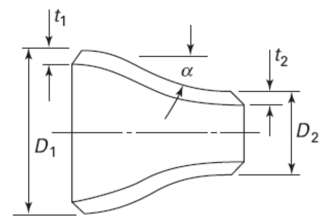
Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/8$ in., and $\delta_{avg}/t =$ any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/t)]$, but not less than 1.0 [Note (11)]	
Butt weld [Note (1)] $t < 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.33$	1		
Fillet welds	1	1.3 [Note (12)]	See Figs. 127.4.4(A), 127.4.4(B), and 127.4.4(C)
Tapered transition per para. 127.4.2(B) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Concentric reducer per ASME B16.9 [Note (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (14)]	5	2.5	. . .

NOTES:

(1) The following nomenclature applies to Table D-1:

B = length of miter segment at crotch, in. (mm)
D_o = outside diameter, in. (mm)
D_{ob} = outside diameter of branch, in. (mm)
R = bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees)
r_x = external crotch radius of welded-in contour inserts and welding tees, in. (mm)
s = miter spacing at centerline, in. (mm)
T_c = crotch thickness of welded-in contour inserts and welding tees, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
t_r = reinforcement pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factors k and stress intensification factors i in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Chart D-1 by entering with the characteristic h computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor c given below, which can be read directly from Chart D-2, entering with the computed h: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i. Values from the Table may be corrected by dividing k by

$$\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}\right]$$

and dividing i by

$$\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}\right]$$

(6) Also includes single miter joints.

(7) If $r_x \geq D_{ob}/8$ and $T_c \geq 1.5t_n$, a flexibility characteristic, h, of $4.4t_n/r$ may be used.

(8) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

(9) The stress intensification factors in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

(10) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of para. 104.3 are met.

(b) The axis of the branch pipe is normal to the surface of run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.

(d) The inside corner radius r_1 (see Fig. D-1) is between 10% and 50% of t_{nh}.

(e) The outer radius r_2 (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b + y)/2$ [shown in Fig. D-1 sketch (c)], or $t_{nh}/2$.

(f) The outer radius r_3 (see Fig. D-1) is not less than the larger of:

(1) $0.002\theta d_o$;

(2) $2(\sin\theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).

(g) $R_m/t_{nh} \leq 50$ and $r'_m/R_m \leq 0.5$.

(11) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875t$ and $1.10t$ for an axial distance of $\sqrt{D_o t}$. D_o and t are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a full weld is made between the pipe and fitting as shown in Fig. 127.4.4(C). For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Fig. 127.4.4(B) and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 127.4.4(A) sketches (b) and (d), has been shown to improve the fatigue performance of the weld.

(13) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(14) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Chart D-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

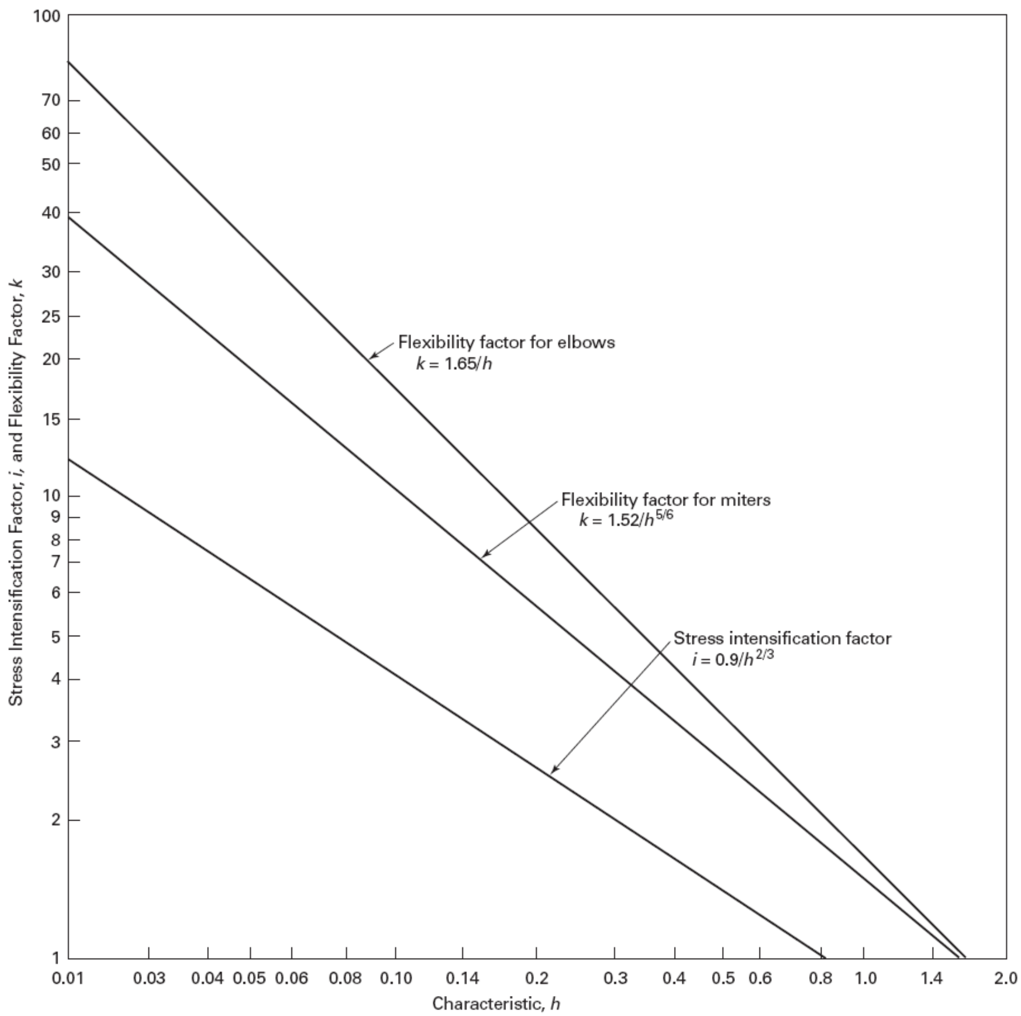
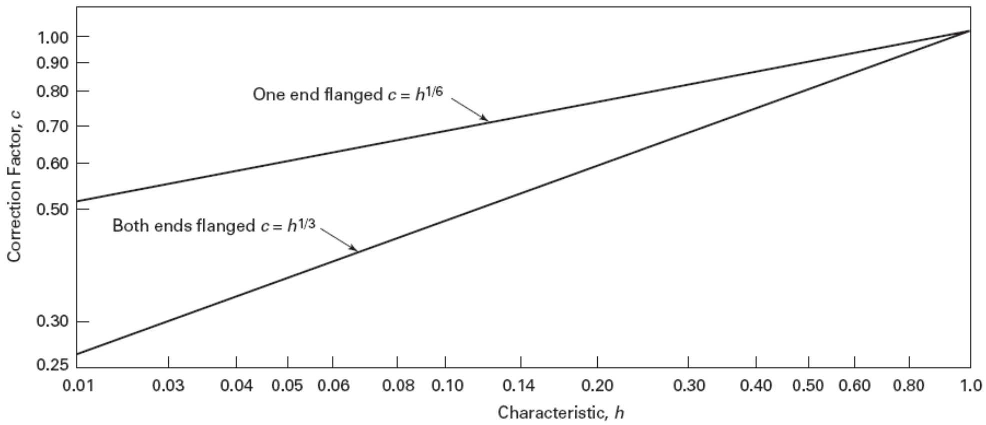


Chart D-2 Correction Factor, *c*



Pressure coefficient 'Y' used in Allowable Design Pressure of components (extracted from Table 104.1.2(A) of ASME B31.1 – 2016).

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloy UNS No. N06690 (NA)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
4.	Other Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
5.	Cast Iron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	Material Types other than those stated from Sl. Nos. 1 to 5.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

5. If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below then

$$Y = \frac{d}{d + D_o}$$

Weld Strength Reduction Factors applied for calculating the Allowable Design Pressure of components (extracted from Table 102.4.7 of ASME B31.1-2016).

Sl. No.	Material Type	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700 (371)	750 (399)	800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)
1	Carbon Steel (CS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
4	Material Types other than those stated in Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

For Austenitic Steels (including 800H and 800 HT) the values upto 1500 deg F are as follows:

Temperature, deg F	Temperature, deg C	Weld Strength Reduction Factor
1250	677	0.73
1300	704	0.68
1350	732	0.64
1400	760	0.59
1450	788	0.55
1500	816	0.50

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from 104.1.2.

$$P = \frac{2SEt_m}{D - 2Yt_m}$$

where

P = allowable pressure
S = allowable stress
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances
= t_n ×(1 – mill tolerance/100) – corrosion allowance
t_n = nominal pipe thickness
D = nominal outside diameter
d = nominal inside diameter
Y = pressure coefficient from Table 104.1.2(a)2

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from 102.3.2(d)

$$S_L = \left|\frac{PD}{4t_m} + \frac{F_A}{A}\right| + \frac{\sqrt{(i_i M_{iA})^2 + (i_o M_{oA})^2}}{Z} \leq S_h$$

where

P = maximum of CAEPIPE input pressures P1 through P10
D = nominal outside diameter
t_m = minimum wall thickness as given above
i_i = in-plane stress intensification factor
i_o = out-of-plane stress intensification factor
F_A = axial force due to weight and other sustained mechanical loads excluding pressure
A = nominal metal area
M_{iA} = in-plane bending moment due to weight and other sustained loads
M_{oA} = out-of-plane bending moment due to weight and other sustained loads
Z = nominal section modulus = un-corroded section modulus
S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

1. When the option "Include axial force in stress calculations" is tuned OFF, then CAEPIPE will exclude the term $\frac{F_A}{A}$ in the equation above.
2. When the option "Pressure stress" is selected as "Pd^2/(D^2-d^2)"; then CAEPIPE will replace the term $\frac{PD}{4t_m}$ with $\frac{Pd^2}{D^2-d^2}$, where, d = nominal inside diameter

Occasional Stress

The stress S_{LO} is calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind. Wind and earthquake are not considered concurrently (102.3.1).

$$S_{LO} = S_L + \left|\frac{(P_o - P)D}{4t_m} + \frac{F_B}{A}\right| + \frac{\sqrt{(i_i M_{iB})^2 + (i_o M_{oB})^2}}{Z} \leq 1.2S_h$$

where

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter
i_i = in-plane stress intensification factor
i_o = out-of-plane stress intensification factor
F_B = axial force due to occasional loads
A = nominal metal area
M_{iB} = in-plane bending moment only due to occasional loads
M_{oB} = out-of-plane bending moment only due to occasional loads
Z = nominal section modulus = un-corroded section modulus
S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

1. When the option "Include axial force in stress calculations" is tuned OFF, then CAEPIPE will exclude the term $\frac{F_B}{A}$ in the equation above.
2. When the option "Pressure stress" is selected as "Pd^2/(D^2-d^2)" then CAEPIPE will replace the term $\frac{(P_o-P)D}{4t_m}$ with $\frac{(P_O-P)d^2}{D^2-d^2}$, where, d = nominal inside diameter

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from (119.6.4).

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

S_b = resultant bending stress = $\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}/Z$
S_t = torsional stress = $M_{tC}/2Z$
Z = un-corroded section modulus; for a branch, effective section modulus
M_{iC} = in-plane bending moment only due to thermal loads
M_{oC} = out-of-plane bending moment only due to thermal loads
M_{tC} = torsional moment only due to thermal loads
S_A = $f(1.25S_c + 0.25S_h)$ as per eq. (1) in para. 102.3.2 (c).

S_C = basic allowable stress at minimum metal temperature expected during the displacement stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement stress range under analysis

f = stress range reduction factor from Table 102.3.2(c).

When S_h is greater than S_L, the allowable stress range may be calculated as

$$S_A = f[1.25(S_c + S_h) - S_L]$$

This is specified as an option (Use liberal allowable stresses) in the menu Options > Analysis on the Code tab.

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

F_C = axial force due to thermal loads only.

A = nominal metal area

Pressure Correction for Bends (Pressure stiffening effect)

In large diameter thin-wall bends, pressure can significantly affect their flexibility and SIF. If pressure correction for bends is turned ON then the Flexibility of the bend is divided by

$$1 + 6 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

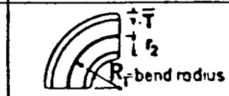
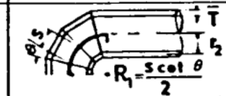
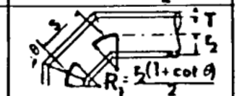
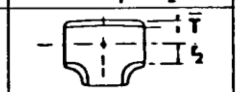
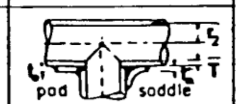
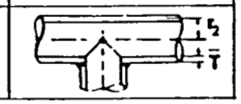
and the SIF for the bend is divided by

$$1 + 3.25 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where

P = pressure, E = elastic modulus, r = mean radius of matching pipe, t = nominal wall thickness and R = bend radius

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility Factor k	Stress Int. Factor i	Flexibility Characteristic h	Sketch
Welding elbow,[1,2,3] or pipe bend	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{(r_2)^2}$	
Closely spaced miter bend[1,2,3] $s < r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta \, \bar{T} s}{2(r_2)^2}$	
Widely spaced miter bend[1,2,4] $s \geq r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2} \frac{\bar{T}}{r_2}$	
Welding tee[1,2,6] per USAS B16.9	1	$\frac{0.9}{h^{2/3}}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee,[1,2,6,8] with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(\bar{T} + \frac{1}{2} t_e)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee[1,2,6]	1	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}}{r_2}$	
Butt-welded joint, reducer, or welded neck flange	1	1.0		
Double welded slip-on flange	1	1.2		
Fillet welded joint, socket welded flange, or single welded slip-on flange	1	1.3		
Lap joint flange (with USAS B16.9 lap joint stub)	1	1.6		
Threaded pipe joint, or threaded flange	1	2.3		
Corrugated straight pipe, or corrugated or creased bend[5]	5	2.5		

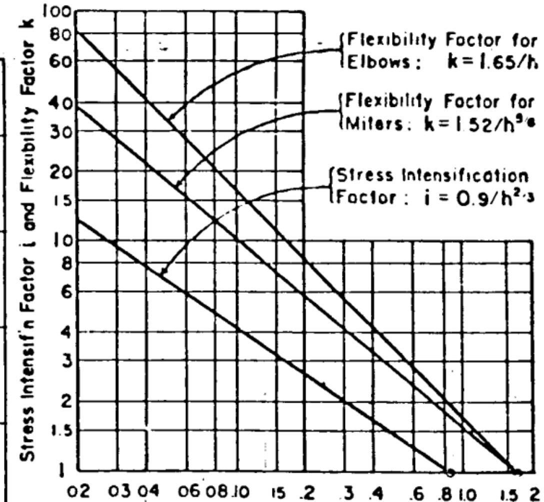


CHART A

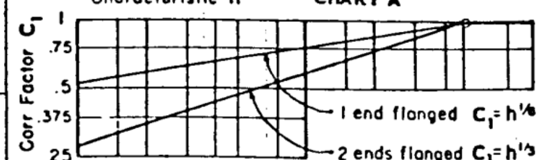


CHART B

[1] The flexibility factors k and stress intensification factors i in the table apply to bending in any plane for fittings shall in no case be taken less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

[2] The values of k and i can be read directly from Chart A above by entering with the characteristic h computed from the formulas given, where:

r_2 = mean radius of matching pipe, inches

$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting (see note 7), inches.

$\bar{T}$ = for tees, the nominal wall thickness of the matching pipe, inches.

R_1 = bend radius of welding elbow or pipe bend, inches.

θ = one-half angle between adjacent miter axes.

s = miter spacing at center line.

t_e = pad or saddle thickness, inches.

[3] Where flanges are attached to one or both ends, the values of k and i in the table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed h:

One end flanged: $h^{1/6}$ Both ends flanged: $h^{1/3}$

[4] Also includes single-miter joint.

[5] Factors shown apply to bending; flexibility factor for torsion equals 0.9.

[6] The stress intensification factors i in the table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

[7] The engineer is cautioned that cast butt-welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

[8] When t_e is $> 1\frac{1}{2}\bar{T}$, use $h = 4.05\frac{\bar{T}}{r_2}$

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated using eq. (4) in para. 104.1.2A.

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)}$$

where
P_a = allowable pressure
SE = maximum allowable stress for the material inclusive of weld joint efficiency factor E (or casting quality factor F) at the design temperature (i.e., at T_{design} input into CAEPIPE). The values of SE/SF are given in Appendix A of B31.1 (1973) Code.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

d = nominal inside diameter
Y = coefficient from Table 104.1.2, A

S. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)					
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7
3.	Nonferrous Steels	0.4	0.4	0.4	0.4	0.4	0.4
4.	Cast Iron	0.4	0.4	0.4	0.4	0.4	0.4
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

1. If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y using eq. (5) in para. 104.1.2.

   $$Y = \frac{d}{d + D_o}$$

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 102.3.2 D.

$$S_L = \left|\frac{Pd^2}{D^2 - d^2}\right| + \frac{\sqrt{(i_i M_{iA})^2 + (i_o M_{oA})^2}}{Z} \leq S_h$$

where

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i_i = in-plane stress intensification factor from Appendix D

i_o = out-of-plane stress intensification factor from Appendix D

M_{iA} = in-plane bending moment due to weight and other sustained mechanical loads (excluding pressure)

M_{oA} = out-of-plane bending moment due to weight and other sustained mechanical loads (excluding pressure)

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 119.7.3.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|\frac{Pd^2}{D^2-d^2}\right|$ with $\left|\frac{Pd^2}{D^2-d^2} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal metal area

Occasional Stress

The stress S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind, shall meet the following conditions as per para. 102.3.3A. Wind and earthquake are not considered concurrently as per para. 101.5.3.

$$S_{LO} = S_L + \left|\frac{(P_o - P)d^2}{D^2 - d^2}\right| + \frac{\sqrt{(i_i M_{iB})^2 + (i_o M_{oB})^2}}{Z} \leq k.S_h$$

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 119.7.3.

M_{iB} = in-plane bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

M_{oB} = out-of-plane bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]
k = 1.2 for Level B

k = 1.8 for Level C

k = 2.40 for Level D

i_i = in-plane stress intensification factor from Appendix D

i_o = out-of-plane stress intensification factor from Appendix D

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|\frac{(P_o-P)d^2}{D^2-d^2}\right|$ with $\left|\frac{(P_o-P)d^2}{D^2-d^2}+\frac{F_B}{A}\right|$

where

F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

A = nominal metal Area

Expansion Stress Range

The stress range (S_E) due to thermal expansion is calculated using eq. (8) in para. 119.6.4A.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress $= \sqrt{(i_iM_{iC})^2 + (i_oM_{oC})^2}/Z$
S_t = torsional stress $= M_{tC}/2Z$
i_i = in-plane stress intensification factor from Appendix D
i_o = out-of-plane stress intensification factor from Appendix D
M_{iC} = in-plane bending moment due to the reference thermal load range
M_{oC} = out of plane bending moment due to the reference thermal load range
Z = un-corroded section modulus; for a branch, effective section modulus as per para. 119.7.3.

$S_A = f(1.25S_c + 0.25S_h)$ as per eq. (1) in para. 102.3.2 (c).

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table 102.3.2, C
When S_h is greater than S_L, the allowable stress range may be calculated as follows, in accordance with para. 102.3.2 D.

$$S_A = f[1.25(S_c + S_h) - S_L]$$

This is specified as an option (Use liberal allowable stresses) in the menu Options > Analysis on the Code tab.

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute SE as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

F_C = axial force due to reference displacement load range.

A = nominal metal area

Pressure Correction for Bends (Pressure stiffening effect)

In large diameter thin-wall bends, pressure can significantly affect their flexibility and SIF. If pressure correction for bends is turned ON then the Flexibility of the bend is divided by

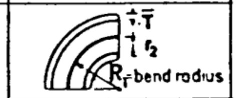
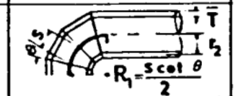
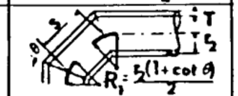
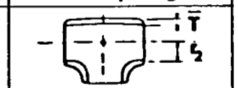
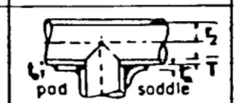
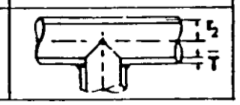
$$1 + 6 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

and the SIF for the bend is divided by

$$1 + 3.25 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where
P = pressure, E = elastic modulus, r = mean radius of matching pipe, t = nominal wall thickness and R = bend radius

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility Factor k	Stress Int. Factor i	Flexibility Characteristic h	Sketch
Welding elbow,[1,2,3] or pipe bend	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{(r_2)^2}$	
Closely spaced miter bend[1,2,3] $s < r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta\,\bar{T}s}{2(r_2)^2}$	
Widely spaced miter bend[1,2,4] $s \geq r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\frac{\bar{T}}{r_2}$	
Welding tee[1,2,6] per USAS B16.9	1	$\frac{0.9}{h^{2/3}}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee,[1,2,6,8] with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(\bar{T} + \frac{1}{2} t_e)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee[1,2,6]	1	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}}{r_2}$	
Butt-welded joint, reducer, or welded neck flange	1	1.0		
Double welded slip-on flange	1	1.2		
Fillet welded joint, socket welded flange, or single welded slip-on flange	1	1.3		
Lap joint flange (with USAS B16.9 lap joint stub)	1	1.6		
Threaded pipe joint, or threaded flange	1	2.3		
Corrugated straight pipe, or corrugated or creased bend[5]	5	2.5		

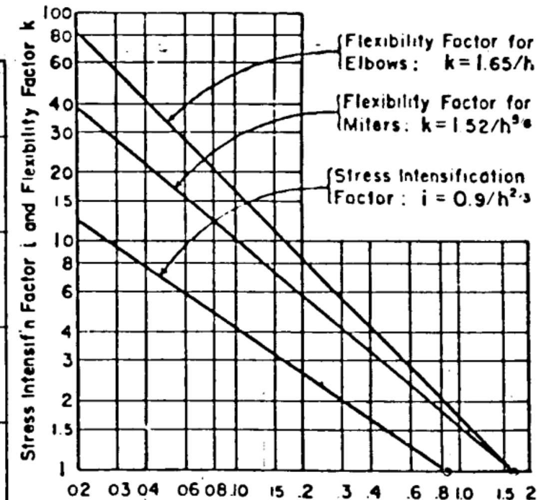


CHART A

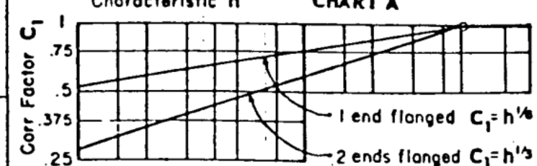


CHART B

[1]The flexibility factors k and stress intensification factors i in the table apply to bending in any plane for fittings shall in no case be taken less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

[2]The values of k and i can be read directly from Chart A above by entering with the characteristic h computed from the formulas given, where:

r_2 = mean radius of matching pipe, inches

$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting (see note 7), inches.

$\bar{T}$ = for tees, the nominal wall thickness of the matching pipe, inches.

R_1 = bend radius of welding elbow or pipe bend, inches.

θ = one-half angle between adjacent miter axes.

s = miter spacing at center line.

t_e = pad or saddle thickness, inches.

[3]Where flanges are attached to one or both ends, the values of k and i in the table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed h:

One end flanged: $h^{1/6}$ Both ends flanged: $h^{1/3}$

[4]Also includes single-miter joint.

[5]Factors shown apply to bending; flexibility factor for torsion equals 0.9.

[6]The stress intensification factors i in the table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

[7]The engineer is cautioned that cast butt-welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

[8]When t_e is $> 1\frac{1}{2}\bar{T}$, use $h = 4.05\frac{\bar{T}}{r_2}$

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated using eq. (4) in para. 104.1.2A.

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)}$$

where

P_a = allowable pressure

SE = maximum allowable stress for the material inclusive of weld joint efficiency factor E (or casting quality factor F) at the design temperature (i.e., at T_{design} input into CAEPIPE). The values of SE or SF are given in Appendix A of B31.1 (1977) Code.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

Y = coefficient from Table 104.1.2A

S. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C) 900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7
3.	Nonferrous Steels	0.4	0.4	0.4	0.4	0.4	0.4
4.	Cast Iron	0.4	0.4	0.4	0.4	0.4	0.4
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4

Notes:

If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y using eq. (5) in para. 104.1.2.

$$Y = \frac{d}{(d + D_o)}$$

where, d = nominal inside diameter

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 102.3.2 D and eq. (11) of para. 104.8.1.

$$S_L = |S_{lp}| + \frac{0.75iM_A}{Z} \leq S_h$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure stress option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from Appendix D and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lp}|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal metal area

Occasional Stress

The stress S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind, shall meet the following conditions as per para. 102.3.3 (A) and eq. (12) of para. 104.8.2. Wind and earthquake are not considered concurrently as per para. 101.5.3.

$$S_{LO} = S_L + |S_{lpo}| + \frac{0.75iM_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress =$\left|\frac{(P_o-P)d^2}{D^2-d^2}\right|$ or $\left|\frac{(P_o-P)D}{4t_n}\right|$ This pressure stress option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

i = stress intensification factor from Appendix D and 0.75i shall not be less than 1.0

k = 1.2 for Level B

k = 1.8 for Level C

k = 2.40 for Level D

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. = $\sqrt{(M_{Bx})^2 + (M_{By})^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lpo}|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

where

F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

A = nominal metal Area

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (13) in para. 104.8.3 (A).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from Appendix D

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + (M_{Cy})^2 + (M_{Cz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

$S_A = f(1.25S_c + 0.25S_h)$ as per eq. (1) in para. 102.3.2 (C).

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table 102.3.2 (C)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

where

F_C = axial force due to displacement load range under analysis.

A = nominal metal area

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated using eq. (14) of para. 104.8.3 (B).

$$S_{TE} = |S_{lp}| + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_A + S_h$$

Where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure stress option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from Appendix D and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + (M_{Cy})^2 + (M_{Cz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lp}|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$ and term $\frac{iM_C}{Z}$ with $\left|\frac{F_C}{A}\right| + \frac{iM_C}{Z}$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

F_C = axial force due to displacement load range under analysis

A = nominal metal area

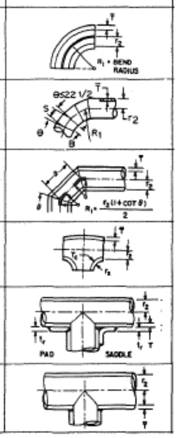
APPENDIX D

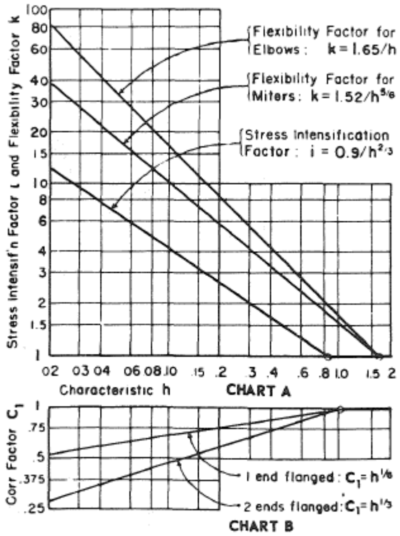
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

137

Table D-1

Description	Flexibility Factor k	Stress Int. Factor i	Flexibility Characteristic h	Sketch
Welding elbow,[1,2,3] or pipe bend	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{(r_2)^2}$	
Closely spaced miter bend[1,2,3] $s < r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{(\cot\theta)\bar{T}s}{2(r_2)^2}$	
Widely spaced miter bend[1,2,4] $s \geq r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{(1+\cot\theta)}{2}\frac{\bar{T}}{r_2}$	
Welding tee[1,2,6] per ANSI B16.9	1	$\frac{0.9}{h^{2/3}}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee,[1,2,6,8] with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(\bar{T}+\frac{1}{2}t_e)^{5/2}}{\bar{T}^{3/2}r_2}$	
Unreinforced fabricated tee[1,2,6]	1	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}}{r_2}$	
Threaded pipe joint, or threaded flange	1	2.3		
Corrugated straight pipe, or corrugated or creased bend[5]	5	2.5		





ANSI B31.1-1977 EDITION

APPENDIX D

[1] The flexibility factors k and stress intensification factors i in the table apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

[2] The values of k and i can be read directly from Chart A above by entering with the characteristic h computed from the formulas given, where:

r_2 = mean radius of matching pipe, inches (mm).

$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting (see note 7), inches (mm).

$\bar{T}$ = for tees, the nominal wall thickness of the matching pipe, inches (mm).

B = length of segment at crotch should be equal to or greater than 6 $\bar{T}$.

R_1 = bend radius of welding elbow or pipe bend, inches (mm).

θ = one-half angle between adjacent miter axes.

s = miter spacing at center line.

t_e = pad or saddle thickness, inches (mm).

S = $2R_1 \tan\theta$

[3] Where flanges are attached to one or both ends, the values of k and i in the table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed h:

One end flanged: $h^{1/6}$ Both ends flanged: $h^{1/3}$

[4] Also includes single-miter joint.

[5] Factors shown apply to bending; flexibility factor for torsion equals 0.9.

[6] The stress intensification factors i in the table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

[7] The engineer is cautioned that cast butt-welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

[8] When t_e is $> 1\frac{1}{2}\bar{T}$, use $h = 4.05\frac{\bar{T}}{r_2}$

SIFs are computed in CAEPIPE as given below for the items listed.

Sl. No.	Component Type	SIF (i)
1.	Flange - Weld neck	1.0
2.	Flange - Double welded	1.2
3.	Flange - Single/Fillet/Socket welded	1.3
4.	Flange – Lap Joint	1.6

Pressure Correction for Bends (Pressure stiffening effect)

In large diameter thin-wall bends, pressure can significantly affect their flexibility and SIF. If pressure correction for bends is turned ON then the Flexibility of the bend is divided by

$$1 + 6 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

and the SIF for the bend is divided by

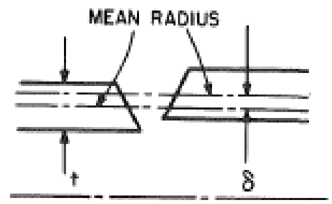
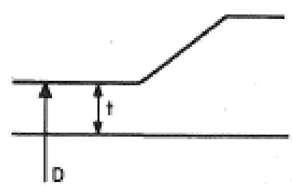
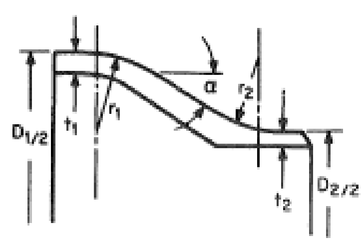
$$1 + 3.25 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where

P = pressure, E = elastic modulus, r = mean radius of matching pipe, t = nominal wall thickness and R = bend radius

APPENDIX D
STRESS INTENSIFICATION FACTORS

Table D-2

Component	Sketch	Stress Intensification Factor
Buttwelds		$t > 3/16$ and $\delta/t \leq 0.1$ $i = 1.0$ $t < 3/16$ or $\delta/t > 0.1$ $i = 1.8$ for as welded $i = 1.0$ for flush welds δ = allowable mismatch
Fillet Welds	See Figures 127.4.4 (a), (b) and (c)	$i = 2.1$ $i = 1.3$ for fillet welds as defined in Note 1.
30° Taper Transition per 127.4.2(c) and ANSI B16.25		$i = 1.9$ max, or $i = 1.30 + 0.0036 D/t + 0.225/t$
Concentric Reducer per B16.9 or MSS-SP48		$i = 2.0$ max or $i = 0.5 + 0.01\,\alpha\,(D_2/t_2)^{1/2}$ (see Note 2)

APPENDIX D — Table D-2 (Cont.)

Component	Sketch	Stress Intensification Factor
Branch Connections	See Figure D-1	$i = 1.5 \left(\frac{R_m}{T_r}\right)^{\frac{2}{3}} \left(\frac{r'_m}{R_m}\right)^{\frac{1}{2}} \left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ (see Notes 3 and 4)

Notes for Table D-2:

Note 1:
Stress intensification factor of 1.3 may be used for socket weld fitting if toe of weld blends smoothly with no undercut with pipe wall as shown in the concave, unequal leg fillet weld of Figure 127.4.4.

Note 2:
The equation applies only if the following conditions are met:
(a) Cone angle, α, does not exceed 60°, and the reducer is concentric.
(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

Note 3:
The equation applies only if the following conditions are met:
(a) The reinforcement area requirements of 104.3 are met.
(b) The axis of the branch pipe is normal to the surface of the run pipe wall.
(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.
(d) The inside corner radius, r_1 (see Fig. D-1) is between 10 percent and 50 percent of T_r.
(e) The outer radius, r_2, (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b + y)/2$ [for Fig. D-1 (c)] or $T_r/2$.
(f) The outer radius, r_3, (see Fig. D-1) is not less than the larger of
  (1) $0.002\ \theta d_o$
  (2) $2 (\sin \theta)^3$ times the offset for the configurations shown in Figs. D-1 (a) and D-1 (b).
(h) $R_m/T_r \leq 50$ and $r'm/Rm \leq 0.5$

Note 4:
The following nomenclature applies to Figure D-1:
- r_i = inside radius of branch pipe, in. (mm)
- r'_m = mean radius of branch pipe, in. (mm)
- T'_b = nominal thickness of branch pipe, in. (mm)
- R_m = mean radius of run pipe, in. (mm)
- T_r = nominal thickness of run pipe, in. (mm)
- d_o = outside diameter of branch, in. (mm)
- T_b, θ, r_1, r_2, r_3, r_p and y are defined in Figure D-1
- t_r = minimum required thickness of run pipe, calculated as a plain cylinder

Note 5:
Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated using eq. (4) in para. 104.1.2A.

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)}$$

where
P_a = allowable pressure
SE = maximum allowable stress for the material inclusive of weld joint efficiency factor E (or casting quality factor F) at the design temperature (i.e., at T_{design} input into CAEPIPE). The values of SE or SF are given in Appendix A of B31.1 (1980) Code.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

Y = coefficient from Table 104.1.2A

S. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)					
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7
3.	Nonferrous Steels	0.4	0.4	0.4	0.4	0.4	0.4
4.	Cast Iron	0.4	0.4	0.4	0.4	0.4	0.4
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4

Notes:
If $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below, CAEPIPE calculates Y using eq. (5) in para. 104.1.2.

$$Y = \frac{d}{(d + D_o)}$$

where, d = nominal inside diameter

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 102.3.2 D and eq. (11) of para. 104.8.1.

$$S_L = |S_{lp}| + \frac{0.75 i M_A}{Z} \leq S_h$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from Appendix D and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lp}|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal metal area

Occasional Stress

The stress S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind, shall meet the following conditions as per para. 102.3.3 (A) and eq. (12) of para. 104.8.2. Wind and earthquake are not considered concurrently as per para. 101.5.3.

$$S_{LO} = S_L + |S_{lpo}| + \frac{0.75 i M_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress = $\left|\frac{(P_o-P)d^2}{D^2-d^2}\right|$ or $\left|\frac{(P_o-P)D}{4t_n}\right|$ This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

i = stress intensification factor from Appendix D and 0.75i shall not be less than 1.0

k = 1.2 for Level B

k = 1.8 for Level C

k = 2.40 for Level D

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. = $\sqrt{(M_{Bx})^2 + (M_{By})^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lpo}|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

where

F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

A = nominal metal Area

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (13) in para. 104.8.3 (A).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from Appendix D

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + (M_{Cy})^2 + (M_{Cz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

$S_A = f(1.25S_c + 0.25S_h)$ as per eq. (1) in para. 102.3.2 (C).

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table 102.3.2 (C)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

where

F_C = axial force due to reference displacement load range.

A = nominal metal area

Sustained + Expansion Stress

Stress due to pressure, weight, other sustained loads and thermal expansion is calculated using eq. (14) of para. 104.8.3 (B).

$$S_{TE} = |S_{lp}| + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_A + S_h$$

Where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from Appendix D and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + (M_{Cy})^2 + (M_{Cz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 104.8.4.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lp}|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$ and term $\frac{iM_C}{Z}$ with $\left|\frac{F_C}{A}\right| + \frac{iM_C}{Z}$

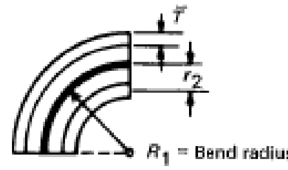
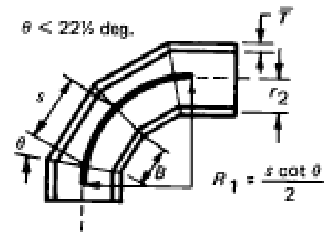
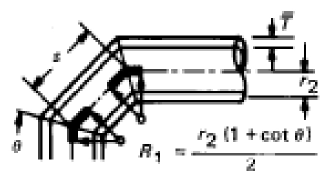
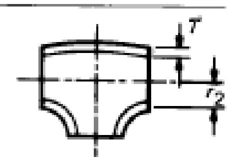
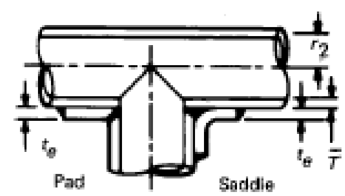
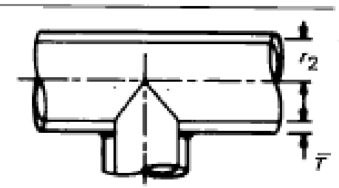
where

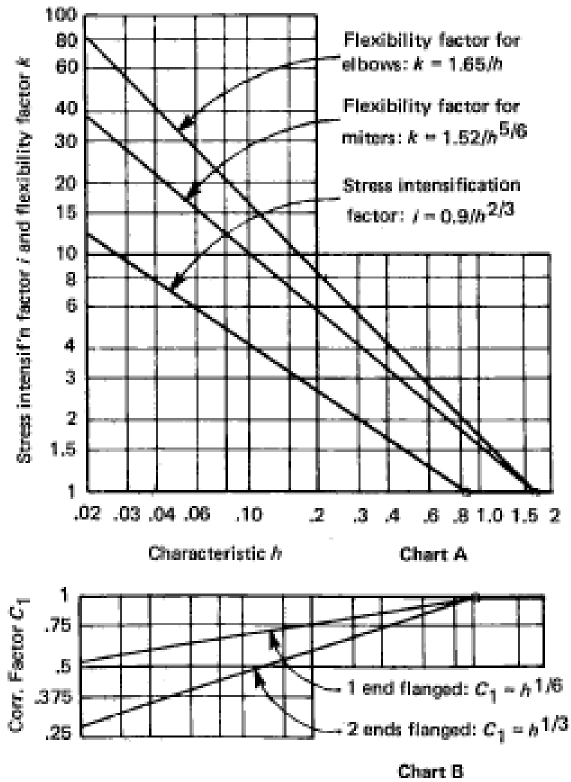
F_A = axial force due to weight and other sustained mechanical loads excluding pressure

F_C = axial force due to displacement load range under analysis

A = nominal metal area

TABLE D-1
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility Factor k	Stress Intensity Factor i	Flexibility Characteristic h	Sketch
Welding elbow, [Notes (1), (2), (3)] or pipe bend	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{(r_2)^2}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r_2(1+\tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{(\cot\theta)\bar{T}s}{2(r_2)^2}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r_2(1+\tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{(1+\cot\theta)}{2}\frac{\bar{T}}{r_2}$	
Welding tee [Notes (1), (2), (6)] per ANSI B16.9	1	$\frac{0.9}{h^{2/3}}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee, [Notes (1), (2), (6), (8)] with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(\bar{T}+\frac{1}{2}t_e)^{5/2}}{\bar{T}^{3/2}r_2}$	
Unreinforced fabricated tee [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}}{r_2}$	
Threaded pipe joint, or threaded flange	1	2.3	. . .	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (5)]	5	2.5	. . .	. . .



NOTES:

(1) The flexibility factors k and stress intensification factors i in the Table apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(2) The values of k and i can be read directly from Chart A above by entering with the characteristic h computed from the formulas given, where

r_2 = mean radius of matching pipe, in. (mm)
$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting [see Note (7)], in. (mm)
$\bar{T}$ = for tees, the nominal wall thickness of the matching pipe, in. (mm)
B = length of segment at crotch should be equal to or greater than $6\bar{T}$
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
θ = one-half angle between adjacent miter axes
s = miter spacing at center line
t_e = pad or saddle thickness, in. (mm)
S = $2R_1 \tan\theta$

(3) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed h:

One end flanged: $h^{1/6}$ Both ends flanged: $h^{1/3}$

(4) Also includes single-miter joint.

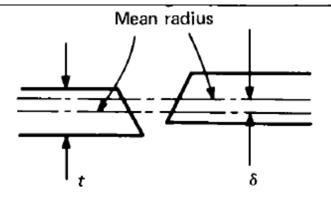
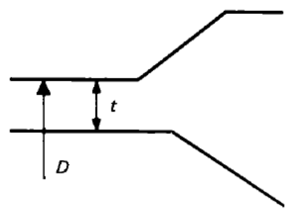
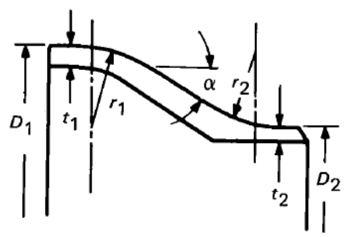
(5) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

(6) The stress intensification factors i in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

(7) The engineer is cautioned that cast butt-welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(8) When t_e is $> 1\frac{1}{2}\bar{T}$, use $h = 4.05\,\bar{T}/r_2$

TABLE D-2
STRESS INTENSIFICATION FACTORS

Component	Sketch	Stress Intensification Factor
Buttwelds		$t > 3/16$ and $\delta/t \leqslant 0.1$ $i = 1.0$ $t < 3/16$ or $\delta/t > 0.1$ $i = 1.8$ for as welded $i = 1.0$ for flush welds δ = allowable mismatch
Fillet welds	See Figs. 127.4.4 (A), (B), and (C)	$i = 2.1$ $i = 1.3$ for fillet welds as defined in Note (1)
Tapered transition per Para. 127.4.2(C) and ANSI B16.25		$i = 1.9$ max., or $i = 1.30 + 0.0036D/t + 0.225/t$
Concentric reducer per ANSI B16.9		$i = 2.0$ max. or $i = 0.5 + 0.01\ \alpha\ (D_2/t_2)^{1/2}$ [see Note (2)]
Branch connections	See Fig. D-1	$i = 1.5 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \times \left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ [see Notes (3) and (4)]

Notes to Table D-2 follow on next page

ANSI/ASME B31.1-1980 EDITION
APPENDIX D, TABLE D-2

AN AMERICAN NATIONAL STANDARD
POWER PIPING

NOTES TO TABLE D-2:

(1) Stress intensification factor of 1.3 may be used for socket weld fitting if toe of weld blends smoothly with no undercut with pipe wall as shown in the concave, unequal leg fillet weld of Fig. 127.4.4.

(2) The equation applies only if the following conditions are met.
 (a) Cone angle α does not exceed 60 deg., and the reducer is concentric.
 (b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
 (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(3) The equation applies only if the following conditions are met.
 (a) The reinforcement area requirements of Para. 104.3 are met.
 (b) The axis of the branch pipe is normal to the surface of the run pipe wall.
 (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.
 (d) The inside corner radius r_1 (see Fig. D-1) is between 10% and 50% of T_r.
 (e) The outer radius r_2 (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b+y)/2$ [for Fig. D-1 sketch (c)], or $T_r/2$.
 (f) The outer radius r_3 (see Fig. D-1) is not less than the larger of
  (1) $0.002\ \theta d_O$
  (2) $2 (\sin \theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).
 (g) $R_m/T_r \leqslant 50$ and $r'_m/R_m \leqslant 0.5$.

(4) The following nomenclature applies to Fig. D-1:
 r'_m = mean radius of branch pipe, in. (mm)
 T_b' = nominal thickness of branch pipe, in. (mm)
 R_m = mean radius of run pipe, in. (mm)
 T_r = nominal thickness of run pipe, in. (mm)
 d_O = outside diameter of branch, in. (mm)
 T_b, θ, r_1, r_2, r_3, r_p and y are defined in Fig. D-1
 t_r = minimum required thickness of run pipe, calculated as a plain cylinder

(5) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

SIFs are computed in CAEPIPE as given below for the items listed.

Sl. No.	Component Type	SIF (i)
1.	Flange - Weld neck	1.0
2.	Flange - Double welded	1.2
3.	Flange - Single/Fillet/Socket welded	1.3
4.	Flange – Lap Joint	1.6

Pressure Correction for Bends (Pressure stiffening effect)

In large diameter thin-wall bends, pressure can significantly affect their flexibility and SIF. If pressure correction for bends is turned ON then the Flexibility of the bend is divided by

$$1 + 6 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

and the SIF for the bend is divided by

$$1 + 3.25 \times \left(\frac{P}{E}\right)\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where
P = pressure, E = elastic modulus, r = mean radius of matching pipe, t = nominal wall thickness and R = bend radius

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) for bends from paras. 304.1.2. and 304.2.1 respectively.

$$P_a = \frac{2SEt_a}{(D - 2Yt_a)} \cdot \left(\frac{W}{I}\right)$$

where

P_a= allowable internal pressure

S = allowable stress at Design Temperature (i.e., at T_{design} input into CAEPIPE) as provided in para. 302.3.1 (a) and as per Table A-1

E = joint factor (input as material property) from Table A-1A as per para. 302.3.3 (b) or Table A-1B as per para. 302.3.4 (a).

W = Weld Joint Strength Reduction Factor at Design Temperature (i.e., at T_{design} input into CAEPIPE) from para. 302.3.5 (e) and as per Table 302.3.5. Refer to the Table listed at the end of this section for details on Weld Strength Reduction Factor implemented in CAEPIPE.

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance "c" in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

Y = coefficient from Table 304.1.1, valid for $t_a < D/6$. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE.

I = 1.0 for straight pipes and at the side wall on the bend / elbow centerline

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4a) and Eq. (4b) from para. 304.2.3 (a) as

$$P_a = min\left[\frac{SEWt_a^2}{r\left(t_a + 0.643\tan\theta\sqrt{rt_a}\right)}, \frac{SEWt_a(R - r)}{r(R - r/2)}\right]$$

For widely spaced miter bends with θ<= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. 304.2.3 (b) (1) as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 0.643\tan\theta\sqrt{rt_a}\right)}$$

For widely spaced miter bends with θ> 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. 304.2.3 (b) (2) as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 1.25\tan\theta\sqrt{rt_a}\right)}$$

where

r = mean radius of pipe using nominal wall thickness = (D- t_n)/2

R = effective bend radius of the miter (see para. 304.2.3 (d) of code for definition) [an input in CAEPIPE for miters]

$$\theta = \text{miter half angle} = \tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r} - 1.0\right)}\right)$$

Note:

As per para. 304.1.2 (a), Eq. 3(a) used above to compute allowable internal pressure is valid only when t_a < D/6. Hence, CAEPIPE will issue a warning message and will leave the Allowable Pressure row BLANK for elements where t_a >= D/6 in Code Compliance Results.

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b), (23c) and (23d) from para. 320.2 and para. 302.3.5 (c).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_h$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = I_a\left[\frac{P\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_S = wall thickness used for sustained stress calculation after deducting corrosion allowance from the nominal thickness

t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1

d = corroded inside diameter = $D - 2t_S$

A_p = sustained corroded cross-sectional area of the pipe computed using t_s as per para. 320.2.

I_a = longitudinal force index = 1.0

F_a = longitudinal force due to sustained loads (pressure and weight)

R = axial force due to weight alone, where weight is computed using nominal thickness.

I_i = sustained in-plane moment index = $0.75 i_i$ or 1.0, whichever is greater.

I_o = sustained out-of-plane moment index = $0.75 i_o$ or 1.0, whichever is greater.

I_t = sustained torsional moment index = 1.0

M_i = in-plane bending moment due to sustained loads, e.g., pressure and weight

M_o = out-of-plane bending moment due to sustained loads, e.g., pressure and weight

M_t = torsional moment due to sustained loads, e.g., pressure and weight

Z_m = corroded section modulus as per para. 320.1
S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
$\mathrm{i_i}$ and $\mathrm{i_o}$ = in-plane and out-of-plane index from ASME B31J (2017) respectively.

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently. See para. 302.3.6 (a).

For temp ≤ 427^0 C or 800^0 F

$S_{LO} \leq 1.33 S_h$ as per para. 302.3.6 (a)(1)

For temp > 427^0 C or 800^0 F

$S_{LO} \leq \min(0.9 W S_y, 4 S_h)$ as per para. 302.3.6 (a)(2) [only 302.3.6 (a)(2)(-a) and 302.3.6 (a)(2)(-b) considered]

where
$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b), (23c) and (23d) with applicable loads as per para. 302.3.6 (a).

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = I_a \left[\frac{\left(P_{peak} - P\right)\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2 Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P
R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for other materials as per para. 302.3.6(a)(2)
Z_m = corroded section modulus as per para. 320.1

Note: When the field Yield strength is left BLANK or NOT input, then CAEPIPE will compute the Yield Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 1.5 (=3/2). This is because; the allowable stress for material below creep is generally 2/3 of Yield Strength.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. 319.4.4 and shall not exceed (S_A) as per para.302.3.5 (d).

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_A$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A = <u>un-corroded</u> cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.
i_a= axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ for other components as per ASME B31J (2017)
F_a =<u>range</u> of axial force between any two thermal conditions being evaluated
i_i = in-plane stress intensification factor (SIF) as per ASME B31J (2017); shall not be < 1.0
i_o = out-of-plane SIF as per ASME B31J (2017); shall not be < 1.0
i_t = torsional SIF as per ASME B31J (2017); shall not be < 1.0
M_i = in-plane bending moment range between any two conditions being evaluated
M_o = out-of-plane bending moment range between any two conditions being evaluated
M_t = torsional moment range between any two conditions being evaluated
Z = <u>un-corroded</u> section modulus as per para. 319.3.5 and para. 319.4.4 (a)
$S_A = f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)
f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $20(N)^{-0.333} <= f_m$ & f >= 0.15
f_m = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths <= 75 ksi) and at metal temperatures <=700° F; otherwise $f_m = 1.0$
N= equivalent number of full displacement cycles during expected service of piping (= Number of Thermal Cycles input into CAEPIPE through Options > Analysis > Temperature)
S_C= basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h= basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis
when S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d). This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 3** below)

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout > Options > Analysis > Code tab.

Notes:

1. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).
2. Refer to the end of this appendix for the details of "Thickness and Section Modulus used for weight, allowable pressure and stress calculations".
3. Para. 302.3.5 provides maximum value of S_c and S_h as 138 MPa (20 ksi). The reason for this criterion is explicitly stated in Note 2 of para. 102.3.5 (b) (1) of ASME B31.1 (2022) as "For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1a) and (1b) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_l) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1a).
4. Para. 319.2.1(c), implies that wind sway at a piping support (e.g., piping supported from a tall slender tower) could be considered as an imposed thermal displacement at that support. Since CAEPIPE allows up to 10 thermal loads, the question arises "under which thermal load should this wind sway to be included". Hence, we recommend that wind sway is to be input as a part of "wind displacement under occasional stress condition".

Operating Stress for Impact Test Exemption

The combined stress (S_{opr}) due to pressure, dead loads, live loads and displacement strain for Operating Load Case 1 condition is calculated using Eqs. (23a), (23b), (23c) and (23d) from para. 320.2 as per para. 323.2.2 (b)(3). The combined stress thus computed is then divided by the basic allowable stress at the Operating 1 Temperature (T1) and reported under "Operating Stress for Impact Test Exemption".

This can be seen by turning ON the option "Show Opr. Stress – Impact Test Exemption" by using the Mouse Right Click while in "Sorted Stresses" results of CAEPIPE. See the Section titled "Operating Stress for NDE/Impact Test/Impact Test Exemption" in this manual for further details.

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_h$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Operating\ 1} = I_a\left[\frac{P\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Operating\ 1}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Operating\ 1}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Operating\ 1}$$

P = CAEPIPE input pressure P1
D = outside diameter
t_S = wall thickness after deducting corrosion allowance from the nominal thickness
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1
d = corroded inside diameter = $D - 2t_S$
A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 323.2.2 (b)(3)
I_a = longitudinal force index = 1.0
F_a = longitudinal force due to Operating load case 1
R = axial force due to Operating load case 1
I_i = in-plane moment index = 1.0
I_o = out-of-plane moment index = 1.0
I_t = torsional moment index = 1.0
M_i = in-plane bending moment due to Operating load case 1
M_o = out-of-plane bending moment due to Operating load case 1
M_t = torsional moment due to Operating load case 1
Z_m = corroded section modulus computed using t_s as per para. 323.2.2 (b)(3)
S_h = basic allowable stress at temperature T1 input in CAEPIPE

Notes on Material Library for B313-2022.mat supplied with CAEPIPE:

Material library for ASME B31.3 (2022) [B313-2022.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix A and Appendix C of ASME B31.3 (2022).

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 304.1.1 of ASME B31.3 – 2022)

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Weld Joint Strength Reduction Factors used in CAEPIPE to calculate the Allowable Internal Pressure of components (extracted from Table 302.3.5 of ASME B31.3-2022)

Sl. No.	Material Type/Material Description	Weld Joint Strength Reduction Factor W for Temperature, Deg F (Deg C)														
		<=800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677)	1300 (704)	1350 (732)	1400 (760)	1450 (788)	1500 (816)
1	Carbon Steel (CS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Material Description that contains a string “CrMo”	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.64	0.64	0.64	0.64	0.64	0.64
3	Ferritic Steels (FS) [CSEF & CSEF (N+T)]	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.77
4	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
5	Nickel Alloy (NA)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
6	Stainless Steel (SS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Material Types other than those stated in Sl. Nos. 1 to 6	1.00	W = 1 – 0.000909 (T_{max} – T_{cr}) for T_{max}> 800 deg. F (or 427 deg. C) and <= 1500 deg. F (or 816 deg. C), where, T_{cr} is taken as 800 deg. F													

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) for bends from paras. 304.1.2. and 304.2.1 respectively.

$$P_a = \frac{2SEt_a}{(D_o - 2Yt_a)} . \left(\frac{W}{I}\right)$$

where

P_a= allowable internal pressure

S = allowable stress at Design Temperature (i.e., at T_{design} input into CAEPIPE) as provided in para. 302.3.1 (a) and as per Table A-1

E = joint factor (input as material property) from Table A-1A as per para. 302.3.3 (b) or Table A-1B as per para. 302.3.4 9 (a).

W = Weld Joint Strength Reduction Factor at Design Temperature (i.e., at T_{design} input into CAEPIPE) from para. 302.3.5 (e) and as per Table 302.3.5. Refer to the Table listed at the end of this section for details on Weld Strength Reduction Factor implemented in CAEPIPE.

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance "c" in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

Y = coefficient from Table 304.1.1, valid for $t_a < D/6$. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE.

I = 1.0 for straight pipes and at the side wall on the bend / elbow centerline

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4a) and Eq. (4b) from para. 304.2.3 (a) as

$$P_a = min\left[\frac{SEWt_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{rt_a}\right)}, \frac{SEWt_a(R-r)}{r(R-r/2)}\right]$$

For widely spaced miter bends with θ<= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. 304.2.3 (b) (1) as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{rt_a}\right)}$$

For widely spaced miter bends with θ> 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. 304.2.3 (b) (2) as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 1.25 \tan\theta \sqrt{rt_a}\right)}$$

where

r = mean radius of pipe using nominal wall thickness = $(D- t_n)/2$

R = effective bend radius of the miter (see para. 304.2.3 (d) of code for definition) [an input in CAEPIPE for miters]

θ = miter half angle = $\tan^{-1}\left(\dfrac{1.0}{\left(\dfrac{2R}{r}-1.0\right)}\right)$

Note:

As per para. 304.1.2 (a), Eq. 3(a) used above to compute allowable internal pressure is valid only when t_a < D/6. Hence, CAEPIPE will issue a warning message and will leave the Allowable Pressure row BLANK for elements where t_a >= D/6 in Code Compliance Results.

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b), (23c) and (23d) from para. 320.2 and para. 302.3.5 (c).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \le S_h$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = I_a\left[\frac{P\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_S = wall thickness used for sustained stress calculation after deducting corrosion allowance from the nominal thickness

t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1

A_p = sustained <u>corroded</u> cross-sectional area of the pipe computed using t_s as per para. 320.2.

I_a = longitudinal force index = 1.0

F_a = longitudinal force due to sustained loads (pressure and weight)

R = axial force due to weight alone, where weight is computed using nominal thickness.

I_i = sustained in-plane moment index = $0.75i_i$ or 1.0, whichever is greater.

I_o = sustained out-of-plane moment index = $0.75i_o$ or 1.0, whichever is greater.

I_t = sustained torsional moment index = 1.0

M_i = in-plane bending moment due to sustained loads, e.g., pressure and weight

M_o = out-of-plane bending moment due to sustained loads, e.g., pressure and weight

M_t = torsional moment due to sustained loads, e.g., pressure and weight

Z_m = <u>corroded</u> section modulus as per para. 320.1

S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
$\mathrm{i_i}$ and $\mathrm{i_o}$ = in-plane and out-of-plane index from ASME B31J (2017) respectively.

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently. See para. 302.3.6 (a).

For temp ≤ 427^0 C or 800^0 F

$S_{LO} \leq 1.33 S_h$ as per para. 302.3.6 (a)(1)

For temp > 427^0 C or 800^0 F

$S_{LO} \leq \min(0.9 W S_y, 4 S_h)$as per para. 302.3.6 (a)(2) [only 302.3.6 (a)(2)(-a) and 302.3.6 (a)(2)(-b) considered]

where
$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b), (23c) and (23d) with applicable loads as per para. 302.3.6 (a).

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = I_a \left[\frac{\left(P_{peak} - P\right)\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2 Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P
R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for other materials as per para. 302.3.6(a)(2)
Z_m = corroded section modulus as per para. 320.1

Note: When the field Yield strength is left BLANK or NOT input, then CAEPIPE will compute the Yield Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 1.5 (=3/2). This is because; the allowable stress for material below creep is generally 2/3 of Yield Strength.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. 319.4.4 and shall not exceed (S_A) as per para.302.3.5 (d).

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_A$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.
i_a= axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ for other components as per ASME B31J (2017)
F_a = range of axial force between any two thermal conditions being evaluated
i_i = in-plane stress intensification factor (SIF) as per ASME B31J (2017); shall not be < 1.0
i_o = out-of-plane SIF as per ASME B31J (2017); shall not be < 1.0
i_t = torsional SIF as per ASME B31J (2017); shall not be < 1.0
M_i = in-plane bending moment range between any two conditions being evaluated
M_o = out-of-plane bending moment range between any two conditions being evaluated
M_t = torsional moment range between any two conditions being evaluated
Z = un-corroded section modulus as per para. 319.3.5 and para. 319.4.4 (a)
S_A =$f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)
f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$ where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)
N= equivalent number of full displacement cycles during expected service of piping (= Number of Thermal Cycles input into CAEPIPE through Options > Analysis > Temperature)
S_C= basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h= basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

when S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d). This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 3** below)

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout > Options > Analysis > Code tab.

Notes:

5. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).
6. Refer to the end of this appendix for the details of "Thickness and Section Modulus used for weight, allowable pressure and stress calculations".
7. Para. 302.3.5 provides maximum value of Sc and Sh as 138 MPa (20 ksi). The reason for this criterion is explicitly stated in Note 2 of para. 102.3.5 (b) (1) of ASME B31.1 (2020) as "For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1a) and (1b) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_L) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1a).
8. As per para. 319.2.1 (c), wind sway should be input into appropriate thermal load displacement.

Notes on Material Library for B313-2020.mat supplied with CAEPIPE:

Material library for ASME B31.3 (2020) [B313-2020.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix A and Appendix C of ASME B31.3 (2020).

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 304.1.1 of ASME B31.3 – 2020)

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Weld Joint Strength Reduction Factors used in CAEPIPE to calculate the Allowable Internal Pressure of components (extracted from Table 302.3.5 of ASME B31.3-2020)

Sl. No.	Material Type/Material Description	Weld Joint Strength Reduction Factor W for Temperature, Deg F (Deg C)														
		<=800 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677)	1300 (704)	1350 (732)	1400 (760)	1450 (788)	1500 (816)
1	Carbon Steel (CS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Material Description that contains a string “CrMo”	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.64	0.64	0.64	0.64	0.64	0.64
3	Ferritic Steels (FS) [CSEF & CSEF (N+T)]	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.77
4	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
5	Nickel Alloy (NA)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
6	Stainless Steel (SS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Material Types other than those stated in Sl. Nos. 1 to 6	1.00	W = 1 – 0.000909 (T_{max} – T_{cr}) for T_{max}> 800 deg. F (or 427 deg. C) and <= 1500 deg. F (or 816 deg. C), where, T_{cr} is taken as 800 deg. F													

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with I = 1.0 for bends from paras. 304.1.2. and 304.2.1. respectively.

$$P_a = \frac{2SEWt_a}{D - 2Yt_a}$$

where

P_a= allowable pressure

S = allowable stress as provided in para. 302.3.1 (a) and as per Table A-1

E = joint factor (input as material property) from Table A-1A as per para. 302.3.3. or Table A-1B as per para. 302.3.4.

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5.Refer to the Table listed at the end of this section for details on Weld strength reduction factor implemented in CAEPIPE.

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance "c" in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

d= inside diameter

Y = coefficient from Table 304.1.1, valid for $t_a < D/6$. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE.

$Y = \frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$ for all material types.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4b) from para. 304.2.3.

$$P_a = \frac{SEWt_a(R-r)}{r(R-r/2)}$$

For widely spaced miter bends with θ<= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. 304.2.3 as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{rt_a}\right)}$$

For widely spaced miter bends with θ> 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. 304.2.3 as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 1.25\tan\theta\sqrt{rt_a}\right)}$$

where

r = mean radius of pipe = (D- t_n)/2

R = effective bend radius of the miter (see para. 304.2.3 of code for definition) [an input in CAEPIPE for miters]

θ= miter half angle = $\tan^{-1}\left(\dfrac{1.0}{\left(\dfrac{2R}{r} - 1.0\right)}\right)$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) from para. 320.2 and para. 302.3.5 (c).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \le S_h$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

For branch (Leg 3 in Fig. 319.4.4B),

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_3}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_S = wall thickness used for sustained stress calculation after deducting corrosion allowance from the nominal thickness

t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1

A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 320.1.

I_a = longitudinal force index = 1.0

F_a = longitudinal force due to sustained loads (pressure and weight)

R = axial force due to weight alone, where weight is computed using nominal thickness.

I_i = sustained in-plane moment index = $0.75i_i$ or 1.0, whichever is greater.
I_o = sustained out-of-plane moment index = $0.75i_o$ or 1.0, whichever is greater.
I_t = torsional moment index = 1.0
M_i = in-plane bending moment due to sustained loads e.g., pressure and weight
M_o = out-of-plane bending moment due to sustained loads e.g., pressure and weight
M_t = torsional moment due to sustained loads e.g., pressure and weight
Z_m = corroded section modulus as per para. 320.1
Z_3= effective corroded section modulus (Z_e) when Appendix D of B31.3 is used to compute $\mathrm{i_i}$ and $\mathrm{i_o}$(or) corroded section modulus (Z_m) when B31J is used to compute $\mathrm{i_i}$ and $\mathrm{i_o}$
S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})

Note:
$\mathrm{i_i}$ and $\mathrm{i_o}$ are taken from Appendix D of B31.3 (2018) or ASME B31J (2017), when the Analysis option "Use B31J for SIFs and Flexibility Factors" is Turned ON in CAEPIPE.

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. 302.3.6(a)).

For temp ≤ 427^0 C or 800^0 F

$S_{LO} \leq 1.33S_h$as per para. 302.3.6 (a)(1)

For temp > 427^0 C or 800^0 F

$S_{LO} \leq \min(0.9WS_y, 4S_h)$as per para. 302.3.6 (a)(2) [only 302.3.6 (a)(2)(-a) and 302.3.6 (a)(2)(-b) considered]

where
$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) with applicable loads as per para. 302.3.6 (a).

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = \left[\frac{(P_{peak} - P)D}{4t_s} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

For branch (Leg 3 in Fig. 319.4.4B)

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_3}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P
R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for all other materials as per para. 302.3.6(a)
Z_m = corroded section modulus as per para. 320.1
Z_3= effective corroded section modulus (Z_e) when Appendix D of B31.3 is used to compute $\mathrm{i_i}$ and $\mathrm{i_o}$(or) corroded section modulus (Z_m) when B31J is used to compute $\mathrm{i_i}$ and $\mathrm{i_o}$

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. 319.4.4

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

For branch (Leg 3 in Fig. 319.4.4B)

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_3}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.

i_a= axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o \; or \; i$ for other components as listed in Appendix D of B31.3 or as per B31J

F_a = range of axial force due to displacement strains between any two thermal conditions being evaluated

i_i = in-plane stress intensification factor; shall not be less than 1.0

i_o = out-of-plane stress intensification factor; shall not be less than 1.0

i_t = torsional stress intensification factor as listed in Appendix D of B31.3or as per B31J

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus as per para. 319.3.5 and para. 319.4.4 (a)

Z_3 = effective un-corrodedsection modulus (Z_e) when Appendix D of B31.3 is used to compute $\mathrm{i_i}$ and $\mathrm{i_o}$(or) un-corrodedsection modulus (Z) when B31J is used to compute $\mathrm{i_i}$ and $\mathrm{i_o}$

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)

f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$
where f ≥ 0.15 and f ≤ 1.0 (see Note 1 below)

N= equivalent number of full displacement cycles during expected service of piping (= Number of Thermal Cycles input into CAEPIPE through Options > Analysis > Temperature)

S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater thanS_L, the allowable stress range may be calculated as

S_A = $f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d).

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout > Options > Analysis > Code tab.

Notes:

1. As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.
2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
4. $i_i$andi_o are taken from Appendix D of B31.3 (2018) or ASME B31J (2017), when the Analysis option "Use B31J for SIFs and Flexibility Factors" is Turned ON in CAEPIPE.

Notes on Material Library for B313-2018.mat supplied with CAEPIPE:

Material library for ASME B31.3 (2018) [B313-2018.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix A and Appendix C of ASME B31.3 (2018).

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

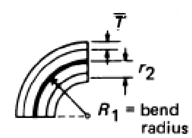
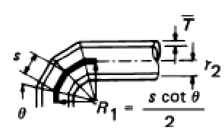
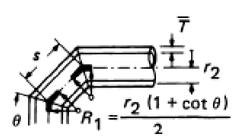
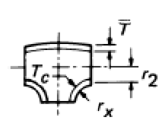
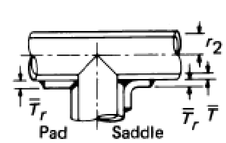
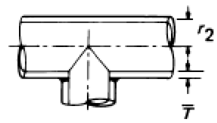
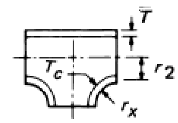
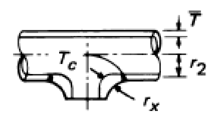
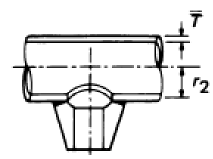
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2\,(1 + \tan\theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2\,(1 + \tan\theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5}\,r_2}$	

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$, $T_c < 1.5\ \bar{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1\ \frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\ \frac{\bar{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

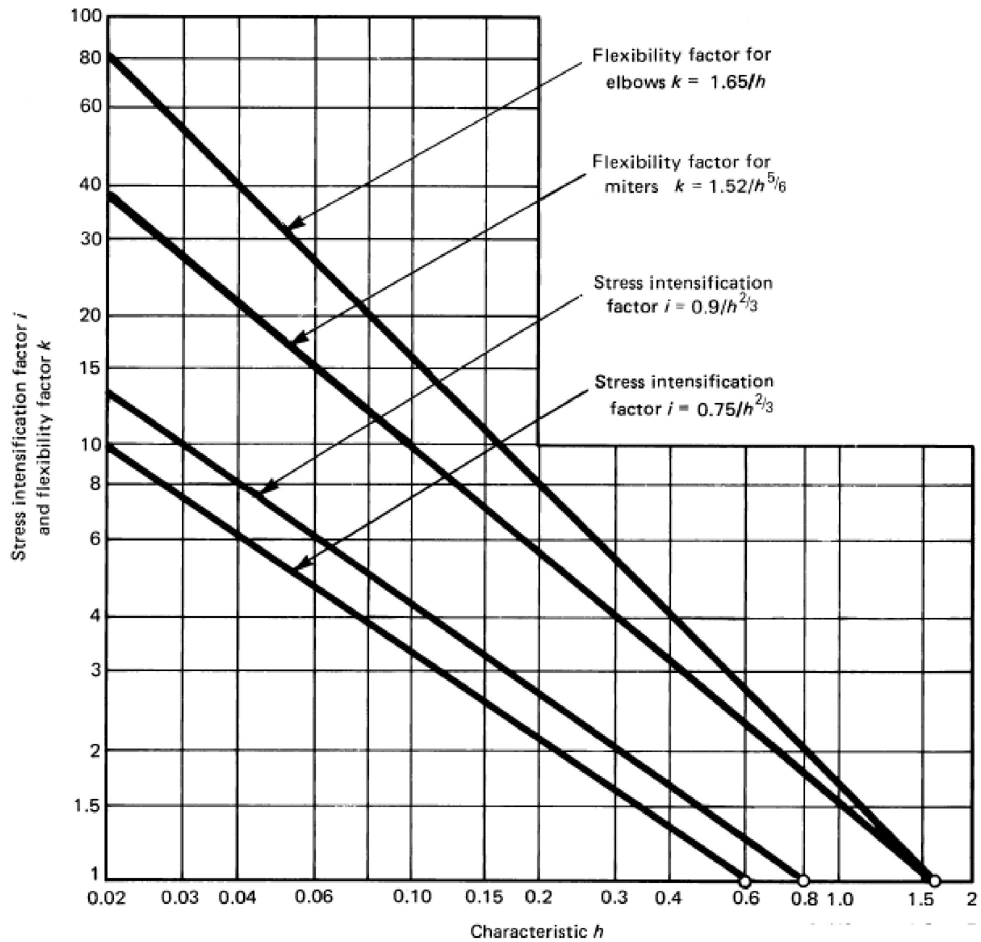


Chart A

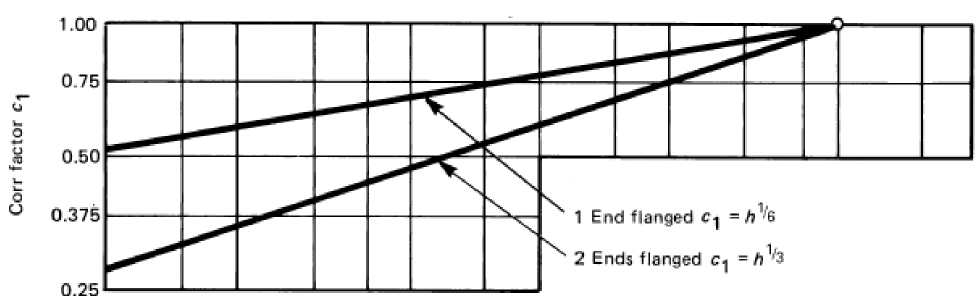


Chart B

Table D300 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd) (14)

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\overline{T} \leq 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\overline{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\overline{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5\overline{T}$, a flexibility characteristic of $4.4\ \overline{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\overline{T}_r$ is $> 1\frac{1}{2}\ \overline{T}$, use $h = 4\ \overline{T}/r_2$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 304.1.1 of ASME B31.3 – 2018)

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Weld Strength Reduction Factors used in CAEPIPE to calculate the Allowable Design Pressure of components (extracted from Table 302.3.5 of ASME B31.3-2018)

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)														
		<=800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500
		(427)	(454)	(482)	(510)	(538)	(566)	(593)	(621)	(649)	(677)	(704)	(732)	(760)	(788)	(816)
1	Carbon Steel (CS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Material Description that contains a string “CrMo”	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.64	0.64	0.64	0.64	0.64	0.64
3	Ferritic Steels (FS) [CSEF & CSEF (N+T)]	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.77
4	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
5	Nickel Alloy (NA)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
6	Stainless Steel (SS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Material Types other than those stated in Sl. Nos. 1 to 6	1.00	W = 1 – 0.000909 (T_{max} – T_{cr}) for T_{max}> 800 deg. F (or 427 deg. C) and <= 1500 deg. F (or 816 deg. C), where, T_{cr} is taken as 800 deg. F													

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with I = 1.0 for bends from paras. 304.1.2. and 304.2.1. respectively.

$$P_a = \frac{2SEWt_a}{D - 2Yt_a}$$

where

P_a= allowable pressure

S = allowable stress as provided in para. 302.3.1 (a) and as per Table A-1

E = joint factor (input as material property) from Table A-1A as per para. 302.3.3. or Table A-1B as per para. 302.3.4.

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5 is implemented in CAEPIPE as follows.

T_{max} below denotes maximum operating temperature (i.e., max of T1 through T10 and Tref in CAEPIPE).

With Material Type in CAEPIPE = CS [CrMo]

W = 1.0 with Tmax<= 800^0 F (or 427^0 C)

W = 0.64 with Tmax> 1200^0 F (or 649^0 C) and

For T_{max}> 800^0 F (or 427^0 C) and <= 1200^0 F (or 649^0 C), the values of W are taken from Table 302.3.5.

W for intermediate temperatures is linearly interpolated.

With Material Type in CAEPIPE = FS [CSEF (Subcritical)]

W = 1.0 with Tmax<= 900^0 F (or 482^0 C)

W = 0.5 with Tmax> 900^0 F (or 482^0C)

With Material Type in CAEPIPE = AS or NA

W = 1.0 with Tmax<= 950^0 F (or 510^0 C)

For Tmax> 950^0 F (or 510^0 C), the values of W are taken as per Table 302.3.5.

W for intermediate temperatures is linearly interpolated.

With Material Type in CAEPIPE = SS

W = 1.0 with Tmax<= 1500^0 F (or 816^0 C)

For Other Material Types in CAEPIPE

W = 1.0 with Tmax<= 800^0 F (or 427^0 C)

W = 1 – 0.000909 (T_{max} – T_{cr}) for T_{max}> 800^0 F (or 427^0 C) and<= 1500^{0}F (or 810^{0}C)

where, T_{cr} is taken as 800^0 F

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

d = inside diameter
Y = coefficient from Table 304.1.1, valid for $t_a < D/6$. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE.
Y = $\frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$ for all material types.

<u>For closely spaced miter bends</u>, the allowable pressure is calculated in CAEPIPE using Eq. (4b) from para. 304.2.3.

$$P_a = \frac{SEWt_a(R-r)}{r(R-r/2)}$$

<u>For widely spaced miter bends with</u> θ<= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. 304.2.3 as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 0.643\tan\theta\sqrt{rt_a}\right)}$$

<u>For widely spaced miter bends with</u> θ> 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. 304.2.3 as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 1.25\tan\theta\sqrt{rt_a}\right)}$$

where
r = mean radius of pipe = (D- t_n)/2
R = effective bend radius of the miter (see para. 304.2.3 of code for definition) [an input in CAEPIPE for miters]

θ= miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r}-1.0\right)}\right)$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) from para. 320.2 and para. 302.3.5 (c).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_h$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

For branch (Leg 3 in Fig. 319.4.4B),

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10
D = outside diameter
t_S = wall thickness used for sustained stress calculation after deducting corrosion allowance from the nominal thickness
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1
A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 320.1.
I_a = longitudinal force index = 1.0
F_a = longitudinal force due to sustained loads (pressure and weight)
R = axial force due to weight alone, where weight is computed using nominal thickness.
I_i = sustained in-plane moment index = $0.75i_i$ or 1.0, whichever is greater.
I_o = sustained out-of-plane moment index = $0.75i_o$ or 1.0, whichever is greater.
where i_i and i_o are taken from Appendix D of B31.3 (2016).
I_t = torsional moment index = 1.0
M_i = in-plane bending moment due to sustained loads e.g., pressure and weight
M_o = out-of-plane bending moment due to sustained loads e.g., pressure and weight
M_t = torsional moment due to sustained loads e.g., pressure and weight
Z_m = corroded section modulus as per para. 320.1
Z_e = effective corroded section modulus for branch as per para. 320.2

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. 302.3.6(a)).

For temp ≤ 427^0 C or 800^0 F

$S_{LO} \leq 1.33 S_h$

For temp > 427^0 C or 800^0 F

$S_{LO} \leq 0.9 W S_y$

where
$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) with applicable loads.

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = \left[\frac{(P_{peak} - P)D}{4t_s} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

For branch (Leg 3 in Fig. 319.4.4B)

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P
R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for all other materials as per para. 302.3.6(a)
Z_m = corroded section modulus as per para. 320.1
Z_e = effective corroded section modulus for branch as per para. 320.2

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. 319.4.4

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

For branch (Leg 3 in Fig. 319.4.4B)

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_e}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.
i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ *or* i for other components as listed in Appendix D of B31.3 (2016)
F_a = range of axial force due to displacement strains between any two thermal conditions being evaluated
i_i = in-plane stress intensification factor; shall not be less than 1.0
i_o = out-of-plane stress intensification factor; shall not be less than 1.0
i_t = torsional stress intensification factor = 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus as per para. 319.3.5 and para. 319.4.4 (a)
Z_e = un-corroded effective section modulus as per para. 319.3.5 and para. 319.4.4 (c)

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)
f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$ where f ≥ 0.15 and f ≤ 1.0 (see Note 1 below)
S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

S_A = $f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d).

This is specified as an analysis option “Use liberal allowable stresses”, in the menu Layout > Options > Analysis > Code tab.

Notes:

1. As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.
2. Young’s modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).
3. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

Notes on Material Library for B313-2016.mat supplied with CAEPIPE:

Material library for ASME B31.3 (2016) [B313-2016.mat]supplied with CAEPIPE has been created by referring to the values provided in Appendix A and Appendix C of ASME B31.3 (2016).

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

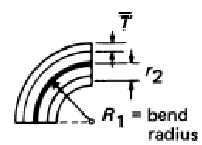
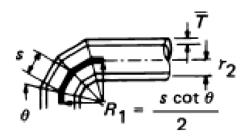
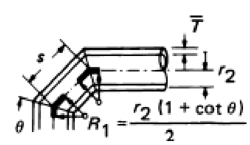
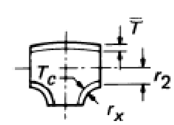
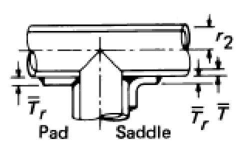
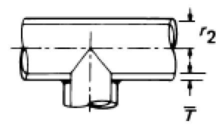
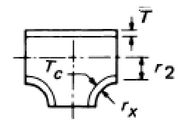
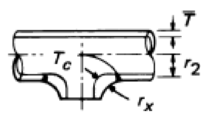
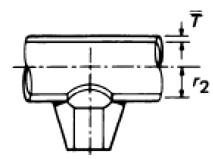
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2(1 + \tan\theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2(1 + \tan\theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5}r_2}$	

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded welding tee with $r_x \ge 0.05\ D_b$ $T_c < 1.5\ \bar{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1\ \frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\ \frac{\bar{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

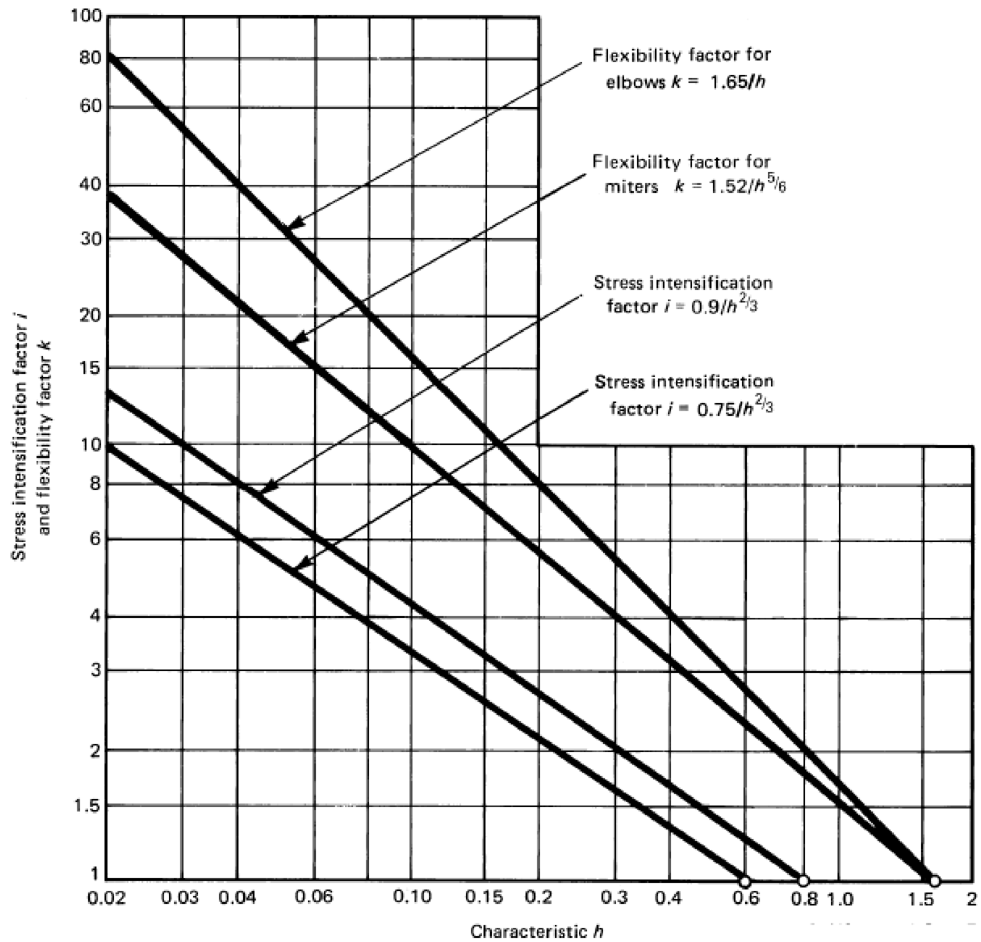


Chart A

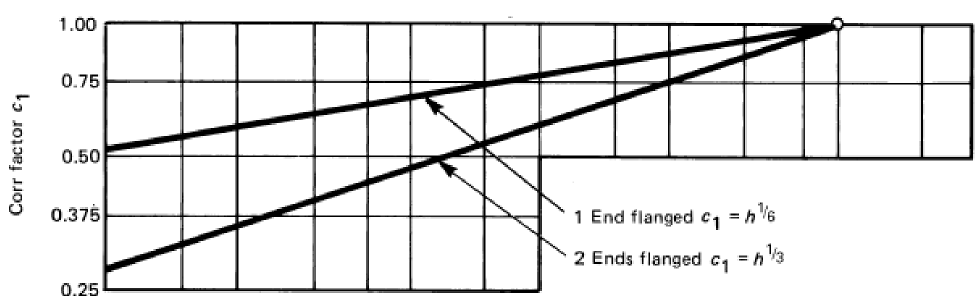


Chart B

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd) (14)

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\bar{T} \leq 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\bar{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5\bar{T}$, a flexibility characteristic of $4.4\,\bar{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\bar{T}_r$ is $> 1\frac{1}{2}\,\bar{T}$, use $h = 4\,\bar{T}/r_2$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 304.1.1 of ASME B31.3 – 2016)

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with I = 1.0 for bends from paras. 304.1.2. and 304.2.1. respectively.

$$P_a = \frac{2SEWt_a}{D - 2Yt_a}$$

where

P_a= allowable pressure

S = allowable stress as provided in para. 302.3.1 (a) and as per Table A-1

E = joint factor (input as material property) from Table A-1A or A-1B from para. 302.3.3. and para. 302.3.4.

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5 is implemented in CAEPIPE as follows. T_{max} below denotes maximum operating temperature (i.e., max of T1 through T10 and Tref in CAEPIPE).

With Material Type in CAEPIPE = CS [CrMo]

W = 1.0 with Tmax<= 800^0 F (or 427^0 C)

W = 0.64 with Tmax> 1200^0 F (or 649^0 C) and

For T_{max}> 800^0 F (or 427^0 C) and <= 1200^0 F (or 649^0 C), the values of W are taken from Table 302.3.5.

W for intermediate temperatures is linearly interpolated.

With Material Type in CAEPIPE = FS [CSEF (Subcritical)]

W = 1.0 with Tmax<= 900^0 F (or 482^0 C)

W = 0.5 with Tmax> 900^0 F (or 482^0C)

With Material Type in CAEPIPE = AS or NA

W = 1.0 with Tmax<= 950^0 F (or 510^0 C)

For Tmax> 950^0 F (or 510^0 C), the values of W are taken as per Table 302.3.5.

W for intermediate temperatures is linearly interpolated.

With Material Type in CAEPIPE = SS

W = 1.0 with Tmax<= 1500^0 F (or 816^0 C)

For Other Material Types in CAEPIPE

W = 1.0 with Tmax<= 800^0 F (or 427^0 C)

W = 1 – 0.000909 (T_{max} – T_{cr}) for T_{max}> 800^0 F (or 427^0 C) and<= 1500^0F (or 810^0C) where, T_{cr} is taken as 800^0 F

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

d = inside diameter
Y = Pressure coefficient from Table 304.1.1, valid for $t_a < D/6$, and
Y = $\frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$

For closely spaced miter bends, the allowable pressure is calculated using Eq. (4b) from para. 304.2.3.

$$P_a = \frac{SEWt_a(R-r)}{r(R-r/2)}$$

where
r = mean radius of pipe = (D- t_n)/2
R = effective bend radius of the miter (see para. 304.2.3 of code for definition)
For widely spaced miter bends, the allowable pressure is calculated using Eq. (4c) from para. 304.2.3 as

$$P_a = \frac{SEWt_a^2}{r\left(t_a + 1.25\tan\theta\sqrt{rt_a}\right)}$$

where
θ = miter half angle

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eq. (23a) and (23b) from para. 320.2 and para. 302.3.5 (c).

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_h$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10
D = outside diameter
t_S = wall thickness used for sustained stress calculation after deducting corrosion allowance from the nominal thickness
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1
A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 320.1.
I_a = longitudinal force index = 1.0
F_a = longitudinal force due to sustained loads (pressure and weight)
R = axial force due to weight
I_i = in-plane stress intensification factor; the product of $0.75 i_i$ shall not be less than 1.0
I_o = out-of-plane stress intensification factor; the product of $0.75 i_o$ shall not be less than 1.0
I_t = torsional moment index = 1.0
M_i = in-plane bending moment due to sustained loads e.g., pressure and weight
M_o = out-of-plane bending moment due to sustained loads e.g., pressure and weight
M_t = torsional moment due to sustained loads e.g., pressure and weight
Z_m = corroded section modulus as per para. 320.1; for reduced outlets / branch connections, effective section modulus
Z_m = hot allowable stress at maximum temperature [i.e., at Max(Tref, T1 through T10)]

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress due to sustained loads such as due to pressure and weight (S_L) and stress due to occasional loads (S_o) such as due to earthquake or wind. Wind and earthquake are not considered concurrently (see para. 302.3.6(a)).

For temp ≤ 427⁰ C or 800⁰ F

$$S_{LO} \leq 1.33 S_h$$

For temp > 427⁰ C or 800⁰ F

$$S_{LO} \leq 0.9 W S_y$$

where
$S_{LO} = S_L + S_O$, where S_L is computed as above, and

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = \left[\frac{(P_{peak} - P)D}{4t_s} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

$S_{to} = \left[\frac{I_t M_t}{2Z_m}\right]_{Occasional}$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P
R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max(T_{ref}, T_1 through T_{10})
W = 1.0 for Austeniticstainless steel and 0.8 for all other materials as per para.302.3.6(a)

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. 319.4.4

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where

$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$

$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$

$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.
i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ for other components as listed in Appendix D of B31.3 (2014)
F_a = range of axial force due to displacement strains between any two thermal conditions being evaluated
i_i = in-plane stress intensification factor; shall not be less than 1.0
i_o = out-of-plane stress intensification factor; shall not be less than 1.0
i_t = torsional stress intensification factor = 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus as per para. 319.3.5; for reduced outlets/branch connections, effective section modulus as per para. 319.4.4 (a)
S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)
f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$ where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)
S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

S_A = $f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d).

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout >Options>Analysis >Code tab.

Notes:

1. As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

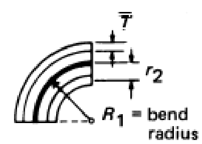
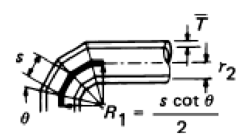
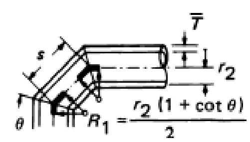
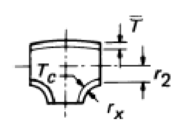
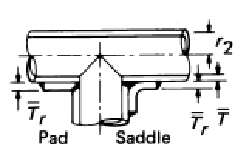
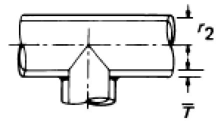
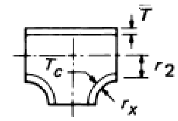
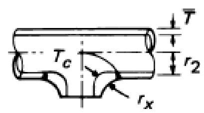
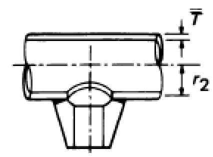
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2 (1 + \tan \theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5} r_2}$	

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\overline{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$ $T_c < 1.5\ \overline{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\overline{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1\ \frac{\overline{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\ \frac{\overline{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

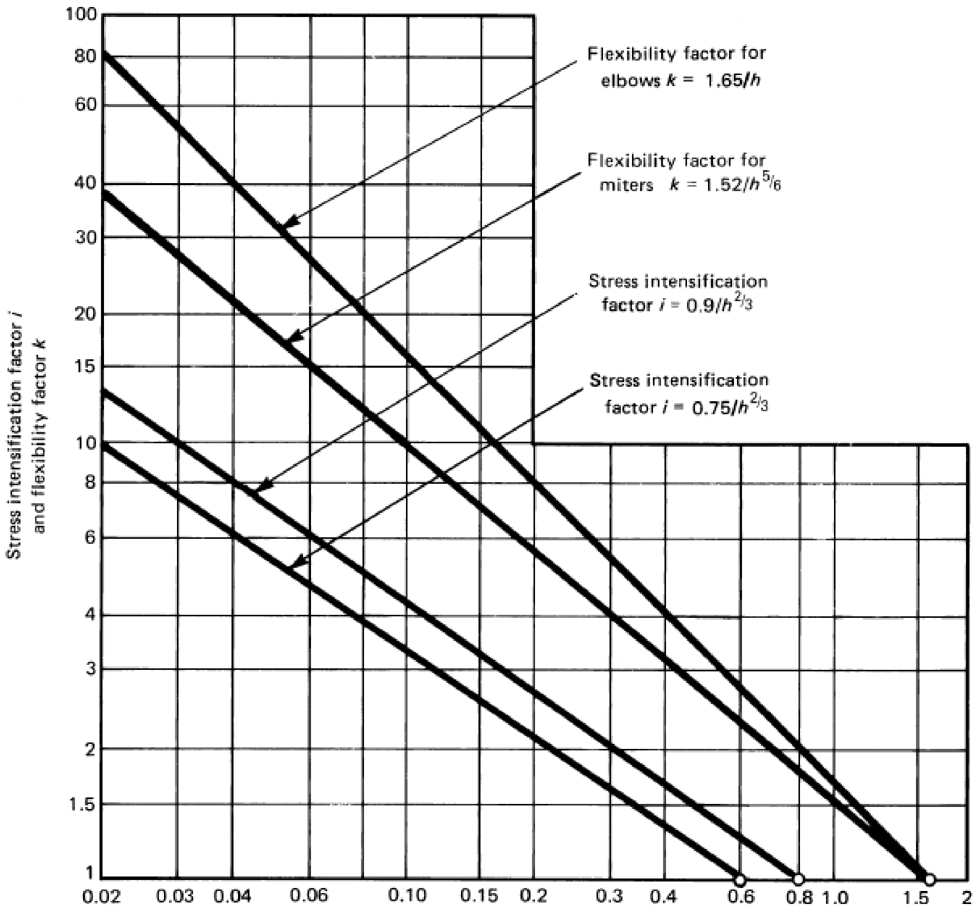


Chart A

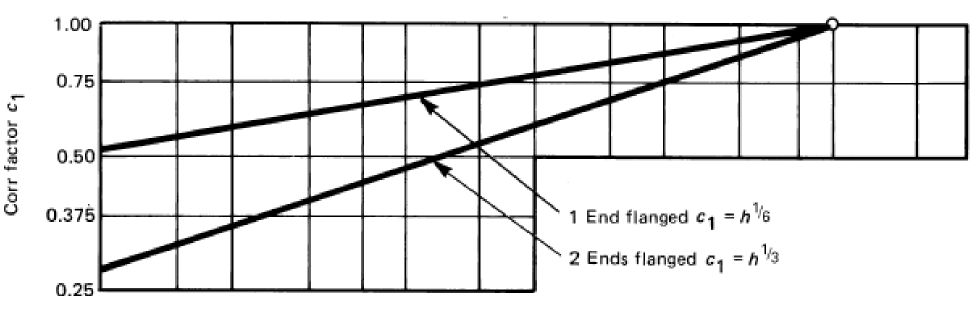


Chart B

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd) (14)

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\bar{T} \le 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\bar{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \ge \frac{1}{8} D_b$ and $T_c \ge 1.5\bar{T}$, a flexibility characteristic of $4.4\,\bar{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\bar{T}_r$ is $> 1\frac{1}{2}\,\bar{T}$, use $h = 4\,\bar{T}/r_2$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 403.2.1.

$$P_i = \frac{2St_a}{D}$$

where

P_i = allowable pressure
S = allowable stress = F x E x S_y
F = Design Factor = 0.72 as specified in para 403.2.1
S_y = specified minimum yield strength of pipe at Design Temperature input in CAEPIPE
E = weld joint factor as defined in Table 403.2.1-1
t_a = available thickness for pressure design
= $t_n \times$(1 – mill tolerance/100) – sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.
D = outside diameter

Stress due to Sustained Loads [Unrestrained (above ground) Piping]

The sum of longitudinal stress due to pressure and due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, etc. is calculated as follows.

For Pipes (as per para. 402.6.2)

$$S_L = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor; for straight pipes, i_i = 1.0 (See Note 5)
i_o = out-of-plane stress intensification factor; for straight pipes, i_o = 1.0 (See Note 5)

For Fittings & Components.(as per para. 402.6.2)

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

P = maximum operating pressure = max. of CAEPIPE input pressures P1 through P10 Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.
D = nominal outside diameter

t_n = nominal thickness as per para. 402.1

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0 (See Note 5)

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0 (See Note 5)

M_i = in-plane bending moment due to weight and other external loads

M_o = out-of-plane bending moment due to weight and other external loads

M_t = torsional moment due to weight and other external loads

Z = un-corroded section modulus; for reduced outlets, effective section modulus

F_a = axial force component for external loads

A = nominal metal cross-section area

S_y = specified minimum yield strength of pipe at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

Stress due to Sustained Loads + Occasional Loads [Unrestrained (above ground) Piping]

The sum of longitudinal pressure stress due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated as follows. Wind and Seismic is not considered to act concurrently.

For Pipes (as per para. 402.6.2)

$$S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

$$S_{LO(fc)} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

where

P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with 1.0 ≤ peak pressure factor ≥ 1.1 as per para. 403.3.4

Expansion Stress [Unrestrained (above ground) Piping]

The stress range (S_E) due to thermal expansion is calculated from para.402.5.2

$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$ as per Table 403.3.1-1 and para. 403.3.2

where

S_b = resultant bending stress $= \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$
S_t = torsional stress $= \frac{M_t}{2Z}$
M_i = in-plane bending moment due to thermal expansion
M_o = out-of-plane bending moment due to thermal expansion
M_t = torsional moment due to thermal expansion
Z = un-corroded section modulus; for reduced outlets, effective section modulus

S_A = $f[1.25(S_c + S_h) - S_L]$
f = stress range reduction factor $= 6/N^{0.2}$, where $N =$ number of equivalent full range Cycles, where $f \leq 1.2$ (from para. 403.3.2). See Note below.

S_c= $0.67S_y$ at the lower of the installed temperature or minimum operating temperature <= 20,000 psi
S_h= $0.67S_y$ at the higher of the installed temperature or maximum operating temperature <= 20,000 psi
S_y= specified minimum yield strength of pipe at maximum operating temperature [i.e., at max (Tref, T1 through T10)]

Note:

As per para. 403.3.2, f cannot exceed 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.

Stress due to Sustained, Thermal and Occasional Loads [Restrained (buried) Piping]

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_{Lp} = S_E + \upsilon S_H + \frac{F_a}{A} + \frac{M}{Z}$$

$$S_{Ln} = S_E + \upsilon S_H + \frac{F_a}{A} - \frac{M}{Z}$$

As per para. 402.6.1, both positive and negative values of M/Z shall be considered for analysis.

Where

S_E = Thermal expansion stress $= E\alpha_m(T_m - T_i)$, which can either be positive or negative

S_H = circumferential (hoop) stress = $\frac{PD}{2t_n}$, which can either be positive or negative as per para. 402.6.1.

υ = Poission's ratio = 0.3 as per para. 402.2.3

F_a = axial force from weight and other sustained and occasional loads. As per para. 402.6.1, F_a can be positive or negative.

M = bending moment from Weight and other Sustained and Occasional loads

For Pipes

$$M = \sqrt{(i_iM_i)^2 + (i_oM_o)^2}$$

For Fittings & Components

$$M = \sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2}$$

where
P = PFO x max. pressure (P1 through P10) entered in CAEPIPE.
PFO = Peak Pressure Factor input. PFO = 1.0, if occasional loads are not present.
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment from Weight and other Sustained and Occasional loads
M_o = out-of-plane bending moment from Weight and other Sustained and Occasional loads
A = nominal metal cross-section area
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S_y = specified minimum yield strength of pipe at maximum operating temperature [i.e., at max (Tref, T1 through T10)]
T_i= installation temperature = T_{ref} in CAEPIPE (see Note below)
T_m= warmest or coldest operating temperature (see Note below)
α_m = coefficient of thermal expansion at T_m defined above (see Note below)
E = young's modulus at ambient (reference) temperature

Note:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress S_T due to thermal expansion as follows.

For a change in temperature from T_{ref} to T_1, $S_{T1} = -E\alpha_1(T_1 - T_{ref})$

For a change in temperature from T_{ref} to T_2, $S_{T2} = -E\alpha_2(T_2 - T_{ref})$

For a change in temperature from T_1 to T_2, $S_{T1->T2} = S_{T2} - S_{T1}$

Please note, that negative (-) sign is added in the above equations as the soil is restraining the thermal expansion / contraction of the buried pipe due to friction at the soil-to-pipe interface.

Combining of Stresses [Restrained (buried) Piping]

The longitudinal and circumferential stresses are combined in accordance with the maximum shear stress theory as follows (by default in CAEPIPE) as per para. 402.7.

$$S_{eq1} = 2\sqrt{\left[\left(S_{Lp} - S_H\right)/2\right]^2 + (S_t)^2} \qquad S_{eq2} = 2\sqrt{[(S_{Ln} - S_H)/2]^2 + (S_t)^2}$$

where, S_{Lp} and S_{Ln} are calculated as given above.

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 4 below):

$$S_{eq1} = \sqrt{(S_H)^2 - S_H S_{Lp} + \left(S_{Lp}\right)^2 + 3(S_t)^2} \qquad S_{eq2} = \sqrt{(S_H)^2 - S_H S_{Ln} + (S_{Ln})^2 + 3(S_t)^2}$$

$S_{eq} = max\{S_{eq1}, S_{eq2}\} \le 0.9S_y$ as per Table 403.3.1-1

where

S_{eq} = equivalent combined stress

S_t = torsional stress $= \frac{M_t}{2Z}$

M_t = torsional moment from Weight and other Sustained and Occasional loads

Notes:

1. Para. 402.6.2 of B31.4 (2022) states that "Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports".

   The above statement implies that "elongation due to Bourdon effect" is to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).

   In view of the above, Bourdon effect is turned ON always and disabled for editing by the user for ASME B31.4. This can be seen through CAEPIPE Layout Window > Options > Analysis > Pressure.

   Please note, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect, by default as part of Thermal Expansion (when "Solve Thermal Case" is opted) or as part of Operating Case (when "Thermal = Operating – Sustained is opted).

2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
4. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, turn ON the analysis option "Combine stresses as per Max. Distortion Energy Theory" through Layout Window > Options > Analysis > Code.
5. Stress Intensification Factors (SIFs) and Flexibility Factors (FFs) are computed using ASME B31J (2017) by default.

Notes on Material Library for B314-2022.mat supplied with CAEPIPE:

Material library for ASME B31.4 (2022) [B314-2022.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 402.2.1 of B31.4 (2022), Coefficient of Thermal Expansion for Carbon and low alloy high tensile steel are entered as 6.5E-6 in./in./^{0}F for temperatures up to 250 ^{0}F.
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy high tensile steel for temperatures up to 250 ^{0}F are entered by referring to the values provided in Table 832.5-1 of ASME B31.8 (2022).
3. **Yield Strength:** Yield Strength for Carbon and low alloy high tensile steel for temperatures up to 250 ^{0}F are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2022).
4. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 403.2.1.

$$P_i = \frac{2St_a}{D}$$

where

P_i = allowable pressure
S = allowable stress = F x E x S_y
F = Design Factor = 0.72 as specified in para 403.2.1
S_y = specified minimum yield strength of pipe at Design Temperature input in CAEPIPE
E = weld joint factor as defined in Table 403.2.1-1
t_a = available thickness for pressure design
= $t_n \times$(1 – mill tolerance/100) – sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.
D = outside diameter

Stress due to Sustained Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

$$S_L = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor; for straight pipes, i_i = 1.0
i_o = out-of-plane stress intensification factor; for straight pipes, i_o = 1.0

For Fittings & Components.(as per para. 402.6.2)

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

P = maximum operating pressure = max. of CAEPIPE input pressures P1 through P10 Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.
D = outside diameter
t_n = nominal thickness as per para. 402.1
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
F_a = axial force component for external loads
A= nominal cross-section area
S_y=specified minimum yield strength of pipe at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

Stress due to Sustained Loads + Occasional Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

$$S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

where
P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with 1.0 ≤ peak pressure factor ≥ 1.1 as per para. 403.3.4

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.402.5.2

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$ as per Table 403.3.1-1 and para. 403.3.2

where
S_b = resultant bending stress $= \frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress $= \frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.4

S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor $= 6/N^{0.2}$, where $N =$ number of equivalent full range

Cycles, where $f \leq 1.2$ (from para. 403.3.2).

$S_c = 0.67S_y$ at the lower of the installed temperature or minimum operating temperature

$S_h = 0.67S_y$ at the higher of the installed temperature or maximum operating temperature

S_y = specified minimum yield strength of pipe at maximum operating temperature [i.e., at max (Tref, T1 through T10)]

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_{Lp} = S_E + \upsilon S_H + \frac{F_a}{A} + \frac{M}{Z}$$

$$S_{Ln} = S_E + \upsilon S_H + \frac{F_a}{A} - \frac{M}{Z}$$

As per para. 402.6.1, both positive and negative values of M/Z shall be considered for analysis.

Where

S_E = Thermal expansion stress $= E\alpha(T_i - T_o)$, which can either be positive <u>or</u> negative

S_H = circumferential (hoop) stress = $\frac{PD}{2t_n}$

υ = Poission's ratio = 0.3 as per para. 402.2.3

As per para. 402.6.1, S_H can be either positive <u>or</u> negative.

F_a = axial force, such as weight on a riser. As per para. 402.6.1, F_a can be positive or negative.

M = bending moment from Weight and other Sustained and Occasional loads

For Pipes

$$M = \sqrt{(i_i M_i)^2 + (i_o M_o)^2}$$

For Fittings & Components

$$M = \sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2}$$

where

P = PFO x max. pressure (P1 through P10) entered in CAEPIPE.

PFO = Peak Pressure Factor input. PFO = 1.0, if occasional loads are not present.

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment from Weight and other Sustained and Occasional loads
M_o = out-of-plane bending moment from Weight and other Sustained and Occasional loads
F_a = axial force component for Weight and other Sustained and Occasional loads
A = nominal cross-section area
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S_y = specified minimum yield strength of pipe at maximum operating temperature [i.e., at max (Tref, T1 through T10)]
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_o defined above
E = young's modulus at ambient (reference) temperature

Combining of Stresses (Restrained Piping)

The longitudinal and circumferential stresses are combined in accordance with the maximum shear stress theory as follows (by default in CAEPIPE).

$$S_{eq1} = 2\sqrt{\left[\left(S_{Lp} - S_H\right)/2\right]^2 + (S_t)^2} \qquad S_{eq2} = 2\sqrt{[(S_{Ln} - S_H)/2]^2 + (S_t)^2}$$

where S_{Lp} and S_{Ln} are calculated as given above.

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 4 below):

$$S_{eq1} = \sqrt{(S_H)^2 - S_H S_{Lp} + \left(S_{Lp}\right)^2 + 3(S_t)^2} \qquad S_{eq2} = \sqrt{(S_H)^2 - S_H S_{Ln} + (S_{Ln})^2 + 3(S_t)^2}$$

$$S_{eq} = max\{S_{eq1}, S_{eq2}\} \leq 0.9 S_y$$

where
S_{eq} = equivalent combined stress
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment from Weight and other Sustained and Occasional loads

Notes:

1. Para. 402.6.2 of B31.4 (2019) states that "Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports".
   The above statement seems to imply that "elongation due to Bourdon effect" is to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).
   On the other hand, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect as part of the results for Thermal Expansion (when "Solve Thermal Case" is opted) or as part of the Operating Case (when "Thermal = Operating – Sustained is opted).

2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
4. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_314" with its value as "YES".
5. Stress Intensification Factors (SIFs) and Flexibility Factors (FFs) are computed using ASME B31.4 (2019) by default. When the option "Use B31J for SIFs and Flexibility Factors" is Turned ON, then CAEPIPE computes SIFs and FFs as per B31J (2017).

Notes on Material Library for B314-2019.mat supplied with CAEPIPE:

Material library for ASME B31.4 (2019) [B314-2019.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 402.2.1 of B31.4 (2019), Coefficient of Thermal Expansion for Carbon and low alloy high tensile steel are entered as 6.5E-6 in./in./^{0}F for temperatures up to 250 ^{0}F.
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy high tensile steel for temperatures up to 250 ^{0}F are entered by referring to the values provided in Table 832.5-1 of ASME B31.8 (2018).
3. **Yield Strength:** Yield Strength for Carbon and low alloy high tensile steel for temperatures up to 250 ^{0}F are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2018).
4. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.

Table 402.1-1 Flexibility Factor, k, and Stress Intensification Factor, i

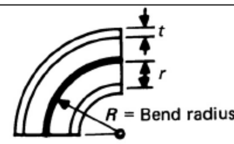
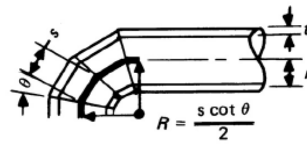
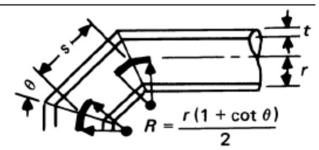
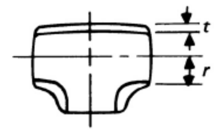
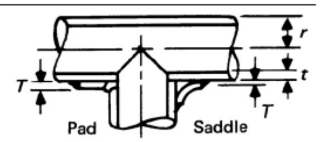
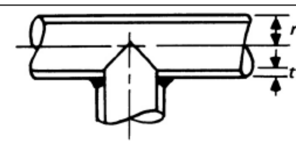
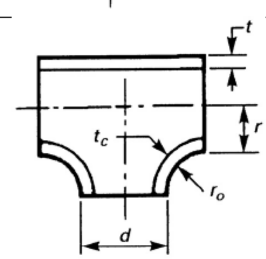
Description	Flexibility Factor, k	Stress Intensification Factor: i_i [Note (1)]	Stress Intensification Factor: i_o [Note (2)]	Flexibility Characteristic, h	Sketch
Welding elbow, or pipe bend [Notes (3)–(7)]	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{tR}{r^2}$	
Closely spaced miter bend, [Notes (3)–(5), and (7)] $s < r(1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{\cot \theta}{2} \frac{ts}{r^2}$	
Widely spaced miter bend, [Notes (3),(4), (7), and (8)] $s \geq r(1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{1 + \cot \theta}{2} \frac{t}{r}$	
Welding tee [Notes (3) and (4)] per ASME B16.9	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{t}{r}$	
Reinforced tee [Notes (3),(4), and (9)] with pad or saddle	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2\ T)^{5/2}}{t^{3/2}\ r}$	
Unreinforced fabricated tee [Notes (3) and (4)]	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	
Extruded welding tee [Notes (3),(4), and (10)] $r_o \geq 0.05d$ $t_c < 1.5t$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\left(1 + \frac{r_o}{r}\right) \frac{t}{r}$	
Butt welded joint, reducer, or welding neck flange	1	1.0		. . .	. . .
Double welded slip-on flange	1	1.2		. . .	. . .
Fillet welded joint (single welded), or single welded slip-on flange	1	1.3		. . .	. . .

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Flexibility Characteristic, h	Sketch
Lapped flange (with ANSI B16.9 lap-joint stub)	1	1.6		. . .	. . .
Threaded pipe joint, or threaded flange	1	2.3		. . .	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (11)]	5	2.5		. . .	. . .

NOTES:
(1) In-plane.
(2) Out-of-plane.
(3) For fittings and miter bends, the flexibility factors, k, and stress intensification factors, i, in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
(4) The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the equations given, where

d = outside diameter of branch
R = bend radius of welding elbow or pipe bend, in. (mm)
r = mean radius of matching pipe, in. (mm)
r_o = see Note (10)
s = miter spacing at center line
T = pad or saddle thickness, in. (mm)
t = nominal wall thickness of: part itself, for elbows and curved or mited bends; matching pipe, for welding tees; run or header, for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run O.D. to each side of the branch O.D.)
t_c = the crotch thickness of tees
θ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of k and i in this Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed h: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/3} \geq 1$.
(6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
(7) In large diameter thin wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from this Table for the pressure effect, divide

Flexibility factor, k, by $$1 + 6\frac{P}{E_c}\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

Stress intensification factor, i, by $$1 + 3.25\frac{P}{E_c}\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where
E_c = cold modulus of elasticity
P = gage pressure

(8) Also includes single miter joint.
(9) When $T > 1\frac{1}{2}t$, use $h = 4.05\ t/r$.
(10) Radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch. This is subject to the following limitations:
 (a) minimum radius, r_o: the lesser of 0.05d or 38 mm (1.5 in.)
 (b) maximum radius, r_o shall not exceed
  (1) for branches DN 200 (NPS 8) and larger, 0.10d + 13 mm (0.50 in.)
  (2) for branches less than DN 200 (NPS 8), 32 mm (1.25 in.)
 (c) when the external contour contains more than one radius, the radius on any arc sector of approximately 45 deg shall meet the requirements of (a) and (b) above
 (d) machining shall not be employed in order to meet the above requirements
(11) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

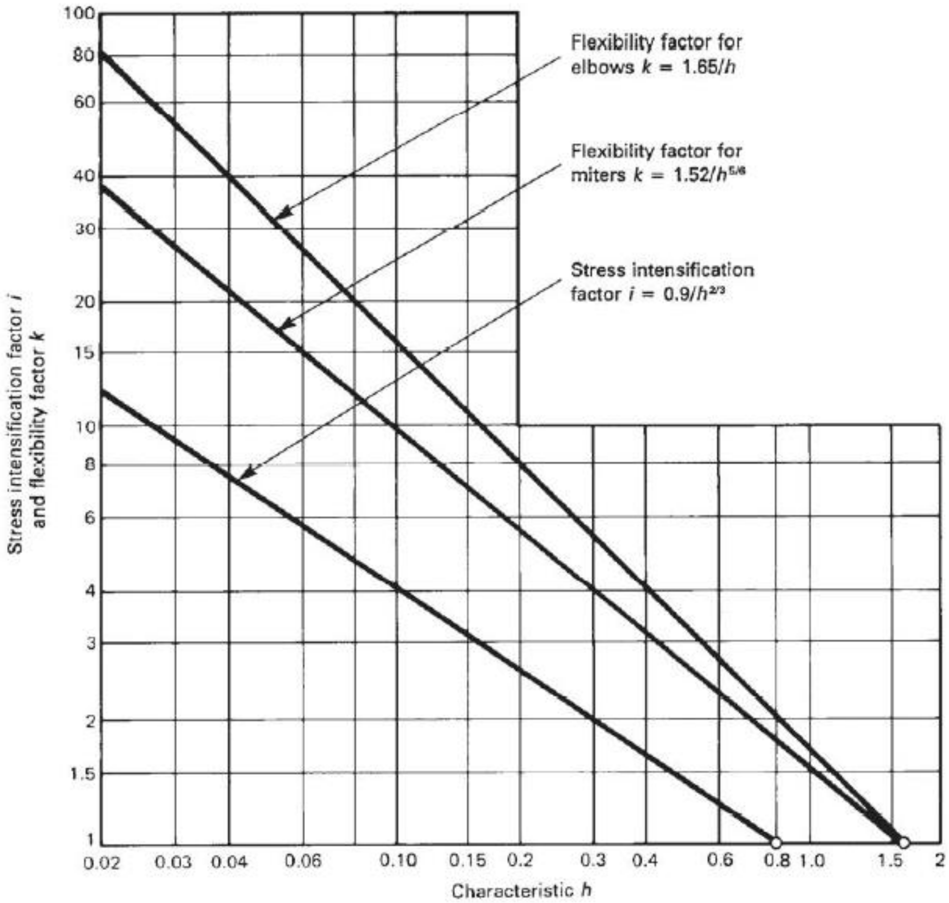


Chart A

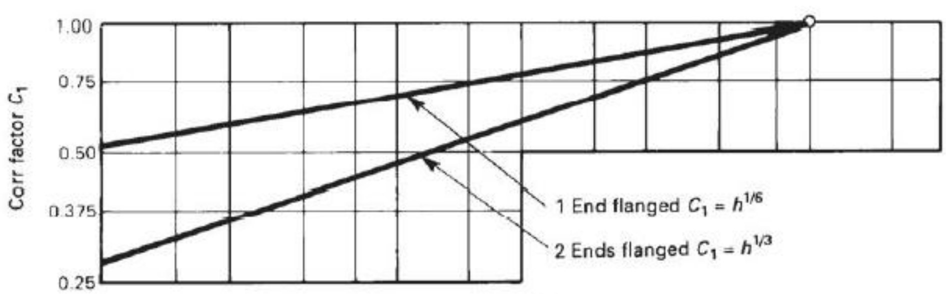


Chart B

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 403.2.1.

$$P_i = \frac{2SEt_a}{D}$$

where

P_i = allowable pressure

S = allowable stress = 0.72 S_y, where S_y is specified minimum yield strength of pipe

E = weld joint factor as defined in Table 403.2.1-1

t_a = available thickness for pressure design

= t_n ×(1 – mill tolerance/100) – sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.

D = outside diameter

Stress due to Sustained Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

$$S_L = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor = 1.0 for pipes

i_o = out-of-plane stress intensification factor = 1.0 for pipes

For Fittings & Components.(as per para. 402.6.2)

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

P = maximum operating pressure = max of CAEPIPE input pressures (P1 through P10). Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.

D = outside diameter

t_n = nominal thickness as per para. 402.1

i_i = in-plane stress intensification factor; the product 0.75i_i shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product 0.75i_o shall not be less than 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
F_a = axial force component for external loads
A = nominal cross-section area
S_y = specified minimum yield strength of pipe

Stress due to Sustained Loads + Occasional Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

$$S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

where
P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with 1.0 ≤ peak pressure factor ≥ 1.1 as per para. 403.3.4

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.402.5.2

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$ as per Table 403.3.1-1 and para. 403.3.2

where
S_b = resultant bending stress = $\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.4

S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor $= 6/N^{0.2}$, where N = number of equivalent full range cycles
where $f \leq 1.2$ (from para. 403.3.2).
S_c = $0.67S_y$ at the lower of the installed temperature or minimum operating temperature

S_h = $0.67S_y$ at the higher of the installed temperature or maximum operating temperature where

S_y = specified minimum yield strength of pipe

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_{Lp} = S_E + \upsilon S_H + \frac{F_a}{A} + \frac{M}{Z}$$

$$S_{Ln} = S_E + \upsilon S_H + \frac{F_a}{A} - \frac{M}{Z}$$

As per para. 402.6.1, both positive and negative values of M/Z shall be considered for analysis.

where

S_H = circumferential (hoop) stress = $\frac{PD}{2t_n}$

υ = Poission's ratio = 0.3 as per para. 402.2.3

As per para. 402.6.1, S_H can be either positive <u>or</u> negative.

F_a = axial force, such as weight on a riser. As per para. 402.6.1, F_a can be positive or negative.

M = bending moment from Weight and other External loads

<u>For Pipes</u>

M = $\sqrt{(i_i M_i)^2 + (i_o M_o)^2}$

<u>For Fittings & Components</u>

M = $\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2}$

S_E = Thermal expansion stress $= E\alpha(T_i - T_o)$, which can either be positive <u>or</u> negative

where

P = PFO x maximum pressure (P_1 through P_{10}) entered in CAEPIPE.
PFO = Peak Pressure Factor input. PFO = 1.0, if occasional loads are not present.
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment from Weight and other External loads
M_o = out-of-plane bending moment from Weight and other External loads

F_a = axial force component for Weight and other External loads
A = nominal cross-section area
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S_y = specified minimum yield strength of pipe
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_o defined above
E = young's modulus at ambient (reference) temperature

Combining of Stresses

In restrained pipe, the longitudinal and circumferential stresses are combined in accordance with the maximum shear stress theory as follows (by default in CAEPIPE).

$$S_{eq1} = 2\sqrt{\left[\left(S_{Lp} - S_H\right)/2\right]^2 + (S_t)^2} \qquad S_{eq2} = 2\sqrt{[(S_{Ln} - S_H)/2]^2 + (S_t)^2}$$

Where S_{Lp} and S_{Ln} are calculated as given above.

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 4 below):

$$S_{eq1} = \sqrt{(S_H)^2 - S_H S_{Lp} + \left(S_{Lp}\right)^2 + 3(S_t)^2} \qquad S_{eq2} = \sqrt{(S_H)^2 - S_H S_{Ln} + (S_{Ln})^2 + 3(S_t)^2}$$

$$S_{eq} = max\{S_{eq1}, S_{eq2}\} \leq 0.9S_y$$

where
S_{eq} = equivalent combined stress
S_t = torsional stress

Notes:

5. Para. 402.6.2 of B31.4 (2016) states that "Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports".
   The above statement seems to imply that "elongation due to Bourdon effect" is to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).
   On the other hand, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect as part of the results for Thermal Expansion (when "Solve Thermal Case" is opted) or as part of the Operating Case (when "Thermal = Operating – Sustained is opted).
6. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
7. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

8. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_314" with its value as "YES".

Notes on Material Library for B314-2016.mat supplied with CAEPIPE:

Material library for ASME B31.4 (2016) [B314-2016.mat] has been created and supplied with CAEPIPE as mentioned below.

9. **Coefficient of Thermal Expansion:** As stated in para. 402.2.1 of B31.4 (2016), Coefficient of Thermal Expansion for Carbon and low alloy high tensile steel are entered as 6.5E-6 in./in./^{0}F for temperatures up to 250 ^{0}F.
10. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy high tensile steel for temperatures up to 250 ^{0}F are entered by referring to the values provided in Table 832.5-1 of ASME B31.8 (2016).
11. **Yield Strength:** Yield Strength for Carbon and low alloy high tensile steel for temperatures up to 250 ^{0}F are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2016).
12. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.
13. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy high tensile steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2016).

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

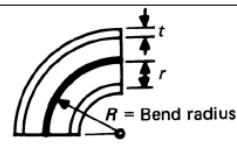
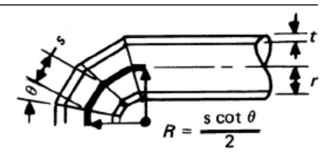
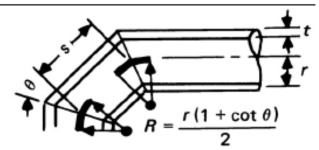
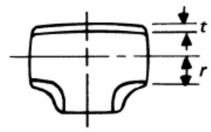
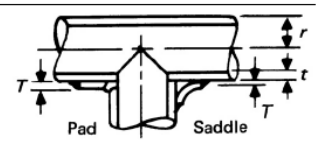
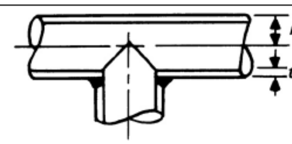
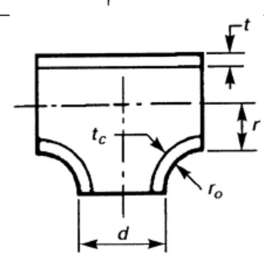
Description	Flexibility Factor, k	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Flexibility Characteristic, h	Sketch
Welding elbow, or pipe bend [Notes (3)–(7)]	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{tR}{r^2}$	
Closely spaced miter bend, [Notes (3)–(5), and (7)] $s < r(1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{\cot\theta}{2}\,\frac{ts}{r^2}$	
Widely spaced miter bend, [Notes (3),(4), (7), and (8)] $s \geq r(1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\,\frac{t}{r}$	
Welding tee [Notes (3) and (4)] per ASME B16.9	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$4.4\,\frac{t}{r}$	
Reinforced tee [Notes (3),(4), and (9)] with pad or saddle	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2\,T)^{5/2}}{t^{3/2}\,r}$	
Unreinforced fabricated tee [Notes (3) and (4)]	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	
Extruded welding tee [Notes (3),(4), and (10)] $r_o \geq 0.05d$ $t_c < 1.5t$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\left(1 + \frac{r_o}{r}\right)\frac{t}{r}$	
Butt welded joint, reducer, or welding neck flange	1	1.0		. . .	. . .
Double welded slip-on flange	1	1.2		. . .	. . .
Fillet welded joint (single welded), or single welded slip-on flange	1	1.3		. . .	. . .

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Flexibility Characteristic, h	Sketch
Lapped flange (with ANSI B16.9 lap-joint stub)	1	1.6		. . .	. . .
Threaded pipe joint, or threaded flange	1	2.3		. . .	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (11)]	5	2.5		. . .	. . .

NOTES:
(1) In-plane.
(2) Out-of-plane.
(3) For fittings and miter bends, the flexibility factors, k, and stress intensification factors, i, in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
(4) The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the equations given, where

d = outside diameter of branch
R = bend radius of welding elbow or pipe bend, in. (mm)
r = mean radius of matching pipe, in. (mm)
r_o = see Note (10)
s = miter spacing at center line
T = pad or saddle thickness, in. (mm)
t = nominal wall thickness of: part itself, for elbows and curved or mited bends; matching pipe, for welding tees; run or header, for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run O.D. to each side of the branch O.D.)
t_c = the crotch thickness of tees
θ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of k and i in this Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed h: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/3} \geq 1$.
(6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
(7) In large diameter thin wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from this Table for the pressure effect, divide

Flexibility factor, k, by $$1 + 6\frac{P}{E_c}\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

Stress intensification factor, i, by $$1 + 3.25\frac{P}{E_c}\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where
E_c = cold modulus of elasticity
P = gage pressure

(8) Also includes single miter joint.
(9) When $T > 1\frac{1}{2}t$, use $h = 4.05\ t/r$.
(10) Radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch. This is subject to the following limitations:
- (a) minimum radius, r_o: the lesser of 0.05d or 38 mm (1.5 in.)
- (b) maximum radius, r_o shall not exceed
  - (1) for branches DN 200 (NPS 8) and larger, 0.10d + 13 mm (0.50 in.)
  - (2) for branches less than DN 200 (NPS 8), 32 mm (1.25 in.)
- (c) when the external contour contains more than one radius, the radius on any arc sector of approximately 45 deg shall meet the requirements of (a) and (b) above
- (d) machining shall not be employed in order to meet the above requirements

(11) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

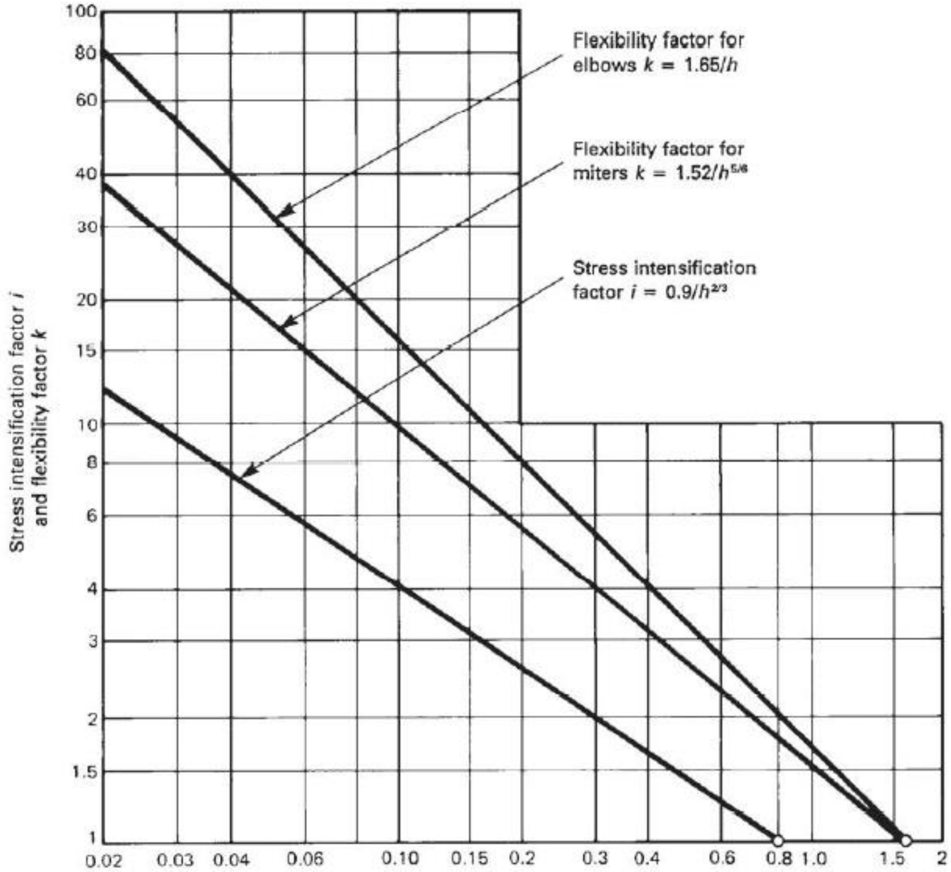


Chart A

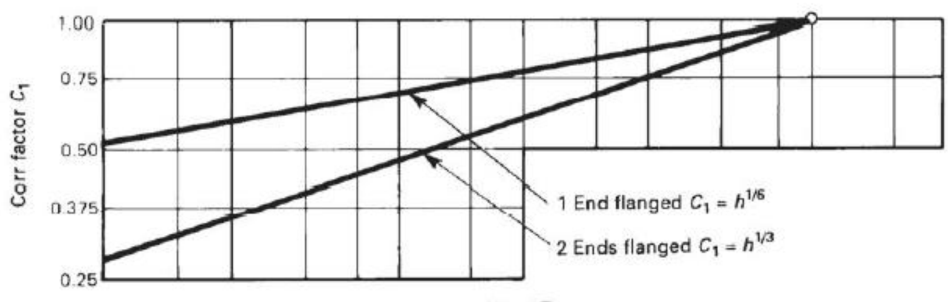


Chart B

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 403.2.1.

$$P_i = \frac{2SEt_a}{D}$$

where

P_i = allowable pressure
S = allowable stress = 0.72 S_y
S_y = specified minimum yield strength of pipe
E = weld joint factor as defined in Table 403.2.1-1
t_a = available thickness for pressure design
= t_n ×(1 – mill tolerance/100) – sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.
D = outside diameter

Stress due to Sustained Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

$$S_L = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor = 1.0 for pipes
i_o = out-of-plane stress intensification factor = 1.0 for pipes

For Fittings & Components.(as per para. 402.6.2)

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75S_y$$

as per Table 403.3.1-1

where

P = maximum operating pressure = max of CAEPIPE input pressures (P1 through P10). Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.
D = outside diameter
t_n = nominal thickness as per para. 402.1
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
F_a = axial force component for external loads
A = nominal cross-section area
S_y = specified minimum yield strength of pipe

Stress due to Sustained Loads + Occasional Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

$$S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.8S_y$$

as per Table 403.3.1-1

where
P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with 1.0 ≤ peak pressure factor ≥ 1.1 as per para. 403.3.4

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.402.5.2

$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$ as per Table 403.3.1-1 and para. 403.3.2

where
S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.4

S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor $= 6/N^{0.2}$, where $N =$ number of equivalent full range cycles

where $f \leq 1.2$ (from para. 403.3.2).

S_c = $0.67S_y$ at the lower of the installed temperature or minimum operating temperature
= $0.67S_y$ at the higher of the installed temperature or maximum operating temperature

where

S_c = specified minimum yield strength of pipe

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_L = \max\left(\left|S_p + S_x + S_B\right|, \left|S_p + S_x - S_B\right|\right)_{sustained} + \max\left(\left|S_p + S_x + S_B\right|, \left|S_p + S_x - S_B\right|\right)_{Occasional} + \max\left(|S_T|_{warmest}, |S_T|_{coldest}\right) \leq 0.9S_y$$

where

Pressure stress $= S_p = \upsilon \frac{PD}{2t_n} =$ where $\upsilon = 0.3$ as per para. 402.2.3 and can be either positive <u>or</u> negative

Stress due to axial loading (other than temperature and pressure)$= S_x = \frac{F_a}{A}$

and can be positive or negative.

Nominal bending stress S_B from Weight and / or other External loads for

<u>For Pipes</u>

$$S_B = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z}$$

<u>For Fittings & Components</u>

$$S_B = \frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}$$

Thermal expansionstress $S_T = E\alpha(T_i - T_o)$, which can either be positive <u>or</u> negative

where

P = maximum operating pressure = max (P_1 through P_{10})
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment

F_a = axial force component for external loads
A = nominal cross-section area
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S_y = specified minimum yield strength of pipe
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_o defined above
E = young's modulus at ambient (reference) temperature

Note:

1. Para. 402.6.2 of B31.4 (2012) states that "Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports".
   The above statement seems to imply that "elongation of pipe and opening of bends due to Bourdon effect" are to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).
   On the other hand, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect as part of the results for Thermal Expansion (when "Solve Thermal Case" is opted) or as part of the Operating Case (when "Thermal = Operating – Sustained is opted).
2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Table 402.1-1 Flexibility Factor, k, and Stress Intensification Factor, i

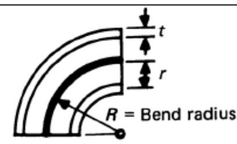
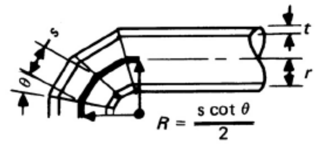
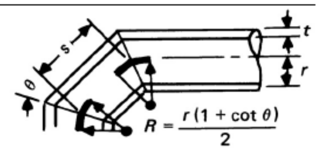
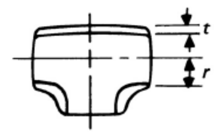
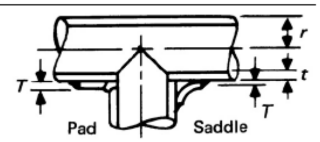
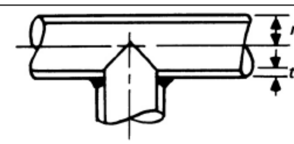
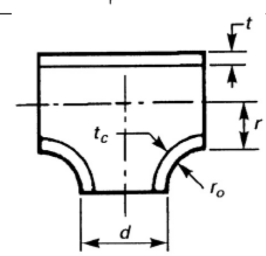
Description	Flexibility Factor, k	Stress Intensification Factor: i_i [Note (1)]	Stress Intensification Factor: i_o [Note (2)]	Flexibility Characteristic, h	Sketch
Welding elbow, or pipe bend [Notes (3)–(7)]	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{tR}{r^2}$	
Closely spaced miter bend, [Notes (3)–(5), and (7)] $s < r(1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{\cot\theta}{2}\ \frac{ts}{r^2}$	
Widely spaced miter bend, [Notes (3),(4), (7), and (8)] $s \geq r(1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\ \frac{t}{r}$	
Welding tee [Notes (3) and (4)] per ASME B16.9	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$4.4\,\frac{t}{r}$	
Reinforced tee [Notes (3),(4), and (9)] with pad or saddle	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2\,T)^{5/2}}{t^{3/2}\,r}$	
Unreinforced fabricated tee [Notes (3) and (4)]	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	
Extruded welding tee [Notes (3),(4), and (10)] $r_o \geq 0.05d$ $t_c < 1.5t$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	$\left(1 + \frac{r_o}{r}\right)\frac{t}{r}$	
Butt welded joint, reducer, or welding neck flange	1	1.0		...	...
Double welded slip-on flange	1	1.2		...	...
Fillet welded joint (single welded), or single welded slip-on flange	1	1.3		...	...

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, *k*	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Flexibility Characteristic, *h*	Sketch
Lapped flange (with ANSI B16.9 lap-joint stub)	1	1.6		...	...
Threaded pipe joint, or threaded flange	1	2.3		...	...
Corrugated straight pipe, or corrugated or creased bend [Note (11)]	5	2.5		...	...

NOTES:
(1) In-plane.
(2) Out-of-plane.
(3) For fittings and miter bends, the flexibility factors, *k*, and stress intensification factors, *i*, in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
(4) The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the equations given, where

d = outside diameter of branch
R = bend radius of welding elbow or pipe bend, in. (mm)
r = mean radius of matching pipe, in. (mm)
r_o = see Note (10)
s = miter spacing at center line
T = pad or saddle thickness, in. (mm)
t = nominal wall thickness of: part itself, for elbows and curved or mited bends; matching pipe, for welding tees; run or header, for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run O.D. to each side of the branch O.D.)
t_c = the crotch thickness of tees
θ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of *k* and *i* in this Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B, entering with the computed *h*: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/3} \geq 1$.
(6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
(7) In large diameter thin wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from this Table for the pressure effect, divide

Flexibility factor, *k*, by $$1 + 6\frac{P}{E_c}\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

Stress intensification factor, *i*, by $$1 + 3.25\frac{P}{E_c}\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where
E_c = cold modulus of elasticity
P = gage pressure

(8) Also includes single miter joint.
(9) When $T > 1\frac{1}{2}t$, use $h = 4.05\ t/r$.
(10) Radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch. This is subject to the following limitations:
  (a) minimum radius, r_o: the lesser of 0.05*d* or 38 mm (1.5 in.)
  (b) maximum radius, r_o shall not exceed
    (1) for branches DN 200 (NPS 8) and larger, 0.10*d* + 13 mm (0.50 in.)
    (2) for branches less than DN 200 (NPS 8), 32 mm (1.25 in.)
  (c) when the external contour contains more than one radius, the radius on any arc sector of approximately 45 deg shall meet the requirements of (a) and (b) above
  (d) machining shall not be employed in order to meet the above requirements
(11) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Table 402.1-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

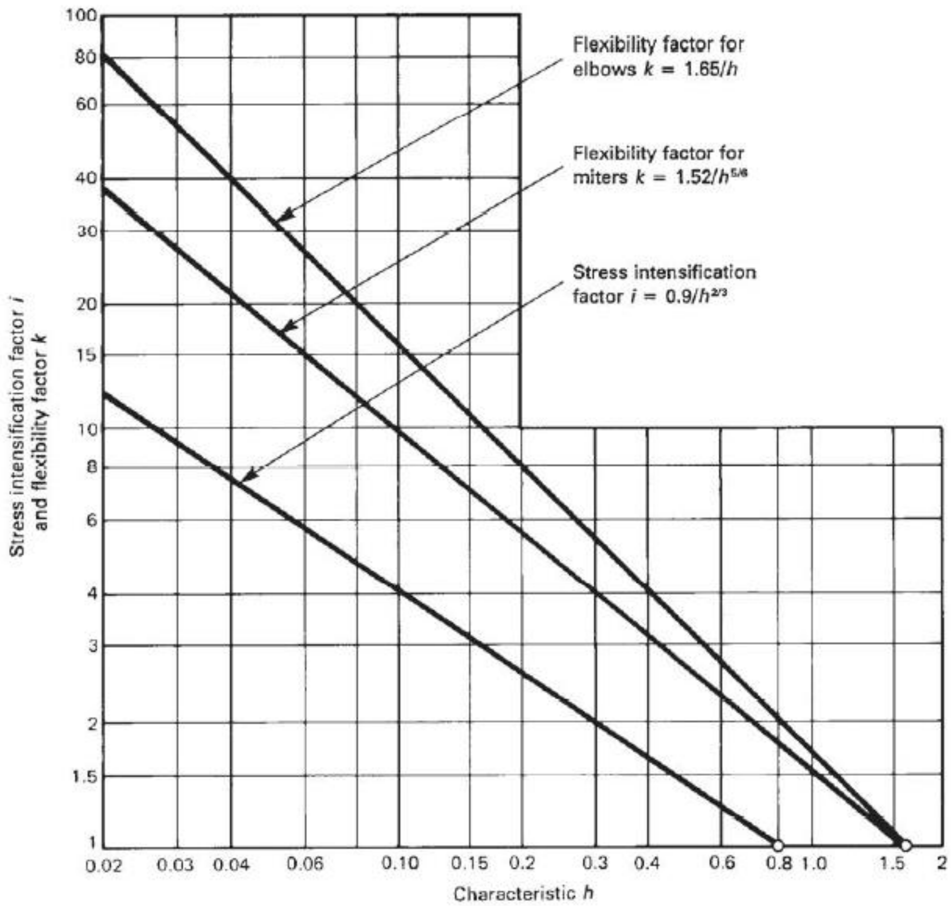


Chart A

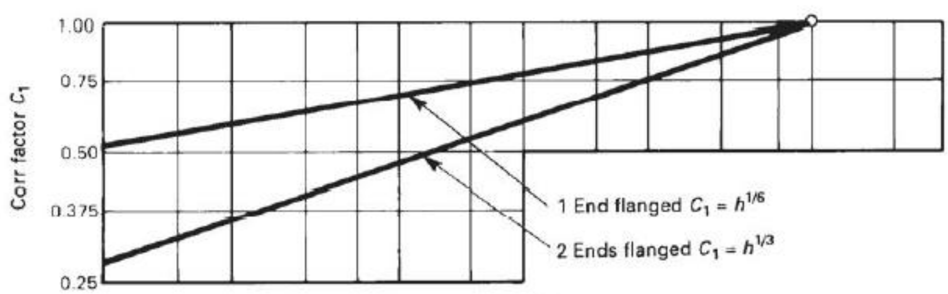


Chart B

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 504.1.2.

$$P = \frac{2SEt_a}{D - 2Yt_a}$$

where

P = allowable pressure

S = basic allowable stress at Design Temperature (i.e., at T_{design} input into CAEPIPE)

E = longitudinal or spiral joint factor (input as material property) from para. 502.3.1 and Table 502.3.1-1

Table 502.3.1-1 provides maximum allowable hoop stress values (SE) as a function of metal temperature and includes Longitudinal or Spiral Joint Factor (E) for various materials. Divide SE value by E value provided in Table 502.3.1-1 to obtain basic allowable stress S. For materials where E is not given explicitly in Table 502.3.1-1, use $E = 1.0$.

SE in the above formula for allowable pressure P is the allowable hoop stress per para. 502.3.1 and Table 502.3.1-1.

t_a = available thickness for pressure design (as per para. 504.1.1)

= $t_n \times$ (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance)

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

For ductile non-ferrous materials and ferritic and austenitic steels from para. 504.1.1,

$Y = 0.4$ and $Y = \frac{d}{d+D}$, for $4 \leq D/t_a < 6$

Y = 0.0 for Cast Iron

Sustained Stress (in corroded condition)

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 502.3.2(d). Also, refer to Note 1 below.

$$S_L = \left|\frac{Pd^2}{(D^2 - d^2)}\right| + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \leq S_h$$

where

P = maximum of CAEPIPE input pressures P_1 through P_{10}

D = outside diameter

t_c = nominal thickness – corrosion allowance, as per para. 502.3.2 (d)

d = inside diameter = $D - 2.t_c$

i_i = in-plane stress intensification factor from Table 519.3.6-1

i_o = out-of-plane stress intensification factor from Table 519.3.6-1
M_i = in-plane bending moment due to sustained loads, e.g., pressure and weight
M_o = out-of-plane bending moment due to sustained loads, e.g., pressure and weight
Z_c = corroded section modulus as per para. 502.3.2 (d)
S_h = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in corroded condition)

The stress (S_{Lo}) due to occasional loads is calculated as the sum of stress due to sustained loads such as pressure, weight and other sustained mechanical loads (S_L) and stress due to occasional loads (S_o) such as earthquake or wind. Wind and earthquake are not considered concurrently (see para. 502.3.3 (a)). Also, refer to Note 1 and Note 3 below.

$$S_{LO} = S_{LO} + \left[\left| \frac{(P_{peak} - P)d^2}{\left(D^2 - d^2\right)} \right| + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \right] \leq 1.33.(S_h E)$$

where
P_{peak} = peak pressure = (peak pressure factor) x P, where P is defined above
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
Z_c = corroded section modulus as per para. 502.3.2 (d)
D = outside diameter
t_c = nominal thickness – corrosion allowance, as per para. 502.3.2 (d)
d = inside diameter = $D - 2.t_c$
i_i = in-plane stress intensification factor from Table 519.3.6-1
i_o = out-of-plane stress intensification factor from Table 519.3.6-1
S_h = basic allowable stress (input as material property) at maximum of CAEPIPE input temperatures T_1 through T_{10}
E = longitudinal or spiral joint factor (input as material property) from para. 502.3.1 and Table 502.3.1-1

Expansion Stress (in un-corroded condition)

The stress range (S_E) due to thermal expansion is calculated from para. 519.4.5 and para. 519.3. See Note 3 below.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress = $\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_i = in-plane bending moment range between any two conditions being evaluated
M_o = out-of-plane bending moment range between any two conditions being evaluated
M_t = torsional moment range between any two conditions being evaluated
Z = un-corroded section modulus; for reduced outlets, effective section modulus

i_i = in-plane stress intensification factor from Table 519.3.6-1
i_o = out-of-plane stress intensification factor from Table 519.3.6-1
S_A = $f(1.25S_{cold} + 0.25S_{hot})$ (see para. 502.3.2 (c))
f = stress range reduction factor from Figure 502.3.2-1. f >= 0.5 and f <= 1.0
S_{cold} = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_{hot} = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$$S_A = S_A + f(S_h - S_L)$$

where, S_h= basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options->Analysis on the Code tab.

Notes:

1. As per para. 502.3.2 (d), the pressure stress should be calculated using the formula $Pd^2/(D^2 - d^2)$, where d is the internal diameter = $D - 2t_c$. Hence, "$Pd^2/(D^2 - d^2)$" (available through CAEPIPE Layout > Options > Analysis > Pressure) is set as "default" and is disabled for user to modify.

2. As per para. 519.4.5(a), Bending and torsional stress shall be computed using the as-installed modulus of elasticity, i.e., Ec at installation temperature. Hence, "Use modulus at reference temperature" (available through CAEPIPE Layout > Options > Analysis > Temperature) is set as "default" and is disabled for user to modify.

3. Para. 519.2.2 requires wind sway (displacement at support due to wind) to be included as a part of Thermal Load Displacement. Since CAEPIPE allows up to 10 thermal loads, the question arises "under which thermal load should this wind sway to be included". Hence, we recommend that wind sway is to be input as a part of "wind displacement under occasional stress condition".

4. Table 502.3.1-1 provides maximum allowable hoop stress values (SE) as a function of metal temperature and includes Longitudinal or Spiral Joint Factor (E) for various materials. Hence, while entering Allowable Stress (S) into CAEPIPE Material Properties or in Material Library, divide SE value by E value provided in Table 502.3.1-1 to obtain basic allowable stress S. For materials where E is not given explicitly in Table 502.3.1-1, use $E = 1.0$.

Operating Stress for Impact Test

Allowable stress for Impact Test is specified for the materials given in Table 502.3.1 of ASME B31.5 (2022) Code. Accordingly, "Sall" is computed and shown above.

The equation used to calculate the operating stresses is modeled along the lines of a piping code specified stress equation. The three components of the equation are:

1. Axial stress combined with the longitudinal pressure stress,
2. Bending stress from in-plane and out-of-plane bending moments, and
3. A torsional stress from the torsion term.

The allowable stress for this case is simply a combination of the sustained and the thermal allowable stresses.

Note that the Operating Stress is calculated and shown only for the first Operating case (W+P1+T1). Details follow.

The stress (S_{opr}) due to operating loads (pressure, weight and thermal load T_1) is calculated as

$$S_{opr} = S_a + \sqrt{(S_a)^2 + (2S_t)^2} \leq S_{all}$$

where

$S_a = \left[\frac{PD}{4_t} + \frac{F}{A}\right]_{Operating1}$

$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Operating1}$

$S_t = \left[\frac{M_t}{2Z}\right]_{Operating1}$

P = maximum of CAEPIPE input pressures P1 through P10
D = outside diameter
t = nominal wall thickness
A = un-corroded cross-sectional area of the pipe
F = longitudinal force
i_i = in-plane stress intensification factor according to analysis code selected in CAEPIPE
i_o = out-of-plane stress intensification factor according to analysis code selected in CAEPIPE

Note: If the analysis code selected provides only the stress intensification i, then $i_i = i_o = i$.

M_i = in-plane bending moment
M_o = factor for loose type flanges (from Fig. 2-7.5)
M_t = factor for loose type flanges (from Fig. 2-7.4)
Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
S_{all} = $f(1.25S_{cold} + 0.25S_{hot}) + S_{hot}$ for all codes excepting ASME B31.5. For ASME B31.5, it is calculated as 0.35 S_{hot}.

f = stress range reduction factor = $6/N^{0.2}$
N = Number of equivalent full-range thermal cycles
S_{cold} = basic allowable stress at T_{ref}
S_{hot} = basic allowable stress at CAEPIPE input temperature T_1

Refer to Section titled "Operating Stress for NDE/Impact Test/Impact Test Exemption" in this manual for details regarding the requirements and implementation of Impact Test in CAEPIPE for this code.

Table 519.3.6-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i*

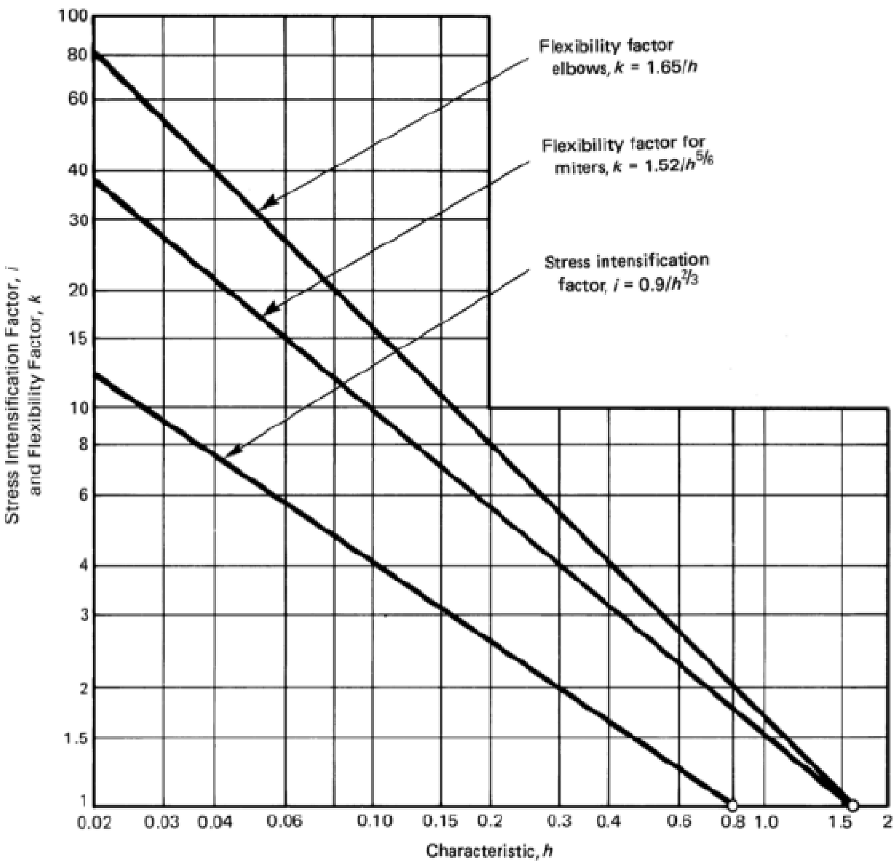


Chart A

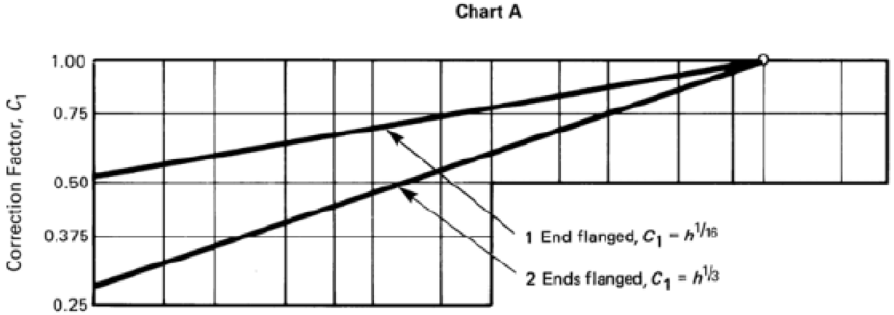


Chart B

Table 519.3.6-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

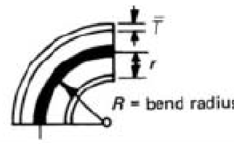
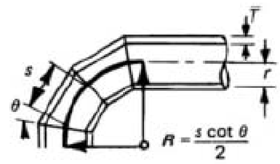
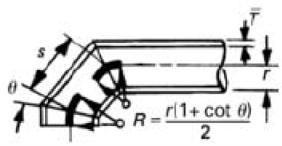
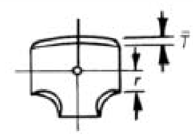
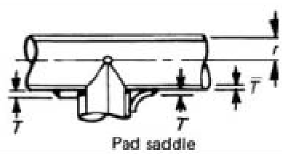
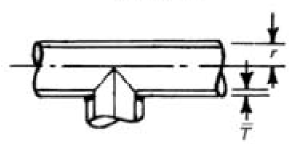
Description	Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Illustration
Welding elbow or pipe bend [Notes (3) through (7)]	$\frac{\bar{T}R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Closely spaced miter bend [Notes (3), (4), (5), and (7)], $s < r(1 + \tan\theta)$	$\frac{\bar{T}s}{r^2}\left(\frac{\cot\theta}{2}\right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan\theta)$	$\frac{\bar{T}}{r}\left(\frac{1+\cot\theta}{2}\right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Welding tee ASME B16.9 [Notes (3) and (4)]	$4.4\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)]	$\frac{(\bar{T}+1/2T)^{5/2}}{t^{3/2}r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (3) and (4)]	$\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Butt welded joint, reducer, or welding neck flange	...	1	1.0	1.0	...
Double-welded slip-on flange	...	1	1.2	1.2	...
Fillet welded joint (single-welded), socket welded flange, or single-welded slip-on flange	...	1	1.3	1.3	...
Lap flange (with ASME B16.9 lap-joint stub)	...	1	1.6	1.6	...
Threaded pipe joint or threaded flange	...	1	2.3	2.3	...

Table 519.3.6-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Illustration
Corrugated straight pipe, or corrugated or creased bend [Note (10)]	...	5	2.5	2.5	...

GENERAL NOTE: For reference, see Chart A and Chart B on first page of this table.

NOTES:

(1) In-plane.

(2) Out-plane.

(3) For fittings and miter bends the flexibility factors, *k*, and stress intensification factors, *i*, in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity.

(4) Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows and to the intersection point for tees. The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the equations given where

R = bend radius of welding elbow or pipe bend, in. (mm)
r = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
T = pad or saddle thickness, in. (mm)
$\bar{T}$ = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; matching pipe for welding tees; run or header for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter)
θ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of *k* and *T* in the Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B; entering with the computed *h*: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/3} \geq 1$.

(6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(7) In large-diameter thin-wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from the Table for the pressure effect, divide

(a) flexibility factor, *k*, by

$$1 + 6\frac{P}{E_c}\left(\frac{r}{\bar{T}}\right)^{1/3}\left(\frac{R}{r}\right)^{1/3}$$

(b) stress intensification factor, *i*, by

$$1 + 3.25\frac{P}{E_c}\left(\frac{r}{\bar{T}}\right)^{5/2}\left(\frac{R}{r}\right)^{1/3}$$

where
E_c = cold modulus of elasticity, ksi (MPa)
P = internal design pressure, psi (kPa)

(8) Also includes single-miter joint.

(9) When $T > 1.5\bar{T}$, use $h = 4.05\bar{T}/r$.

(10) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 504.1.2.

$$P = \frac{2SEt_a}{D - 2Yt_a}$$

where

P = allowable pressure

S = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

E = longitudinal or spiral joint factor (input as material property) from para. 502.3.1 and Table 502.3.1-1

Table 502.3.1-1 provides maximum allowable hoop stress values (SE) as a function of metal temperature and includes Longitudinal or Spiral Joint Factor (E) for various materials. Divide SE value by E value provided in Table 502.3.1-1 to obtain basic allowable stress S. For materials where E is not given explicitly in Table 502.3.1-1, use $E = 1.0$.

SE in the above formula for allowable pressure P is the allowable hoop stress per para. 502.3.1 and Table 502.3.1-1.

t_a = available thickness for pressure design (as per para. 504.1.1)
= $t_n \times$ (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance)

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

For ductile non-ferrous materials and ferritic and austenitic steels from para. 504.1.1,

$Y = 0.4$ and $Y = \frac{d}{d+D}$, for $4 \leq D/t_a < 6$

Y = 0.0 for Cast Iron

Sustained Stress (in corroded condition)

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 502.3.2(d). Also, refer to Note 1 below.

$$S_L = \frac{PD}{4t_c} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \leq S_h$$

where

P = maximum of CAEPIPE input pressures P_1 through P_{10}

D = outside diameter

t_c = nominal thickness – corrosion allowance, as per para. 502.3.2 (d)

i_i = in-plane stress intensification factor from Table 519.3.6-1

i_o = out-of-plane stress intensification factor from Table 519.3.6-1
M_i = in-plane bending moment
M_o = out-of-plane bending moment
Z_c = corroded section modulus as per para. 502.3.2 (d)
S_h = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in corroded condition)

The stress (S_{Lo}) due to occasional loads is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_o) such as earthquake or wind. Wind and earthquake are not considered concurrently (see para. 502.3.3 (a)). Also, refer to Note 1 below.

$$S_{LO} = \frac{P_{peak}D}{4t_c} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z_c}\right]_{sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z_c}\right]_{occasional} \leq 1.33S_h$$

where
P_{peak}= peak pressure = (peak pressure factor) x P, where P is defined above

Expansion Stress (in un-corroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 519.4.5 and para. 519.3.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress =$\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
i_i = in-plane stress intensification factor from Table 519.3.6-1
i_o = out-of-plane stress intensification factor from Table 519.3.6-1
S_A = $f(1.25S_{cold} + 0.25S_{hot})$(see para. 502.3.2 (c))
f = stress range reduction factor from Figure 502.3.2-1. f >= 0.5 and f <= 1.0
S_{cold} = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_{hot} = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$$S_A = S_A + f(S_h - S_L)$$

where, S_h= basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options->Analysis on the Code tab.

Notes:

1. As per para. 502.3.2 (d), the pressure stress should be calculated using the formula $Pd^2/(D^2-d^2)$, where d is the internal diameter = $D-2t_c$. Hence, "$Pd^2/(D^2-d^2)$" (available through CAEPIPE Layout > Options > Analysis > Pressure) is set as "default" and is disabled for user to modify.
2. As per para. 519.4.5(a), Bending and torsional stress shall be computed using the as-installed modulus of elasticity, i.e., E_c at installation temperature. Hence, "Use modulus at reference temperature" (available through CAEPIPE Layout > Options > Analysis > Temperature) is set as "default" and is disabled for user to modify.
3. As per para. 519.2.2, wind sway should be input into the appropriate Thermal Load Displacement.
4. Refer to Section titled "Operating Stress for NDE/Impact Test" in this manual for details regarding the requirements and implementation of Impact Test in CAEPIPE for this code.

Table 519.3.6 Illustration

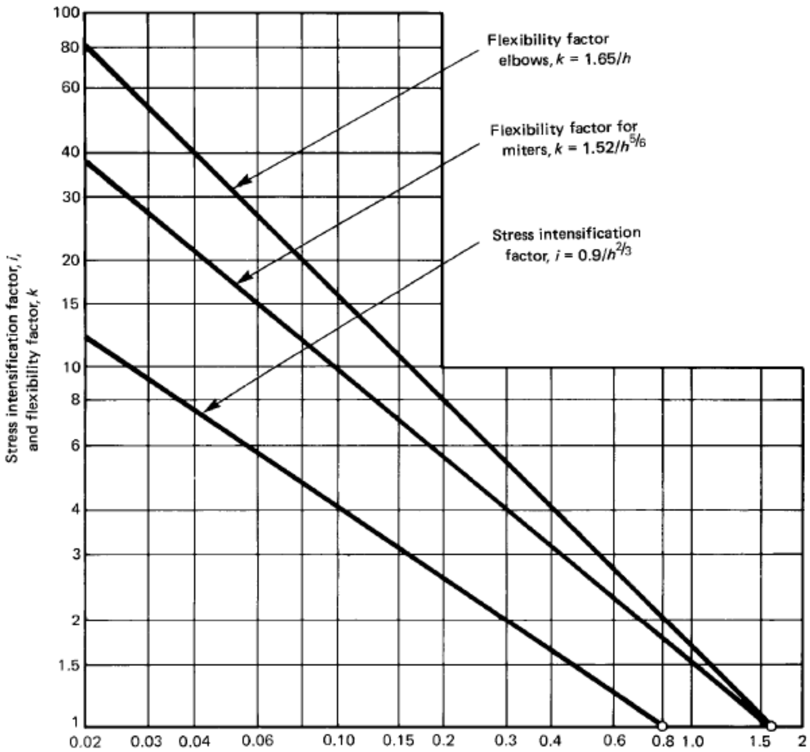


Chart A

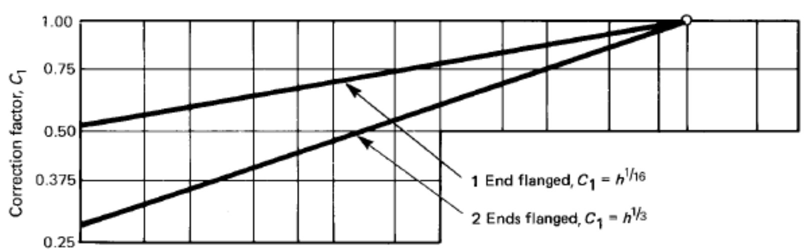


Chart B

Table 519.3.6 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

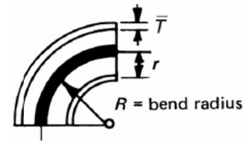
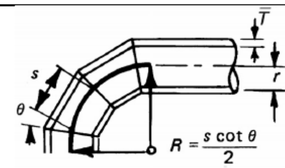
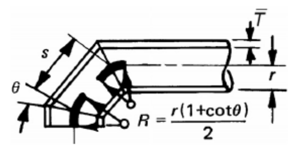
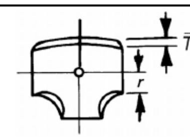
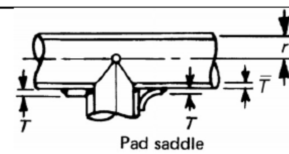
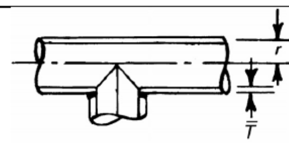
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Illustration
Welding elbow or pipe bend [Notes (3)–(7)]	$\frac{\bar{T}R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Closely spaced miter bend [Notes (3), (4), (5), and (7)], $s < r(1 + \tan\theta)$	$\frac{\bar{T}s}{r^2}\left(\frac{\cot\theta}{2}\right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan\theta)$	$\frac{\bar{T}}{r}\left(\frac{1+\cot\theta}{2}\right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Welding tee ASME B16.9 [Notes (3) and (4)]	$4.4\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)]	$\frac{(\bar{T} + {}^1/_2\, T)^{5/2}}{t^{3/2} r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (3) and (4)]	$\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Butt welded joint, reducer, or welding neck flange	. . .	1	1.0	1.0	. . .
Double-welded slip-on flange	. . .	1	1.2	1.2	. . .

Table 519.3.6 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Illustration
Fillet welded joint (single-welded), socket welded flange, or single-welded slip-on flange	. . .	1	1.3	1.3	. . .
Lap flange (with ASME B16.9 lap-joint stub)	. . .	1	1.6	1.6	. . .
Threaded pipe joint or threaded flange	. . .	1	2.3	2.3	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (10)]	. . .	5	2.5	2.5	. . .

GENERAL NOTE: For reference, see Table 519.3.6 Illustration on page 41.

NOTES:

(1) In-plane.

(2) Out-plane.

(3) For fittings and miter bends the flexibility factors, *k*, and stress intensification factors, *i*, in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity.

(4) Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows and to the intersection point for tees. The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the equations given where

R = bend radius of welding elbow or pipe bend, in. (mm)
r = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\underline{T}$ = pad or saddle thickness, in. (mm)
$\overline{T}$ = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; matching pipe for welding tees; run or header for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter).
θ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of *k* and *T* in the Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B; entering with the computed *h*: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/2} \geq 1$.

(6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(7) In large-diameter thin-wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from the Table for the pressure effect, divide

(a) flexibility factor, *k*, by

$$1 + 6\frac{P}{E_c}\left(\frac{r}{\overline{T}}\right)^{1/3}\left(\frac{R}{r}\right)^{1/3}$$

(b) stress intensification factor, *i*, by

$$1 + 3.25\frac{P}{E_c}\left(\frac{r}{\overline{T}}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where

E_c = cold modulus of elasticity, ksi (MPa)
P = internal design pressure, psi (kPa)

(8) Also includes single-miter joint.

(9) When $T > 1.5\overline{T}$, use $h = 4.05\,\overline{T}/r$.

(10) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 504.1.2.

$$P = \frac{2SEt_a}{D - 2Yt_a}$$

where

P = allowable pressure

S = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

E = longitudinal or spiral joint factor (input as material property) from para. 502.3.1 and Table 502.3.1

Table 502.3.1 provides maximum allowable hoop stress values (SE) as a function of metal temperature and includes Longitudinal or Spiral Joint Factor (E) for various materials. Divide SE value by E value provided in Table 502.3.1 to obtain basic allowable stress S. For materials where E is not given explicitly in Table 502.3.1, use $E = 1.0$.

Hence, SE in the above formula for allowable pressure P is the allowable hoop stress per para. 502.3.1 and Table 502.3.1.

t_a = available thickness for pressure design (as per para. 504.1.1)

= $t_n \times$ (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance)

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

For ductile non-ferrous materials and ferritic and austenitic steels,

$Y = 0.4$ for $D/t_a \geq 6$ and $Y = \frac{d}{d+D}$, for $4 \leq D/t_a < 6$

Y = 0.0 for Cast Iron

Sustained Stress (in corroded condition)

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 502.3.2(d). Also, refer to Note 1 below.

$$S_L = \frac{PD}{4t_c} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \leq S_h$$

where

P = maximum of CAEPIPE input pressures P_1 through P_{10}

D = outside diameter

t_c = nominal thickness – corrosion allowance, as per para. 502.3.2 (d)

i_i = in-plane stress intensification factor

i_o = out-of-plane stress intensification factor

M_i = in-plane bending moment

M_o = out-of-plane bending moment
Z_c = corroded section modulus as per para. 502.3.2 (d)
S_h = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in corroded condition)

The stress (S_{Lo}) due to occasional loads is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_o) such as earthquake or wind. Wind and earthquake are not considered concurrently (see para. 502.3.3 (a)). Also, refer to Note 1 below.

$$S_{LO} = \frac{P_{peak}D}{4t_c} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z_c}\right]_{sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z_c}\right]_{occasional} \leq 1.33S_h$$

where
P_{peak}= peak pressure = (peak pressure factor) x P, where P is defined above

Expansion Stress (in un-corroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 519.4.5 and para. 519.3.5.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress =$\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S_A = $f(1.25S_{cold} + 0.25S_{hot})$(see para. 502.3.2 (c))
f = stress range reduction factor from Figure 502.3.2
S_{cold} = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis
S_{hot} = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as

$$S_A = S_A + f(S_h - S_L)$$

where, S_h= basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options->Analysis on the Code tab.

Notes:

1. As per para. 502.3.2 (d), the pressure stress should be calculated using the formula $Pd^2/(D^2 - d^2)$, where d is the internal diameter = $D - 2t_c$. This can be selected through Options > Analysis > Pressure.
2. As per para. 519.4.5(a), Bending and torsional stress shall be computed using the as-installed modulus of elasticity, i.e., E_c at installation temperature. Hence, "Use modulus at reference temperature" (available through CAEPIPE Layout > Options > Analysis > Temperature) is set as "default" and is disabled for user to modify.
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Table 519.3.6 Illustration

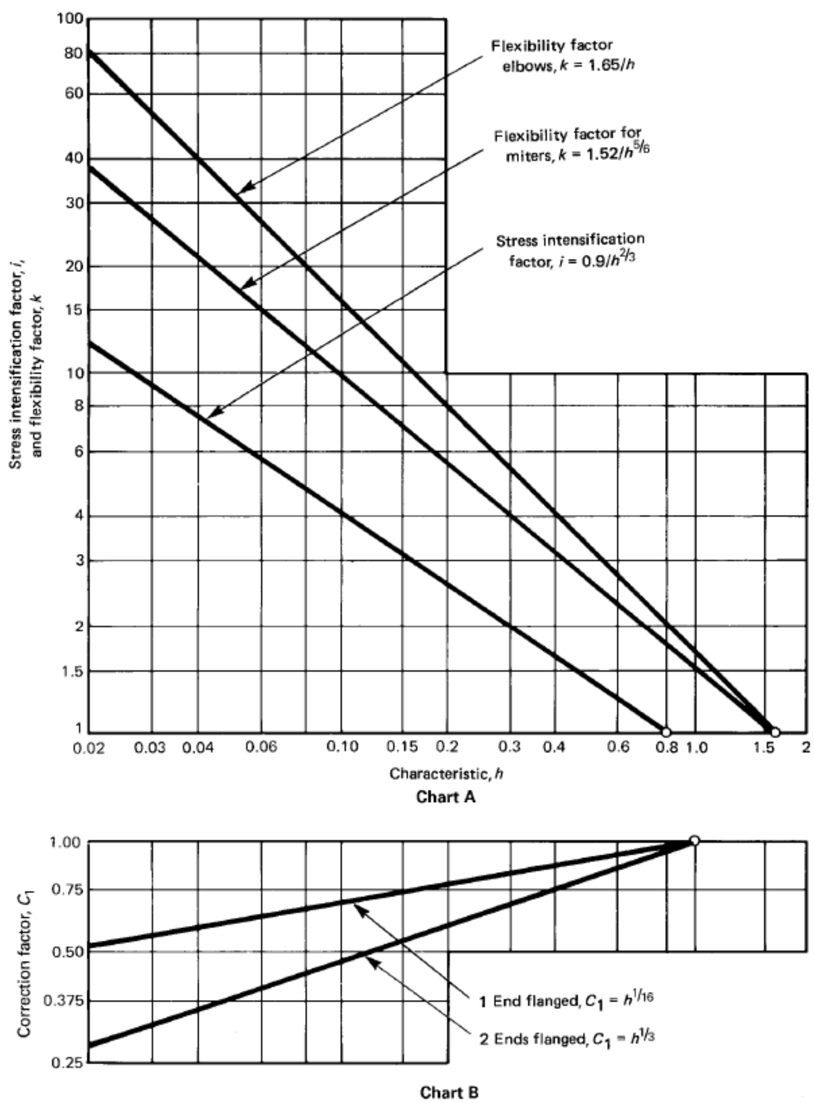


Table 519.3.6 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

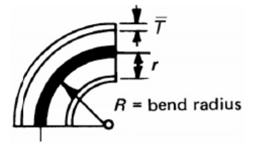
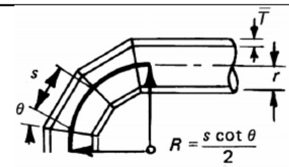
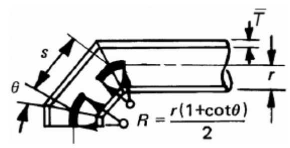
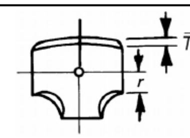
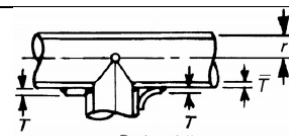
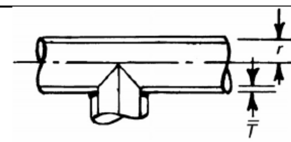
Description	Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Illustration
Welding elbow or pipe bend [Notes (3)–(7)]	$\frac{\bar{T}R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Closely spaced miter bend [Notes (3), (4), (5), and (7)], $s < r(1 + \tan\theta)$	$\frac{\bar{T}s}{r^2}\left(\frac{\cot\theta}{2}\right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan\theta)$	$\frac{\bar{T}}{r}\left(\frac{1+\cot\theta}{2}\right)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Welding tee ASME B16.9 [Notes (3) and (4)]	$4.4\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)]	$\frac{(\bar{T} + \frac{1}{2}T)^{5/2}}{t^{3/2}r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	 Pad saddle
Unreinforced fabricated tee [Notes (3) and (4)]	$\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Butt welded joint, reducer, or welding neck flange	. . .	1	1.0	1.0	. . .
Double-welded slip-on flange	. . .	1	1.2	1.2	. . .

Table 519.3.6 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Characteristic, *h*	Flexibility Factor, *k*	Stress Intensification Factor		Illustration
			i_i [Note (1)]	i_o [Note (2)]	
Fillet welded joint (single-welded), socket welded flange, or single-welded slip-on flange	. . .	1	1.3	1.3	. . .
Lap flange (with ASME B16.9 lap-joint stub)	. . .	1	1.6	1.6	. . .
Threaded pipe joint or threaded flange	. . .	1	2.3	2.3	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (10)]	. . .	5	2.5	2.5	. . .

GENERAL NOTE: For reference, see Table 519.3.6 Illustration on page 41.

NOTES:

(1) In-plane.

(2) Out-plane.

(3) For fittings and miter bends the flexibility factors, *k*, and stress intensification factors, *i*, in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity.

(4) Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows and to the intersection point for tees. The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the equations given where

R = bend radius of welding elbow or pipe bend, in. (mm)
r = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
T = pad or saddle thickness, in. (mm)
$\overline{T}$ = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; matching pipe for welding tees; run or header for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter).
θ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of *k* and T in the Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B; entering with the computed h: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/3} \geq 1$.

(6) The engineer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(7) In large-diameter thin-wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from the Table for the pressure effect, divide

(a) flexibility factor, *k*, by

$$1 + 6\frac{P}{E_c}\left(\frac{r}{\overline{T}}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

(b) stress intensification factor, *i*, by

$$1 + 3.25\frac{P}{E_c}\left(\frac{r}{\overline{T}}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

where

E_c = cold modulus of elasticity, ksi (MPa)
P = internal design pressure, psi (kPa)

(8) Also includes single-miter joint.

(9) When $T > 1.5\overline{T}$, use $h = 4.05\,\overline{T}/r$.

(10) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends) of Steel gas piping systems, the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

When $D/t_n < 30$, then

$$P = \frac{2SEt_nFT}{D - t_n}$$

where

P = allowable pressure
S = specified minimum yield strength from para. 841.1.1 (a), as input in CAEPIPE material properties
E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)
t_n = nominal pipe thickness
D = nominal outside diameter
F = construction location design factor, obtained from Table 841.1.6-1
T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Note:

Allowable pressure calculation for Ductile Iron and Plastic piping systems as per this code are not included in CAEPIPE.

Stress due to Sustained & Occasional Loads [Unrestrained (above ground) Piping]

The sum of longitudinal stress due to internal pressure and due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, occasional loads such as seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f). Wind and seismic are not considered to act concurrently.

Please note, the "include axial force in stress calculations" option is turned ON by default for ASME B31.8 in CAEPIPE.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

For other Fittings and Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST}$$

For other Fittings and Components

$$S_{LO(fc)} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where

P = maximum operating pressure = max (P_1 through P_{10})

P_{peak} = Peak pressure factor x P

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o= out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0

M_i = in-plane bending moment due to weight and other external loads

M_o= out-of-plane bending moment due to weight and other external loads

M_t= torsional moment due to weight and other external loads

Z = un-corroded section modulus; for reduced outlets, effective section modulus

R = axial force due to external loads (other than due to thermal expansion and pressure)

A = un-corroded pipe metal cross-section area

S = specified minimum yield strength from para. 841.1.1(a)

T= temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with para. 832.3(g).

Expansion Stress [Unrestrained (above ground) Piping]

The stress (S_E) due to thermal expansion is calculated from para.833.8.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$

S_t = torsional stress = $\frac{M_t}{2Z}$

M_i = in-plane bending moment due to thermal expansion

M_o= out-of-plane bending moment to thermal expansion

M_t= torsional moment due to thermal expansion

Z = un-corroded section modulus; for reduced outlets, effective section modulus
S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles
where $f \leq 1.0$ (from para. 833.8 (b)).
S_L = sustained stress computed as per equation given above
S_C = 0.33SuT at the minimum installed or operating temperature
S_h = 0.33SuT at the maximum installed or operating temperature

where
S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and
S_y = specified minimum yield strength as per para. 841.1.1(a)
T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [= min(T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with para. 832.3 (g).

Sustained, Thermal & Occasional Stress [Restrained (buried) Piping]

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per 833.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.
where

$S_p = 0.3S_H = 0.3\frac{PD}{2t_n}$ = longitudinal stress due to internal pressure in restrained pipeline

S_H = hoop stress = $\frac{PD}{2t_n}$ as per para. 805.2.3

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha_m(T_i - T_m)$ (see Note 1 below)

S_X = stress due to axial loading (other than thermal expansion and pressure) $= \frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads (other than thermal expansion)

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}$$

For other Fittings and Components.

$$S_B = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}$$

As per para 833.3(a), note that S_B,S_L, S_T or S_X can be positive or negative
where

P = maximum operating pressure = max(P1 through P10)
D = outside diameter
t_n=nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment due to weight and other external loads (other than thermal expansion)
M_o = out-of-plane bending moment due to weight and other external loads (other than thermal expansion)
M_t = torsional moment due to weight and other external loads (other than thermal expansion)
R = axial force due to weight and other external loads (other than thermal expansion and pressure)
A = un-corroded pipe metal cross-sectional area (i.e., before deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
E = Young's modulus at ambient temperature from para. 833.2 (c), i.e., at T_{ref} in CAEPIPE
T_i =installation temperature = T_{ref} in CAEPIPE (see Note 1 below)
T_m = warmest or coldest operating temperature (see Note 1 below)
α_m = coefficient of thermal expansion at T_m in CAEPIPE (see Note 1 below)

Note 1:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress S_T due to thermal expansion as follows.

For a change in temperature from T_{ref} to T_1, $S_{T1} = -E\alpha_1(T_1 - T_{ref})$

For a change in temperature from T_{ref} to T_2, $S_{T2} = -E\alpha_2(T_2 - T_{ref})$

For a change in temperature from T_1 to T_2, $S_{T1-.>T2} = S_{T2} - S_{T1}$

Please note, that negative (-) sign is added in the above equations as the soil is restraining the thermal expansion / contraction of the buried pipe due to friction at the soil-to-pipe interface.

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using maximum shear stress theory as per the calculation given below by default in CAEPIPE as per para. 833.4.

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where

S_{eq} = equivalent combined stress

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{\left(S_{Lp}\right)^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

Notes:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix in accordance with para. 832.3 (g).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
3. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, turn ON the analysis option "Combine stresses as per Max. Distortion Energy Theory" through Layout Window > Options > Analysis > Code.

Notes on Material Library for B318-2022.mat supplied with CAEPIPE:

Material library for ASME B31.8 (2022) [B318-2022.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 832.2 of B31.8 (2022), Coefficient of Thermal Expansion for Carbon and low alloy steel are entered by referring to the values given in Table 832.2-1 of ASME B31.8 (2022).
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy steel are entered by referring to the values given in Table 832.5-1 of ASME B31.8 (2022).
3. **Yield Strength:** Yield Strength for Carbon and low alloy steel are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2022).
4. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.
5. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2022).

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i*

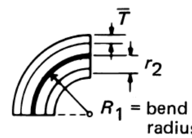
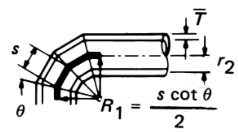
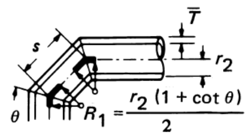
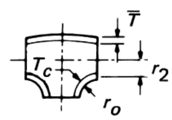
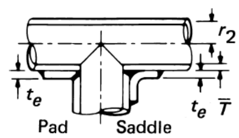
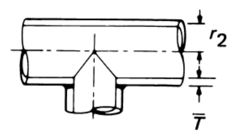
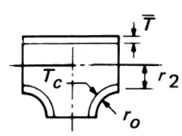
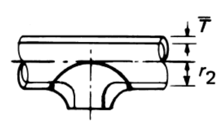
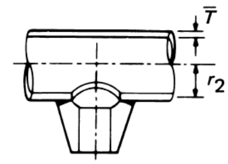
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1), (2)] Out-Plane, i_o	Stress Intensification Factor, i [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Illustration
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^{\,2}}$	
Closely spaced miter bend $s < r_2\,(1 + \tan\theta)$ [Notes (1), (2), (3), (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\,\frac{\bar{T}s}{r_2^{\,2}}$	
Single miter bend or widely spaced miter bend $s \geq r_2\,(1 + \tan\theta)$ [Notes (1), (2), (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\,\frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq d/8$, $T_c \geq 1.5\bar{T}$ [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$\frac{\left(\bar{T} + \frac{1}{2}t_e\right)^{5/2}}{\bar{T}^{3/2}r_2}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$, $T_c < 1.5\,\bar{T}$ [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_0}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq d/8$, $T_c \geq 1.5\bar{T}$ [Notes (1), (2), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, *k*	Stress Intensification Factor, *i* [Notes (1), (2)] Out-Plane, i_o	Stress Intensification Factor, *i* [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, *h*	Illustration
Branch welded-on fitting (integrally reinforced) in accordance with MSS SP-97 [Notes (1), (2), (9), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\overline{T}}{r_2}$	

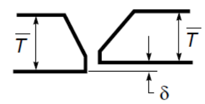
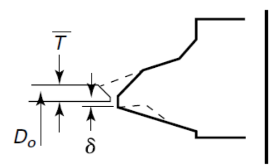
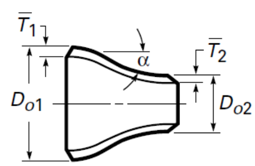
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Illustration
Butt weld [Notes (1), (12)]			
$\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.13$	1	1.0	
$\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq 1/8$ in. (3.18 mm), and $\delta_{avg}/\overline{T}$ = any value	1	1.9 max. or [0.9 + 2.7($\delta_{avg}/\overline{T}$)], but not less than 1.0	
$\overline{T} \leq 0.237$ in. (6.02 mm), $\delta_{max} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.33$			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{\overline{T}} + 3.6\frac{\delta}{\overline{T}}$	
Concentric reducer per ASME B16.9 [Notes (1), (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_{o2}}{\overline{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14), (15)]	1	2.1 max. or 2.1 $\overline{T}/C_x$ but not less than 1.3	
Lap joint flange (with vASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

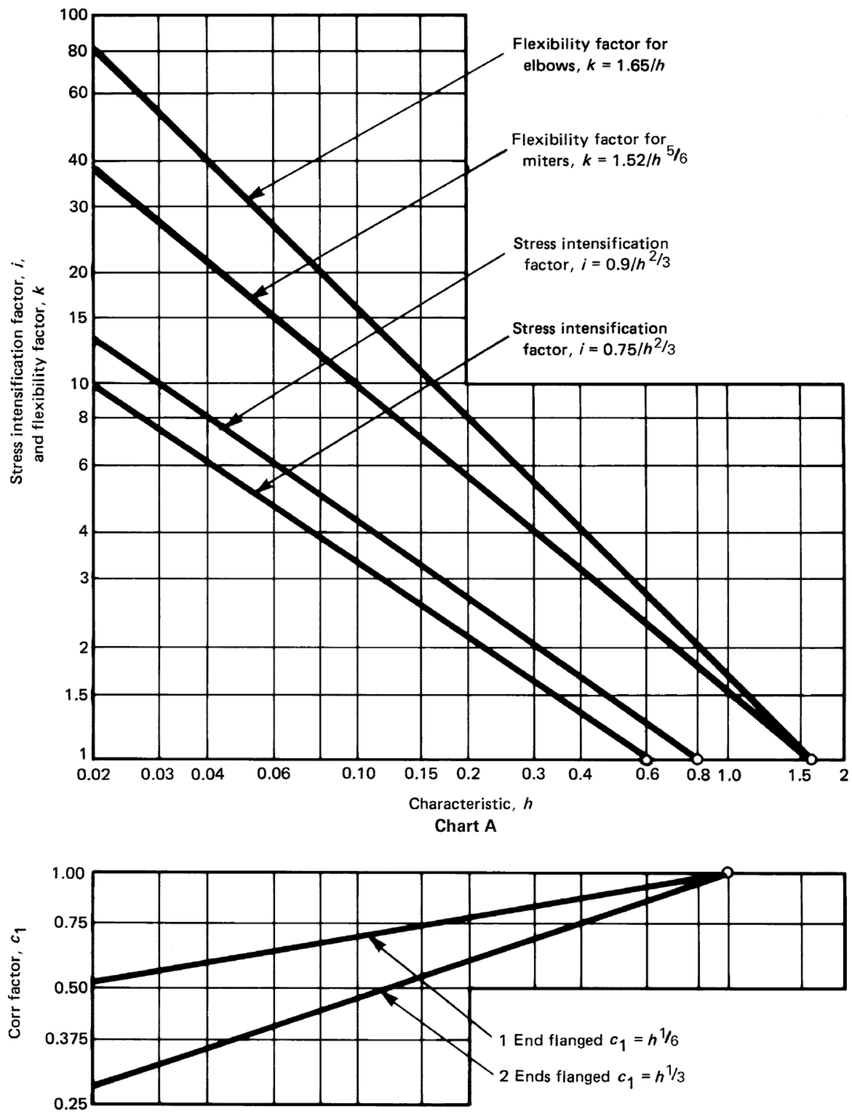


Chart A

Chart B

GENERAL NOTE: The stress intensification and flexibility factors from ASME B31J may be used instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of in-plane (i_i) and out-plane (i_o) stress intensification factors shall be used in calculating stresses in accordance with para. 833.2 or para. A842.2.2. Alternatively, stress intensification factors and branch connection flexibility factors may be developed using ASME B31J, Nonmandatory Appendix A.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES:

(1) The nomenclature is as follows:

D_o = outside diameter, in. (mm)
d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_o = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\overline{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, k, applies to bending in any plane. The flexibility factors, k, and stress intensification factors, i, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends and to the intersection point for tees. The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed h.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the table, divide k by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide i by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where
E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}T$, use $h = 4.05T/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the nominal wall thicknesses are between $0.875\overline{T}$ and $1.10\overline{T}$ for an axial distance of $\sqrt{D_o\overline{T}}$. D_o and $\overline{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.

(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES: (Cont'd)

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\left(S_b A_b - P A_p\right)$$

where

A_b = total area of flange bolts, in.^{2} (mm^3)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

When $D/t_n < 30$, then

$$P = \frac{2SEt_nFT}{D - t_n}$$

where

P = allowable pressure

S = specified minimum yield strength from para. 841.1.1 (a)

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)

t_n = nominal pipe thickness

D = nominal outside diameter

F = construction location design factor selected (obtained from Table 841.1.6-1)

T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Note:

Allowable Pressure calculation for Ductile Iron and Plastic piping systems as per this code are not included in CAEPIPE.

Stress due to Sustained & Occasional Loads [Unrestrained (above ground) Piping]

The sum of longitudinal stress due to internal pressure and due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the "include axial force in stress calculations" option is turned ON by default for ANSI B31.8 in CAEPIPE.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

For other Fittings and Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST}$$

For Fittings and Components

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where
P = maximum operating pressure = max (P_1 through P_{10})
P_{peak} = Peak pressure factor x P
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o= out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment
M_o= out-of-plane bending moment
M_t= torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
R = axial force component for external loads (other than thermal expansion and pressure)
A = un-corroded pipe metal cross-section area
S = specified minimum yield strength from para. 841.1.1(a)
T= temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with para. 832.3(g).

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.
S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles
where$f$ $\leq$ 1.0 (from para. 833.8 (b)).
S_L = sustained stress computed as per equation given above
S_C = 0.33SuT at the minimum installed or operating temperature
S_h = 0.33SuT at the maximum installed or operating temperature

where

S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and

S_y = specified minimum yield strength as per para. 841.1.1(a)

T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with para. 832.4 (g).

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per 833.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.

where

$S_p = 0.3S_H = 0.3\frac{PD}{2t_n}$ = longitudinal stress due to internal pressure in restrained pipeline

S_H = hoop stress = $\frac{PD}{2t_n}$ as per para. 805.2.3

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha(T_i - T_o)$ (see Note 1 below)

S_X = stress due to axial loading (other than thermal expansion and pressure) $= \frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads (other than thermal expansion)

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}$$

For other Fittings and Components.

$$S_B = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}$$

As per para 833.3(a), note that S_B,S_L, S_T *or* S_X can be positive or negative

where

P = maximum operating pressure = max(P1 through P10)

D = outside diameter

t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75 i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75 i_o$ shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
R = axial force component for external loads (other than thermal expansion and pressure)
A = un-corroded pipe metal cross-sectional area (i.e., before deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
E = Young's modulus at ambient temperature from para. 833.2 (c) = T_{ref} in CAEPIPE
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_0 in CAEPIPE

Note 1:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress due to thermal expansion as follows.

$E\alpha_1(T_1 - T_{ref})$ for T1, $E\alpha_2(T_2 - T_{ref})$ for T2 and for

$(T_2 - T_1) = E\alpha_n(T_n - T_{ref}) - E\alpha_m(T_m - T_{ref})$, where n = 1 and m = 2

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE as per para. 833.4.

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where
S_{eq} = equivalent combined stress

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

Notes:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix in accordance with para. 832.3 (g).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
3. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_318" with its value as "YES".

Notes on Material Library for B318-2020.mat supplied with CAEPIPE:

Material library for ASME B31.8 (2020) [B318-2020.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 832.2 of B31.8 (2020), Coefficient of Thermal Expansion for Carbon and low alloy steel are entered by referring to the values given in Table 832.2-1 of ASME B31.8 (2020).
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy steel are entered by referring to the values given in Table 832.5-1 of ASME B31.8 (2020).
3. **Yield Strength:** Yield Strength for Carbon and low alloy steel are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2020).
4. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.
5. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2020).

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

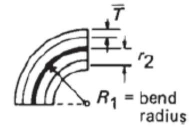
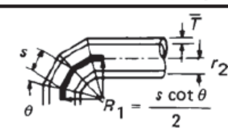
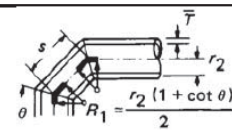
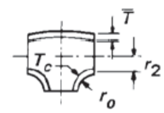
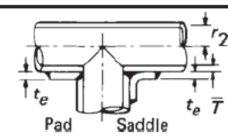
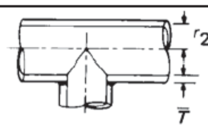
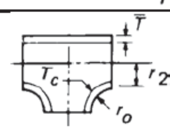
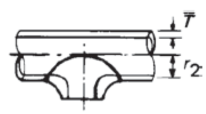
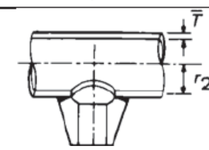
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)] Out-plane, i_o	In-plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\overline{T}R_1}{r_2^2}$	
Closely spaced miter bend [Notes (1), (2), (3), and (5)] $s < r_2 (1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta}{2} \frac{\overline{T}s}{r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta}{2} \frac{\overline{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq \frac{d}{8}$ $T_c \geq 1.5\,\overline{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$4.4 \frac{\overline{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{(\overline{T} + \frac{1}{2} t_e)^{5/2}}{\overline{T}^{3/2} r_2}$	
Unreinforced fabricated tee [Notes (1), (2), and (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\overline{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5\,\overline{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_o}{r_2}\right) \frac{\overline{T}}{r_2}$	
Welded-in contour insert $r_o \geq \frac{d}{8}$ $T_c \geq 1.5\,\overline{T}$ [Notes (1), (2), and (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$4.4 \frac{\overline{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (2), (9), and (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3 \frac{\overline{T}}{r_2}$	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

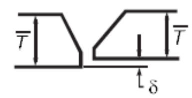
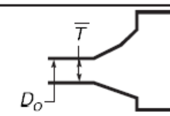
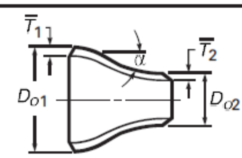
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
Buttweld [Notes (1) and (12)] $\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{8}$ in. (3.18 mm), and $\delta_{avg}/\overline{T}$ = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\overline{T})]$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\overline{T} \leq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.33$			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{\overline{T}} + 3.6\frac{\delta}{\overline{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_{o2}}{\overline{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max or 2.1 $\overline{T}/C_x$ but not less than 1.3	
Lap joint flange (with ASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

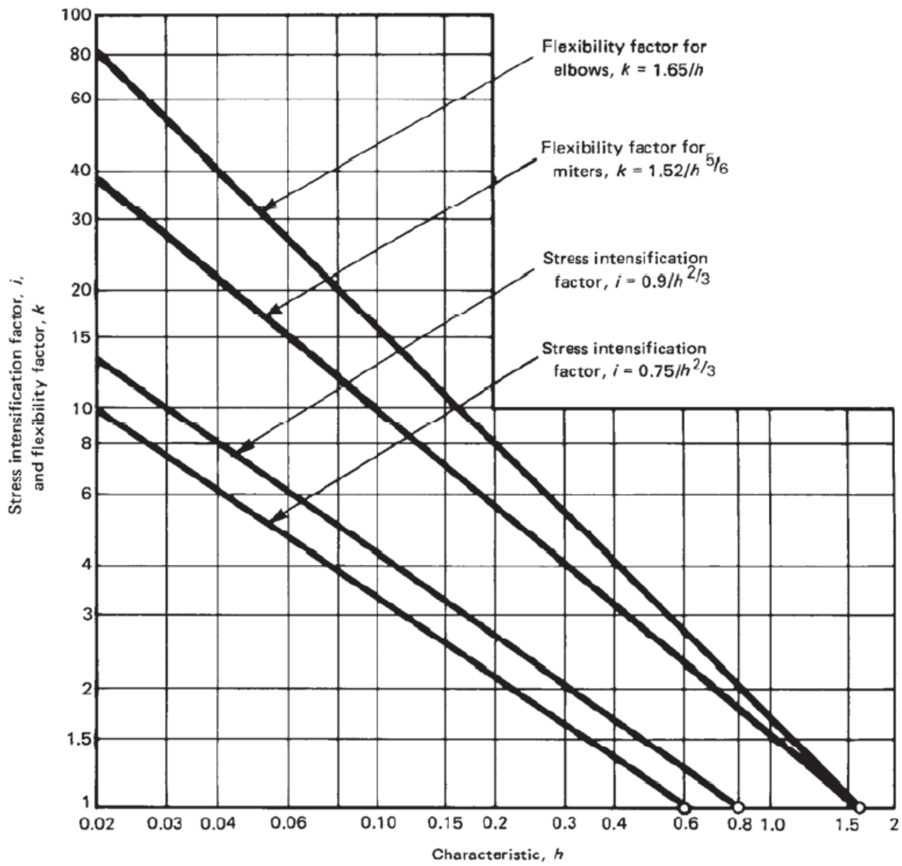


Chart A

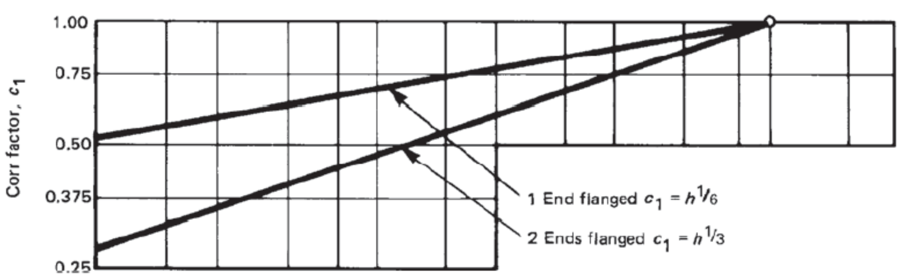


Chart B

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES:

(1) The nomenclature is as follows:

d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_o = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\overline{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, k, applies to bending in any plane. The flexibility factors, k, and stress intensification factors, i, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and to the intersection point for tees.

The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed h.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the table, divide k by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide i by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where

E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}T$, use $h = 4.05T/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875\overline{T}$ and $1.10\overline{T}$ for an axial distance of $\sqrt{D_o\,\overline{T}}$ · D_o and $\overline{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met.

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.

(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\ (S_b\ A_b - PA_p)$$

A_b = total area of flange bolts, in.^{2} (mm^2)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

When $D/t_n < 30$, then

$$P = \frac{2SEt_nFT}{D - t_n}$$

where

P = allowable pressure
S = specified minimum yield strength from para. 841.1.1 (a) and para. 817.1.3 (h)
E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)
t_n = nominal pipe thickness
D = outside diameter
F = construction type design factor, obtained from Table 841.1.6-1
T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Stress due to Sustained and Occasional Loads (Unrestrained Piping)

The sum of longitudinal pressure stress due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the "include axial force in stress calculations" option is turned ON by default for ANSI B31.8 in CAEPIPE.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

For other Fittings and Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST}$$

For Fittings and Components

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where
P = maximum operating pressure = max (P_1 through P_{10})
P_{peak} = Peak pressure factor x P
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o= out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment
M_o= out-of-plane bending moment
M_t= torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
R = axial force component for external loads (other than thermal expansion and pressure)
A = un-corroded cross-section area
S = specified minimum yield strength from para. 841.1.1(a)
T= temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with para. 832.3(g).

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.
S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles
where$f \leq$ 1.0 (from para. 833.8 (b)).
S_L = sustained stress computed as per equation given above
S_C = 0.33SuT at the minimum installed or operating temperature

S_h = 0.33SuT at the maximum installed or operating temperature
where
S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and
S_y = specified minimum yield strength as per para. 841.1.1(a)
T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with para. 832.4(b).

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per 833.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.
where

$S_p = 0.3S_H = 0.3\frac{PD}{2t_n}$ = longitudinal stress due to internal pressure in restrained pipeline

S_H = hoop stress

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha(T_i - T_o)$ (see Note 1 below)

S_X = stress due to axial loading (other than thermal expansion and pressure) $= \frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads(other than thermal expansion)

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}$$

For other Fittings and Components.

$$S_B = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}$$

As per para 833.3(a), note that S_B,S_L, S_T or S_X can be positive or negative
where
P = maximum operating pressure = max(P1 through P10)

D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
R = axial force component for external loads (other than thermal expansion and pressure)
A = un-corroded cross-sectional area (i.e., before deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
E = Young's modulus at ambient temperature= T_{ref} in CAEPIPE
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_0 in CAEPIPE

Note 1:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress due to thermal expansion from T1 to T2 in restrained pipeline as follows.

$E\alpha(T_n - T_m) = E\alpha_n(T_n - T_{ref}) - E\alpha_m(T_m - T_{ref})$, where n = 1 and m = 2

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE.

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \le 0.9ST$$

where
S_{eq} = equivalent combined stress

Notes:

6. Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix in accordance with para. 832.4(b).
7. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
8. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_318" with its value as "YES".

Notes on Material Library for B318-2018.mat supplied with CAEPIPE:

Material library for ASME B31.8 (2018) [B318-2018.mat] has been created and supplied with CAEPIPE as mentioned below.

9. **Coefficient of Thermal Expansion:** As stated in para. 832.2 of B31.8 (2018), Coefficient of Thermal Expansion for Carbon and low alloy steel are entered by referring to the values given in Table 832.2-1 of ASME B31.8 (2018).
10. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy steel are entered by referring to the values given in Table 832.5-1 of ASME B31.8 (2018).
11. **Yield Strength:** Yield Strength for Carbon and low alloy steel are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2018).
12. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.
13. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2018).

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

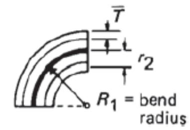
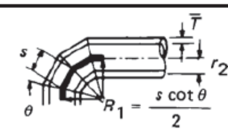
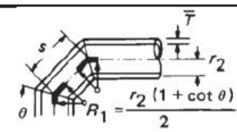
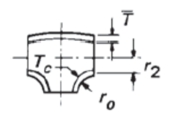
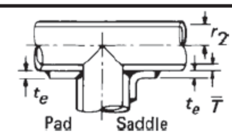
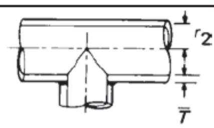
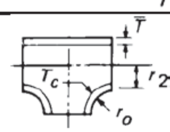
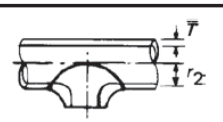
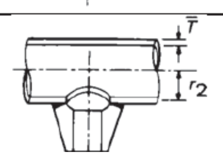
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i* [Notes (1) and (2)] Out-plane, i_o	In-plane, i_i	Flexibility Characteristic, *h*	Sketch
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^2}$	
Closely spaced miter bend [Notes (1), (2), (3), and (5)] $s < r_2 (1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\frac{\bar{T}s}{r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan\theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq \frac{d}{8}$ $T_c \geq 1.5\bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}t_e)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee [Notes (1), (2), and (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5\bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_o}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq \frac{d}{8}$ $T_c \geq 1.5\bar{T}$ [Notes (1), (2), and (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (2), (9), and (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\bar{T}}{r_2}$	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

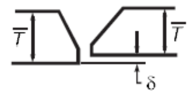
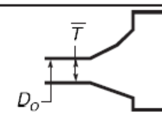
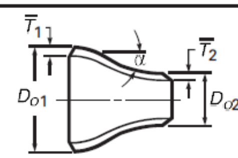
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{8}$ in. (3.18 mm), and $\delta_{avg}/\bar{T}$ = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\bar{T})]$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \leq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{\bar{T}} + 3.6\frac{\delta}{\bar{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max or 2.1 $\bar{T}/C_x$ but not less than 1.3	
Lap joint flange (with ASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

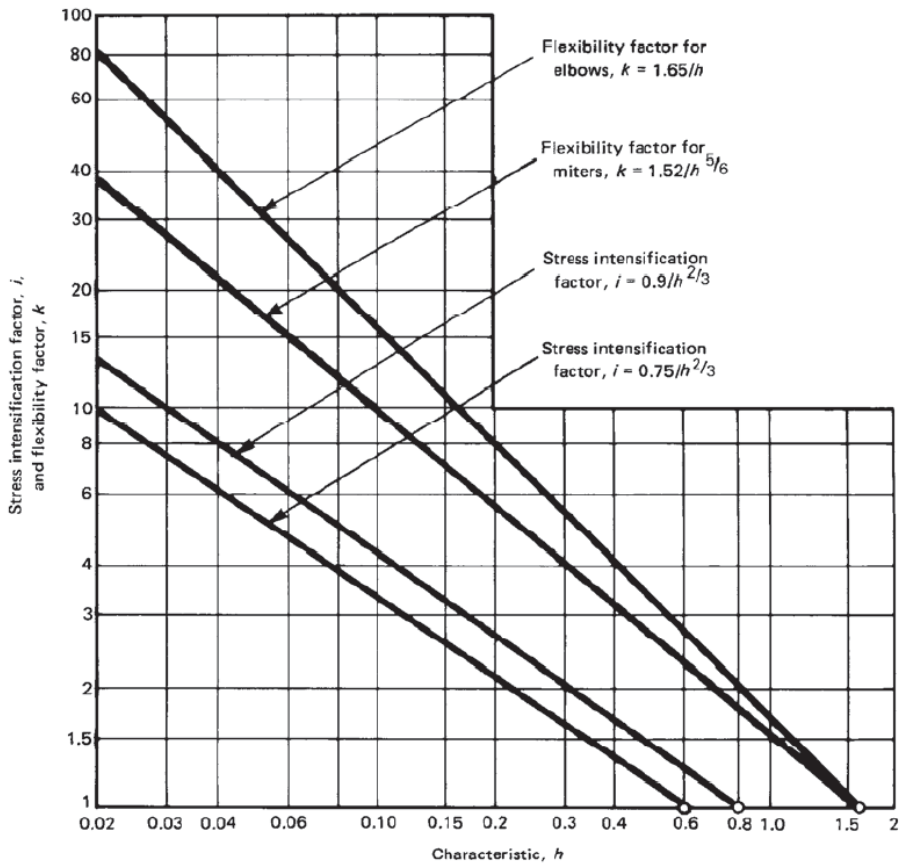


Chart A

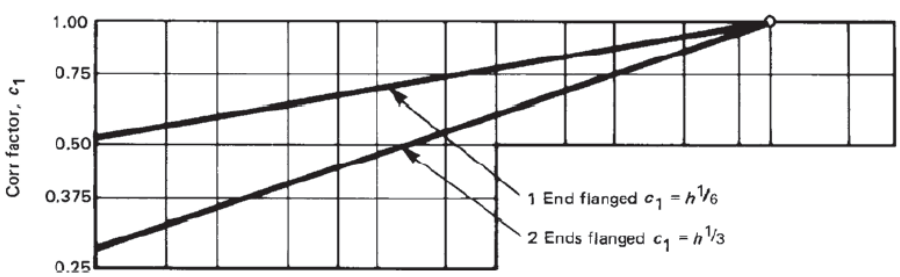


Chart B

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES:

(1) The nomenclature is as follows:

d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_o = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\overline{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, *k*, applies to bending in any plane. The flexibility factors, *k*, and stress intensification factors, *i*, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and to the intersection point for tees.

The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of *k* and *i* shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed *h*.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of *k* and *i*. To correct values from the table, divide *k* by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide *i* by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where

E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}T$, use $h = 4.05T/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875\overline{T}$ and $1.10\overline{T}$ for an axial distance of $\sqrt{D_o \overline{T}} \cdot D_o$ and $\overline{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met.

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.

(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\ (S_b\ A_b - PA_p)$$

A_b = total area of flange bolts, in.^{2} (mm^2)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

where

P = allowable pressure

S = specified minimum yield strength from para. 817.1.3 (h) and para. 841.1.4 (a)

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)

t_n = nominal pipe thickness

D = outside diameter

F = construction type design factor, obtained from Table 841.1.6-2

T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Stress due to Sustained and Occasional Loads (Unrestrained Piping)

The sum of longitudinal pressure stress due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the "include axial force in stress calculations" option is turned ON by default for ANSI B31.8 in CAEPIPE.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

For other Fittings or Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST}$$

For Fittings or Components

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where
P = maximum operating pressure = max (P_1 through P_{10})
P_{peak} = Peak pressure factor x P
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o= out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment
M_o= out-of-plane bending moment
M_t= torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
R = axial force component for external loads (other than thermal expansion and pressure)
A = un-corroded cross-section area
S = specified minimum yield strength from para. 841.1.1(a)
T= temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with para. 832.4(b).

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.
S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles
where$f \leq 1.0$ (from para. 833.8 (b)).
S_C = 0.33SuT at the minimum installed or operating temperature
S_h = 0.33SuT at the maximum installed or operating temperature
where
S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and
S_y = specified minimum yield strength as per para. 841.1.1(a)
T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with para. 832.4(b).

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per 833.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.
where

$S_p = 0.3S_H = 0.3\frac{PD}{2t_n}$ = longitudinal stress due to internal pressure in restrained pipeline

S_H = hoop stress

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha(T_i - T_o)$

S_X = stress due to axial loading (other than thermal expansion and pressure) $= \frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads(other than thermal expansion)

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}$$

For other Fittings or Components.

$$S_B = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}$$

As per para 833.3(a), note that S_B,S_L, S_T *or* S_X can have negative values.
where

P = maximum operating pressure = max(P1 through P10)
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment

R = axial force component for external loads (other than thermal expansion and pressure)
A = un-corroded cross-sectional area (i.e., after deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
E = Young's modulus at ambient (reference) temperature
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_o defined above

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE.

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where
S_{eq} = equivalent combined stress

Notes:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix in accordance with para. 832.4(b).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
3. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_318" with its value as "YES".

Notes on Material Library for B318-2016.mat supplied with CAEPIPE:

Material library for ASME B31.8 (2016) [B318-2016.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 832.2 of B31.8 (2016), Coefficient of Thermal Expansion for Carbon and low alloy steel are entered by referring to the values given in Table 832.2-1 of ASME B31.8 (2016).
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy steel are entered by referring to the values given in Table 832.5-1 of ASME B31.8 (2016).
3. **Yield Strength:** Yield Strength for Carbon and low alloy steel are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2016).
4. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in^3 and 0.3 respectively.
5. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2016).

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

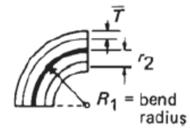
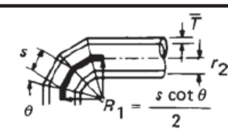
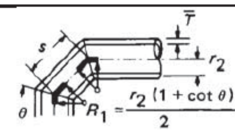
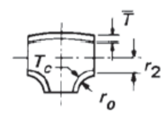
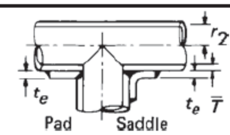
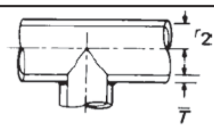
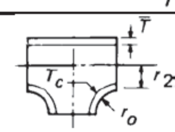
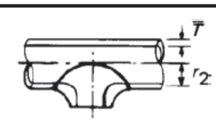
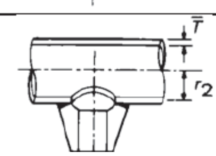
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)] Out-plane, i_o	In-plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^2}$	
Closely spaced miter bend [Notes (1), (2), (3), and (5)] $s < r_2 (1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta}{2} \frac{\bar{T} s}{r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta}{2} \frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq \frac{d}{8}$ $T_c \geq 1.5 \bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$4.4 \frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2} t_e)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee [Notes (1), (2), and (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5 \bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_o}{r_2}\right) \frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq \frac{d}{8}$ $T_c \geq 1.5 \bar{T}$ [Notes (1), (2), and (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$4.4 \frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (2), (9), and (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3 \frac{\bar{T}}{r_2}$	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

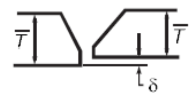
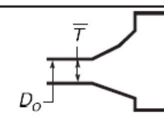
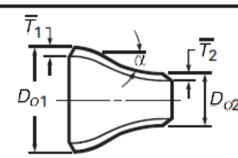
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
Buttweld [Notes (1) and (12)] $\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/8$ in. (3.18 mm), and $\delta_{avg}/\overline{T}$ = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\overline{T})]$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\overline{T} \leq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.33$			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{\overline{T}} + 3.6 \frac{\delta}{\overline{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_{o2}}{\overline{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max or 2.1 $\overline{T}/C_x$ but not less than 1.3	
Lap joint flange (with ASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

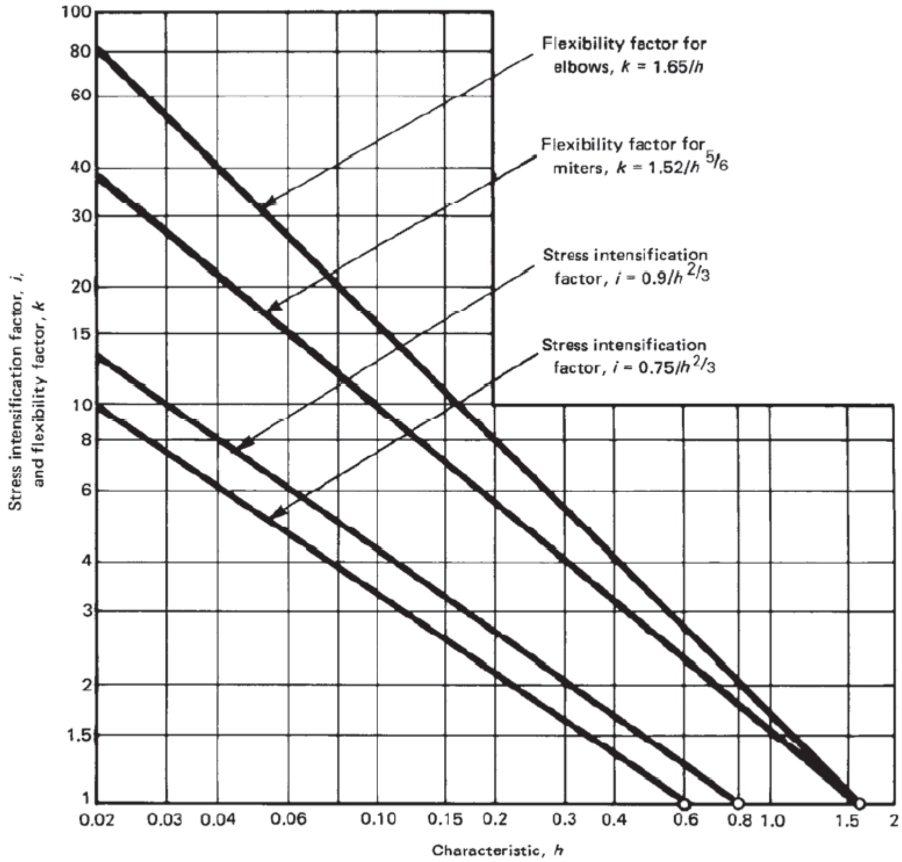


Chart A

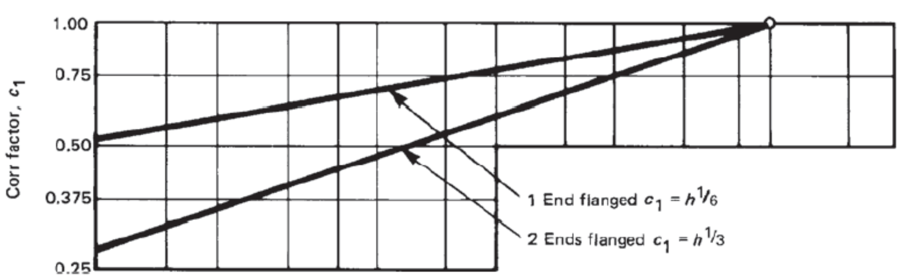


Chart B

Table E-1 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

NOTES:

(1) The nomenclature is as follows:

d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_o = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\bar{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, k, applies to bending in any plane. The flexibility factors, k, and stress intensification factors, i, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and to the intersection point for tees.

The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed h.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the table, divide k by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide i by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where

E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}\bar{T}$, use $h = 4.05\bar{T}/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875\bar{T}$ and $1.10\bar{T}$ for an axial distance of $\sqrt{D_o\,\bar{T}}$. D_o and $\bar{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met.

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.

(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\ (S_b\ A_b - PA_p)$$

A_b = total area of flange bolts, in.^{2} (mm^2)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

where

P = allowable pressure

S = specified minimum yield strength from para. 817.1.3 (h) and para. 841.1.4 (a)

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)

t_n = nominal pipe thickness

D = nominal outside diameter

F = construction type design factor, obtained from Table 841.1.6-1

T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Stress due to Sustained and Occasional Loads (Unrestrained Piping)

The sum of longitudinal pressure stress and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the "include axial force in stress calculations" option is turned ON by default for ANSI B31.8.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z}\right]_{Sustained}$$

For other Fittings or Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained}$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z}\right]_{occasional} \leq 0.75ST}$$

For Fittings or Components

$$S_{LO} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where

P = maximum operating pressure = max (P_1 through P_{10})
P_{peak} = Peak pressure factor x P
D = nominal outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
R = axial force component for external loads (other than thermal expansion and pressure)
A = corroded cross-section area (i.e., after deducting for corrosion)
S = specified minimum yield strength from para. 841.1.1(a)
T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations.

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where

S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_t = torsional moment
Z = un-corroded section modulus; for reduced outlets, effective section modulus
Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.
S_A = $f[1.25(S_C + S_h) - S_L]$
f = stress range reduction factor = 6/N0.2, where N = number of equivalent full range cycles
where $f \leq 1.0$ (from para. 833.8 (b)).
f = 0.33SuT at the minimum installed or operating temperature
S_h = 0.33SuT at the maximum installed or operating temperature
where
S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and

S_y = specified minimum yield strength as per para. 841.1.1(a)
T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix for Expansion load calculations.

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_L = \max\left(|S_p + S_x + S_B|, |S_p + S_x - S_B|\right)_{sustained} + \max\left(|S_p + S_x + S_B|, |S_p + S_x - S_B|\right)_{occasional} + \max(|S_T|_{warmest}, |S_T|_{coldest}) \leq 0.9ST$$

where
Internal pressure stress $= S_p = 0.3\frac{PD}{2t_n}$
Stress due to axial loading (other than thermal expansion and pressure) $= S_x = \frac{R}{A}$, and may be positive or negative

Nominal bending stress SB from Weight and / or other External loads for

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$$

For other Fittings or Components.

$$S_B = \frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}$$

Thermal expansion stress = $S_T = E\alpha(T_i - T_o)$, and may be positive or negative

Where
P = maximum operating pressure = max(P1 through P10)
D = nominal outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
R = axial force component for external loads (other than thermal expansion and pressure)

A = corroded cross-sectional area (i.e., after deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
E = Young's modulus at ambient (reference) temperature
T_i = installation temperature = T_{ref} in CAEPIPE
T_o = warmest or coldest operating temperature
α = coefficient of thermal expansion at T_o defined above

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

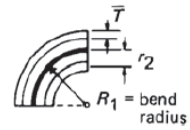
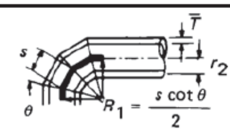
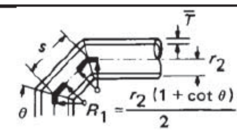
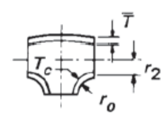
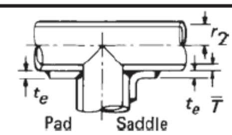
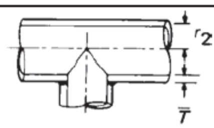
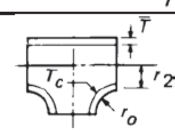
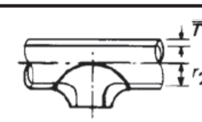
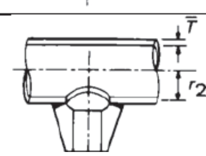
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)] Out-plane, i_o	In-plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend [Notes (1), (2), (3), and (5)] $s < r_2\,(1 + \tan\theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\,\frac{\bar{T}s}{r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2\,(1 + \tan\theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\,\frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq \frac{d}{8}$ $T_c \geq 1.5\,\bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$4.4\,\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}t_e)^{5/2}}{\bar{T}^{3/2}\,r_2}$	
Unreinforced fabricated tee [Notes (1), (2), and (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5\,\bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_o}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq \frac{d}{8}$ $T_c \geq 1.5\,\bar{T}$ [Notes (1), (2), and (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$4.4\,\frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (2), (9), and (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\,\frac{\bar{T}}{r_2}$	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

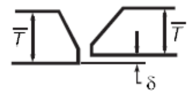
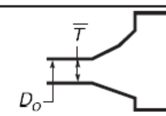
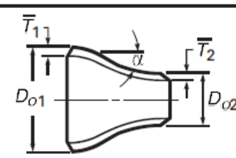
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
Buttweld [Notes (1) and (12)] $\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\overline{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{8}$ in. (3.18 mm), and $\delta_{avg}/\overline{T}$ = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\overline{T})]$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\overline{T} \leq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\overline{T} \leq 0.33$			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{\overline{T}} + 3.6 \frac{\delta}{\overline{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_{o2}}{\overline{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max or 2.1 $\overline{T}/C_x$ but not less than 1.3	
Lap joint flange (with ASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

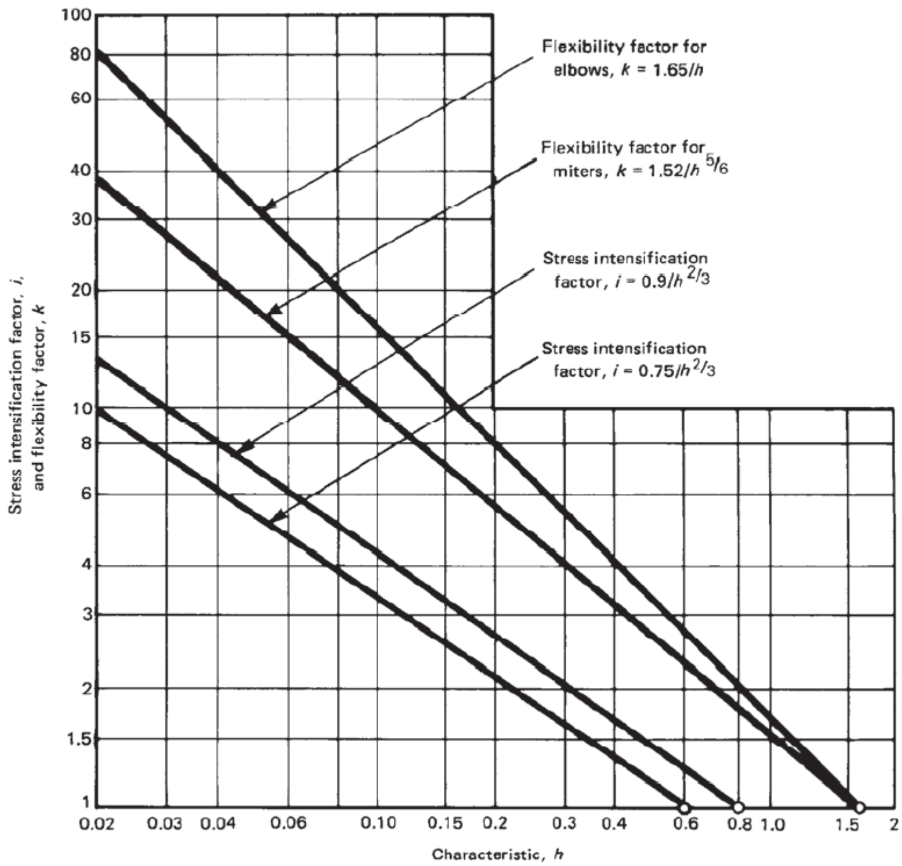


Chart A

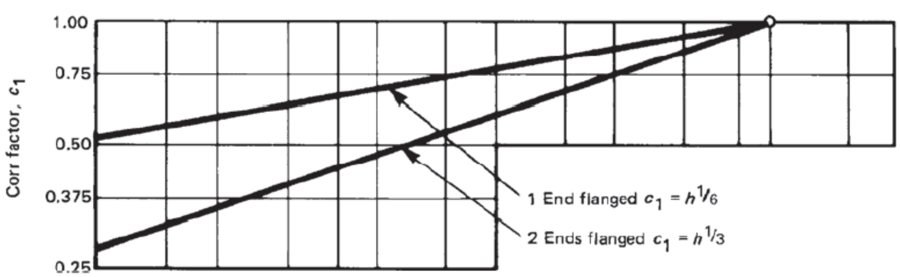


Chart B

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES:

(1) The nomenclature is as follows:

d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_o = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\bar{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, *k*, applies to bending in any plane. The flexibility factors, *k*, and stress intensification factors, *i*, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and to the intersection point for tees.

The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of *k* and *i* shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed *h*.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of *k* and *i*. To correct values from the table, divide *k* by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide *i* by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where

E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}T$, use $h = 4.05T/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875\bar{T}$ and $1.10\bar{T}$ for an axial distance of $\sqrt{D_o \bar{T}}$ · D_o and $\bar{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met.

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.

(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\ (S_b\ A_b - PA_p)$$

A_b = total area of flange bolts, in.^{2} (mm^2)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. (2) of para. 904.1 and 904.2.1.

$$P = \frac{2SE(t_m - A)}{D}$$

where
P = allowable pressure
SE = allowable hoop stress, given in Appendix I of B31.9 (2020) Code, where
E= longitudinal or spiral weld joint efficiency factor as per Table I-1 of Appendix I of ASME B31.9 (2020). For casting materials, factor E is replaced with Casting Qualify Factor F from Table I-1 of Appendix I of ASME B31.9 (2020)
t_m=minimum required pipe thickness as per para. 904.1.1(a) =$t_n \times$ (1 – mill tolerance/100)
t_n=nominal pipe thickness
A= corrosion allowance
(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in "corrosion allowance" in CAEPIPE)
D=outside diameter

For closely and widely spaced miter bends, the allowable pressure shall be the lower positive value calculated from Eqs.(3A) and (3B) of para. 904.2.2(a)

$$P = \frac{SET}{r}\left(\frac{T}{T + 0.64 \tan\theta\sqrt{rT}}\right) \qquad \text{Eq. (3A)}$$

$$P = \frac{SET}{r}\left(\frac{R - r}{R - r/2}\right) \qquad \text{Eq. (3B)}$$

where
r = mean radius of pipe $= (D - t_n)/2$
T = $t_m - A$, where t_m and A are defined above
R = effective bend radius of the miter
θ = miter half angle, with $\theta \le$ 22.5 deg.

Note:

Equations (3A) and (3B) given above is applicable when R entered in CAEPIPE is at least as great as the value calculated by eq. (4) of ASME B31.9 (2020).

Sustained Stress (in un-corroded condition)

The longitudinal sustained stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated as mentioned in para. 902.3.2(d)

$$S_L = \sqrt{\left[\left|\frac{PD_o}{4t_n} + \frac{I_a F_a}{A_p}\right| + \frac{\sqrt{(I_i M_{iA})^2 + (I_o M_{oA})^2}}{Z}\right]^2 + \left(\frac{I_t M_{tA}}{Z}\right)^2} \le S_h$$

where

P = internal design pressure that shall be not less than the maximum sustained operating pressure (MSOP) within the piping system, including the effects of static head = maximum of CAEPIPE pressures P1 through P10

D_o = nominal outside diameter

t_n= nominal wall thickness

F_a= longitudinal force due to weight and other sustained mechanical loads (excluding pressure)

I_a= sustained longitudinal force index = 1.00

I_i = sustained in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = sustained out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = sustained torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iA}, M_{oA}, M_{tA} = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads

Z = nominal section modulus = un-corroded section modulus

A_p= un-corroded nominal cross sectional area

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

S_L = stress due to pressure, weight and other sustained mechanical loads

Occasional Stress (in un-corroded condition)

The stress (SO) due to sustained and occasional loads as mentioned in para.902.3.3 as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind. Wind and earthquake are not considered to act concurrently.

$$S_O = \sqrt{\left[\left|\frac{P_o D_o}{4t_n} + \frac{I_a F_b}{A_p}\right| + \frac{\sqrt{(I_i M_{iB})^2 + (I_o M_{oB})^2}}{Z}\right]^2 + \left(\frac{I_t M_{tB}}{Z}\right)^2} \leq kS_h$$

where

F_b = longitudinal force due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake / wind, etc.
I_a= occasional longitudinal force index = 1.00

I_i = occasional in-plane moment index. I_i is taken as the greater of $0.75i_i$ and 1.00. i_i is taken from ASME B31J, Table 1-1.

I_o = occasional out-of-plane moment index. I_o is taken as the greater of $0.75i_o$ and 1.00. i_o is taken from ASME B31J, Table 1-1.

I_t = occasional torsional moment index. I_t is taken as the greater of $0.75i_t$ and 1.00. i_t is taken from ASME B31J, Table 1-1.

M_{iB}, M_{oB}, M_{tB} = in-plane, out-of-plane and torsional moment respectively due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake / wind, etc.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

S_O = stress due to pressure, weight, other sustained mechanical loads and occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake / wind etc.

k = 1.33 for occasional loads as per para. 902.3.3 (a)

All other terms such as P, A_p, Z, etc. are as defined under Sustained Stress.

For Unsigned occasional load cases such as Earthquake, etc. the forces and moments are combined as given below.

$$\left|\frac{P_oD_o}{4t_n} + \frac{I_aF_b}{A_p}\right| = max\left[\left|\frac{P_oD_o}{4t_n} + \frac{I_aF_{b(sust)}}{A_p}\right| + \left|\frac{I_aF_{b(occa)}}{A_p}\right|, \left|\left|\frac{P_oD_o}{4t_n} + \frac{I_aF_{b(sust)}}{A_p}\right| - \left|\frac{I_aF_{b(occa)}}{A_p}\right|\right|\right]$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)}\right| + \left|M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)}\right| + \left|M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)}\right| + \left|M_{tB(occa)}\right|\right]^2$$

For Signed occasional load cases such as Wind, etc. the forces and moments are combined as given below.

$$\left|\frac{P_oD_o}{4t_n} + \frac{I_aF_b}{A_p}\right| = \left|\frac{P_oD_o}{4t_n} + \frac{I_aF_{b(sust)}}{A_p} + \frac{I_aF_{b(occa)}}{A_p}\right|$$

$$(I_iM_{iB})^2 = (I_i)^2.\left[\left|M_{iB(sust)} + M_{iB(occa)}\right|\right]^2$$

$$(I_oM_{oB})^2 = (I_o)^2.\left[\left|M_{oB(sust)} + M_{oB(occa)}\right|\right]^2$$

$$(I_tM_{tB})^2 = (I_t)^2.\left[\left|M_{tB(sust)} + M_{tB(occa)}\right|\right]^2$$

where

$M_{iB(sust)}$, $M_{oB(sust)}$, $M_{tB(sust)}$ = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads (excluding pressure).

$M_{iB(occa)}$, $M_{oB(occa)}$, $M_{tB(occa)}$ = in-plane, out-of-plane and torsional moment respectively due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake / wind, etc.

$F_{b(sust)}$ = longitudinal force due to weight, other sustained mechanical loads (excluding pressure)

$F_{b(occa)}$ = longitudinal force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake / wind, etc.

Expansion Stress Range (in un-corroded condition)

The stress range (S_E) due to thermal expansion is calculated from para. 902.3.2(c), para. 919.2.1 and para. 919.4.1(b)

$$S_E = \sqrt{\left[\left|\frac{i_a F_c}{A_p}\right| + \frac{\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tC}}{Z}\right)^2} \leq S_A$$

where

F_c = axial force range due to reference displacement load range

A_p= un-corroded nominal cross sectional area

i_a= axial force stress intensification factor = 1.0 for elbows, pipe bends and miter bends (single, closely spaced and widely spaced), and i_a = i_o(or i when listed) in ASME B31J for other components

M_{iC}, M_{oC}, M_{tC} = in-plane, out-of-plane and torsional moment range respectively due to the reference displacement load range

i_i, i_o, i_t = in-plane, out-of-plane and torsional stress intensification factors respectively as defined in ASME B31J, Table 1-1

Z = nominal section modulus = un-corroded section modulus

S_A = $f(1.25S_C + 0.25S_h)$ (See Note 2 below)

f = stress range reduction factor $6/N^{0.2}$, where N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping. Also $0.15 \leq f \leq 1.0$

S_C = basic allowable stress at minimum metal temperature expected during the displacement stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement stress range under analysis

When S_h is greater than S_L, the allowable stress range may be calculated as per para. 902.3.2 (d).

$S_A = f[1.25(S_C + S_h) - S_L]$. This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 2** below)

This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options>Analysis on the "Code" tab is Turned ON.

Notes:

1. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations" as per ASME B31.9 (2020).
2. Para. 902.3.2 (c) and (d) refers to para. 102.3.2 (b) of ASME B31.1 (2020) for Allowable Stress. As per Note 2 of para. 102.3.2 (b) (1) of ASME B31.1 (2020), "For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1A) and (1B) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_L) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1A) to arrive at "Liberal Thermal Allowable Stress".

Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. 2 of para. 904.1 and 904.2.1.

$$P = \frac{2SE(t_m - A)}{D}$$

where
P = allowable pressure
SE = allowable hoop stress, given in Appendix I of B31.9 (2017) Code, where
E= longitudinal or spiral weld joint efficiency factor as per Table I-1 of Appendix I of ASME B31.9 (2017). For casting materials, factor E is replaced with Casting Qualify Factor from Table I-1 of Appendix I of ASME B31.9 (2017)
t_m=minimum required pipe thickness as per para. 904.1.1(a)
=$t_n \times$ (1 – mill tolerance/100)
t_n=nominal pipe thickness
A= corrosion allowance
(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in "corrosion allowance" in CAEPIPE)
D=outside diameter

For closely and widely spaced miter bends, the allowable pressure shall be the lower positive value calculated from Eqs.(3A) and (3B) of para. 904.2.2(a)

$$P = \frac{SET}{r}\left(\frac{T}{T+0.64\tan\theta\sqrt{rT}}\right) \qquad \text{Eq. (3A)}$$

$$P = \frac{SET}{r}\left(\frac{R-r}{R-r/2}\right) \qquad \text{Eq. (3B)}$$

where
r = mean radius of pipe $= (D - t_n)/2$
T = $t_m - A$, where t_m and A are defined above
R = effective bend radius of the miter
θ = miter half angle

Sustained Stress (in un-corroded condition)

The longitudinal stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated as mentioned in para. 902.3.2(d)

$$S_L = \frac{PD_o}{4t_n} + \frac{0.75iM_A}{Z} \leq S_h$$

where
P= maximum of CAEPIPE input pressures P_1 through P_{10}
D_o= outside diameter
t_n=nominal wall thickness

i=stress intensification factor. The product $0.75i$ shall not be less than 1.0. See Note 1 below.

M_A = resultant bending moment due to weight and other sustained loads

Z = un-corroded section modulus; for reduced outlets, effective section modulus

S_h = hot allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in un-corroded condition)

The longitudinal stress (S_{LO})due to occasional loads is calculated as mentioned in para.902.3.3 (a) as the sum of stresses due to pressure, live and dead loads and stress due to occasional loads(S_O) such as earthquake or wind. Wind and earthquake are not considered to occur concurrently.

$$S_{LO} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq 1.33S_h$$

where

M_B = resultant bending moment due to occasional loads

P_{peak} = peak pressure = (peak pressure factor) x P

Expansion Stress (in un-corroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 902.3.2(c), para. 919.2.1 and para. 919.4.1(b)

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

M_C = resultant moment due to thermal expansion

S_A = $f(1.25S_C + 0.25S_h)$

f = stress range reduction factor $6/N^{0.2}$, where N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping. Also $0.15 \leq f \leq 1.0$

S_C = allowable stress at cold temperature, i.e. at minimum of CAEPIPE input temperatures T_1 through T_{10} and T_{ref}

When S_h is greater than S_L, the allowable stress range may be calculated as per para. 902.3.2 (d).

S_A = $f[1.25(S_C + S_h) - S_L]$

This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options>Analysis on the "Code" tab is Turned ON.

Notes:

1. Stress Intensification Factors (SIFs) and Flexibility Factors (FFs) are computed using ASME B31.1 (2016) by default as given below. When the option "Use B31J for SIFs and Flexibility Factors" is Turned ON, then CAEPIPE computes SIFs and FFs as per B31J (2017).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

MANDATORY APPENDIX D

Table D-1 Flexibility and Stress Intensification Factors

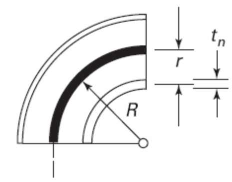
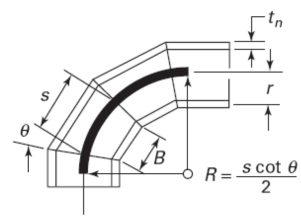
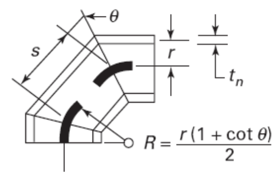
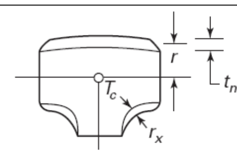
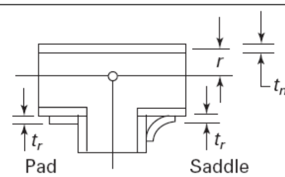
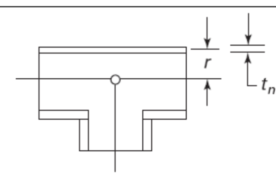
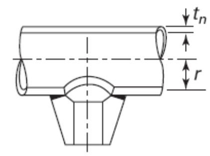
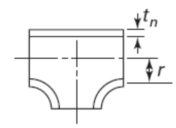
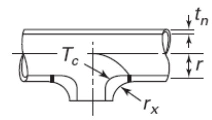
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r(1 + \tan\theta)$ $B \geq 6\ t_n$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (5), (6)] $s \geq r(1 + \tan\theta)$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{t_n (1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Notes (1), (2), (7)]	$\frac{3.1 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (8), (9)]	$\frac{\left(t_n + \frac{t_r}{2}\right)^{5/2}}{r\,(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]	$\frac{3.3t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Extruded outlet meeting the requirements of para. 104.3.1(G) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert [Notes (1), (2), (7)]	$3.1\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

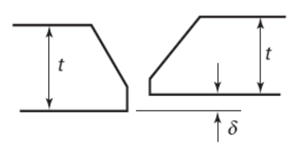
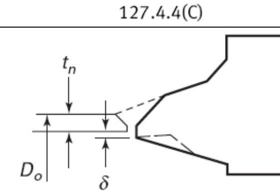
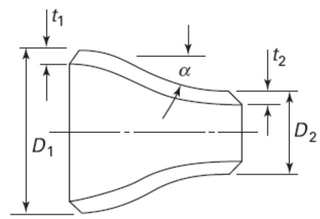
Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/8$ in., and $\delta_{avg}/t =$ any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/t)]$, but not less than 1.0 [Note (11)]	
Butt weld [Note (1)] $t < 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.33$	1		
Fillet welds	1	1.3 [Note (12)]	See Figs. 127.4.4(A), 127.4.4(B), and 127.4.4(C)
Tapered transition per para. 127.4.2(B) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Concentric reducer per ASME B16.9 [Note (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (14)]	5	2.5	. . .

NOTES:

(1) The following nomenclature applies to Table D-1:

B = length of miter segment at crotch, in. (mm)
D_o = outside diameter, in. (mm)
D_{ob} = outside diameter of branch, in. (mm)
R = bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees)
r_x = external crotch radius of welded-in contour inserts and welding tees, in. (mm)
s = miter spacing at centerline, in. (mm)
T_c = crotch thickness of welded-in contour inserts and welding tees, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
t_r = reinforcement pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factors k and stress intensification factors i in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Chart D-1 by entering with the characteristic h computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor c given below, which can be read directly from Chart D-2, entering with the computed h: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i. Values from the Table may be corrected by dividing k by

$$\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}\right]$$

and dividing i by

$$\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}\right]$$

(6) Also includes single miter joints.

(7) If $r_x \geq D_{ob}/8$ and $T_c \geq 1.5t_n$, a flexibility characteristic, h, of $4.4t_n/r$ may be used.

(8) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

(9) The stress intensification factors in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

(10) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of para. 104.3 are met.

(b) The axis of the branch pipe is normal to the surface of run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.

(d) The inside corner radius r_1 (see Fig. D-1) is between 10% and 50% of t_{nh}.

(e) The outer radius r_2 (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b + y)/2$ [shown in Fig. D-1 sketch (c)], or $t_{nh}/2$.

(f) The outer radius r_3 (see Fig. D-1) is not less than the larger of:

(1) $0.002\theta d_o$;

(2) $2(\sin\theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).

(g) $R_m/t_{nh} \le 50$ and $r'_m/R_m \le 0.5$.

(11) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875t$ and $1.10t$ for an axial distance of $\sqrt{D_o t}$. D_o and t are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a full weld is made between the pipe and fitting as shown in Fig. 127.4.4(C). For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Fig. 127.4.4(B) and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 127.4.4(A) sketches (b) and (d), has been shown to improve the fatigue performance of the weld.

(13) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(14) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Chart D-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

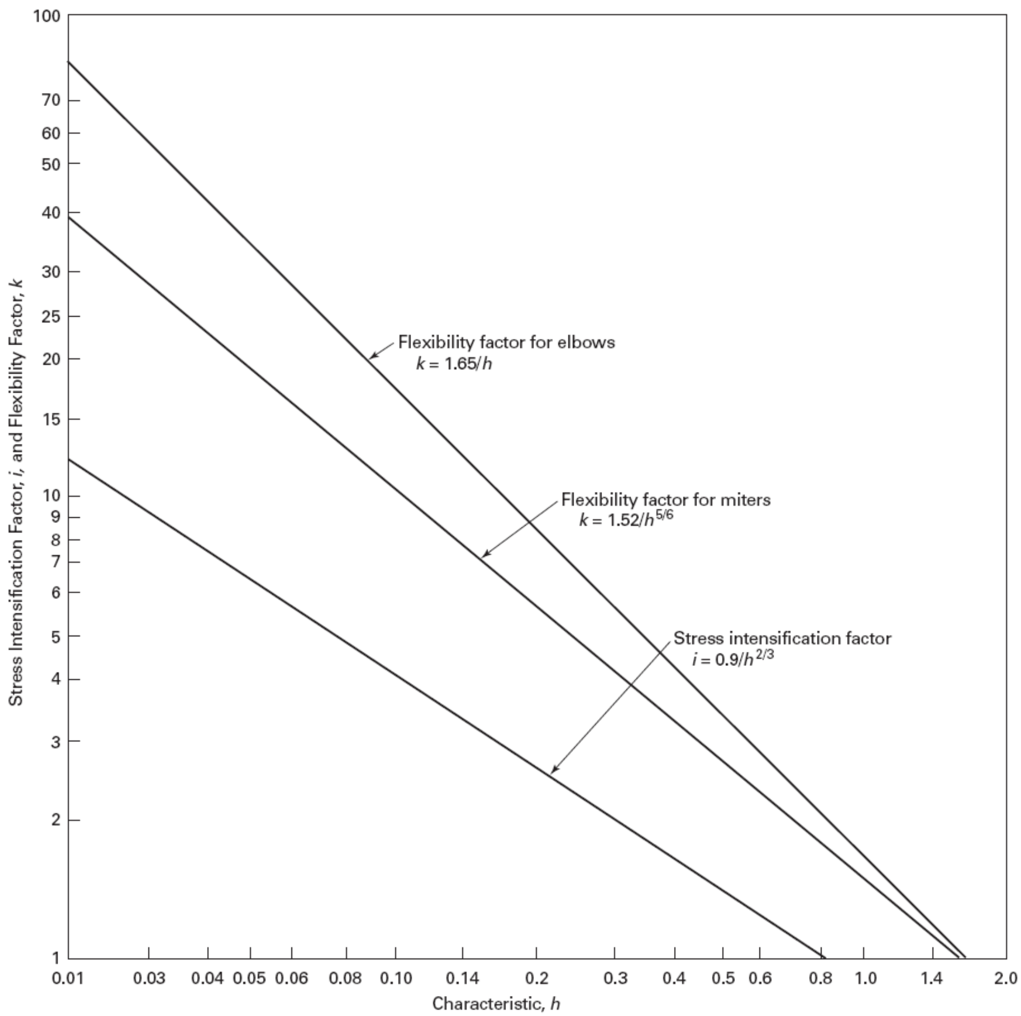
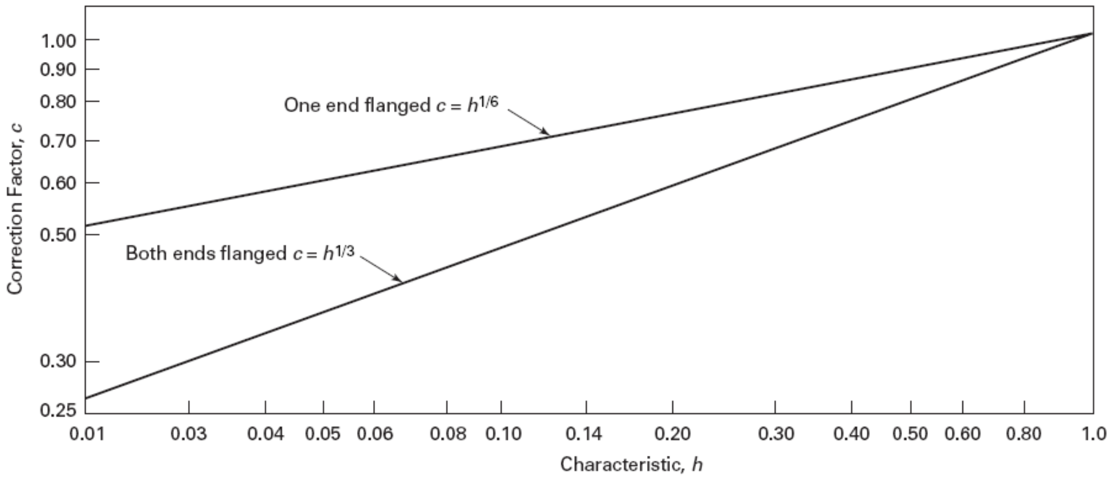


Chart D-2 Correction Factor, *c*



Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. 2 of para. 904.1 and 904.2.1.

$$P = \frac{2SE(t_m - A)}{D}$$

where
P = allowable pressure
SE = allowable hoop stress, given in Appendix I of B31.9 (2014) Code, where
E = longitudinal or spiral weld joint efficiency factor or casting quality factor
t_m = minimum required pipe thickness as per para. 904.1.1(a)
= $t_n \times$ (1 – mill tolerance/100)
t_n = nominal pipe thickness
A = corrosion allowance
(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in "corrosion allowance" in CAEPIPE)
D = outside diameter

For closely and widely spaced miter bends, the allowable pressure shall be the lower positive value calculated from Eqs.(3A) and (3B) of para. 904.2.2(a)

$$P = \frac{SET}{r}\left(\frac{T}{T+0.64\tan\theta\sqrt{rT}}\right) \qquad \text{Eq. (3A)}$$

$$P = \frac{SET}{r}\left(\frac{R-r}{R-r/2}\right) \qquad \text{Eq. (3B)}$$

where
r = mean radius of pipe $= (D - t_n)/2$
T = $t_m - A$, where t_m and A are defined above
R = effective bend radius of the miter
θ = miter half angle

Sustained Stress (in un-corroded condition)

The longitudinal stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated as mentioned in para. 902.3.2(d)

$$S_L = \frac{PD_o}{4t_n} + \frac{0.75iM_A}{Z} \leq S_h$$

where
P = maximum of CAEPIPE pressures P_1 through P_{10}
D_o = outside diameter
t_n = nominal wall thickness
i = stress intensification factor. The product $0.75i$ shall not be less than 1.0.
M_A = resultant bending moment due to weight and other sustained loads
Z = un-corroded section modulus; for reduced outlets, effective section modulus

S_h = hot allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in un-corroded condition)

The longitudinal stress (S_{LO})due to occasional loads is calculated as mentioned in para.902.3.3 (a) as the sum of stresses due to pressure, live and dead loads and stress due to occasional loads(S_O) such as earthquake or wind. Wind and earthquake are not considered to occur concurrently.

$$S_{LO} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq 1.33S_h$$

where

M_B = resultant bending moment due to occasional loads

P_{peak} = peak pressure = (peak pressure factor) x P

Expansion Stress (in un-corroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 902.3.2(c), para. 919.2.1 and para. 919.4.1(b)

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

M_C = resultant moment due to thermal expansion

S_A = $f(1.25S_C + 0.25S_h)$

f = stress range reduction factor $6/N^{0.2}$, where N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping. Also $0.15 \leq f \leq 1.0$

S_C = allowable stress at cold temperature, i.e. at minimum of CAEPIPE input temperaturesT_1 through T_{10} and T_{ref}

When S_h is greater than S_L, the allowable stress range may be calculated as per para. 902.3.2 (d).

S_A = $f[1.25(S_C + S_h) - S_L]$

This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options>Analysis on the "Code" tab.

Note:

Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Stress Intensification Factor (SIF) values for B31.9 (2014) are referred from Appendix D of B31.1 (2012). The same is provided below for details.

MANDATORY APPENDIX D

Table D-1 Flexibility and Stress Intensification Factors

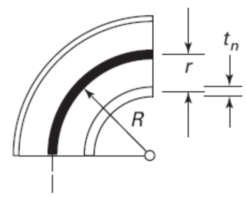
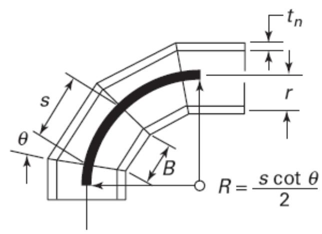
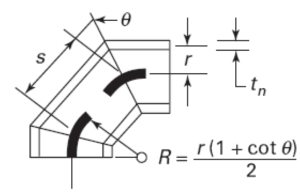
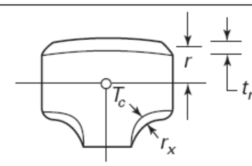
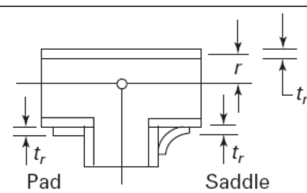
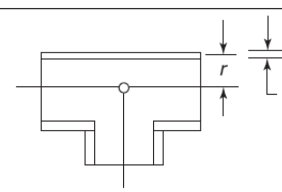
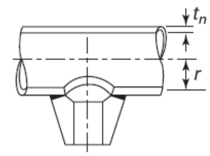
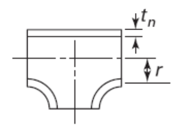
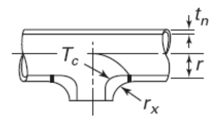
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r(1 + \tan\theta)$ $B \geq 6\ t_n$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (5), (6)] $s \geq r(1 + \tan\theta)$ $\theta \leq 22\frac{1}{2}$ deg	$\frac{t_n (1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Notes (1), (2), (7)]	$\frac{3.1t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (8), (9)]	$\frac{\left(t_n + \frac{t_r}{2}\right)^{5/2}}{r\,(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]	$\frac{3.3t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Extruded outlet meeting the requirements of para. 104.3.1(G) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert [Notes (1), (2), (7)]	$3.1\,\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

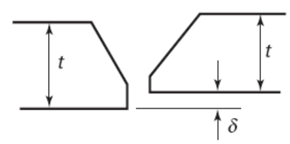
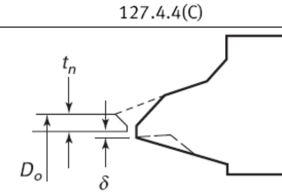
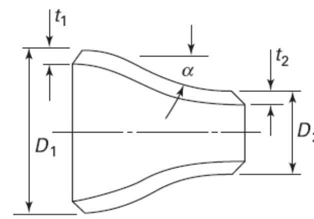
Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/8$ in., and $\delta_{avg}/t =$ any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/t)]$, but not less than 1.0 [Note (11)]	
Butt weld [Note (1)] $t < 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.33$	1		
Fillet welds	1	1.3 [Note (12)]	See Figs. 127.4.4(A), 127.4.4(B), and 127.4.4(C)
Tapered transition per para. 127.4.2(B) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$	

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Concentric reducer per ASME B16.9 [Note (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	. . .
Corrugated straight pipe, or corrugated or creased bend [Note (14)]	5	2.5	. . .

NOTES:

(1) The following nomenclature applies to Table D-1:

B = length of miter segment at crotch, in. (mm)
D_o = outside diameter, in. (mm)
D_{ob} = outside diameter of branch, in. (mm)
R = bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees)
r_x = external crotch radius of welded-in contour inserts and welding tees, in. (mm)
s = miter spacing at centerline, in. (mm)
T_c = crotch thickness of welded-in contour inserts and welding tees, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
t_r = reinforcement pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factors k and stress intensification factors i in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Chart D-1 by entering with the characteristic h computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor c given below, which can be read directly from Chart D-2, entering with the computed h: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i. Values from the Table may be corrected by dividing k by

$$\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}\right]$$

and dividing i by

$$\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}\right]$$

(6) Also includes single miter joints.

(7) If $r_x \geq D_{ob}/8$ and $T_c \geq 1.5t_n$, a flexibility characteristic, h, of $4.4t_n/r$ may be used.

(8) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

(9) The stress intensification factors in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

(10) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of para. 104.3 are met.

(b) The axis of the branch pipe is normal to the surface of run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.

(d) The inside corner radius r_1 (see Fig. D-1) is between 10% and 50% of t_{nh}.

(e) The outer radius r_2 (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b + y)/2$ [shown in Fig. D-1 sketch (c)], or $t_{nh}/2$.

(f) The outer radius r_3 (see Fig. D-1) is not less than the larger of:

(1) $0.002\theta d_o$;

(2) $2(\sin\theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).

(g) $R_m/t_{nh} \le 50$ and $r'_m/R_m \le 0.5$.

(11) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875t$ and $1.10t$ for an axial distance of $\sqrt{D_o t}$. D_o and t are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a full weld is made between the pipe and fitting as shown in Fig. 127.4.4(C). For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Fig. 127.4.4(B) and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 127.4.4(A) sketches (b) and (d), has been shown to improve the fatigue performance of the weld.

(13) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.

(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(14) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Chart D-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

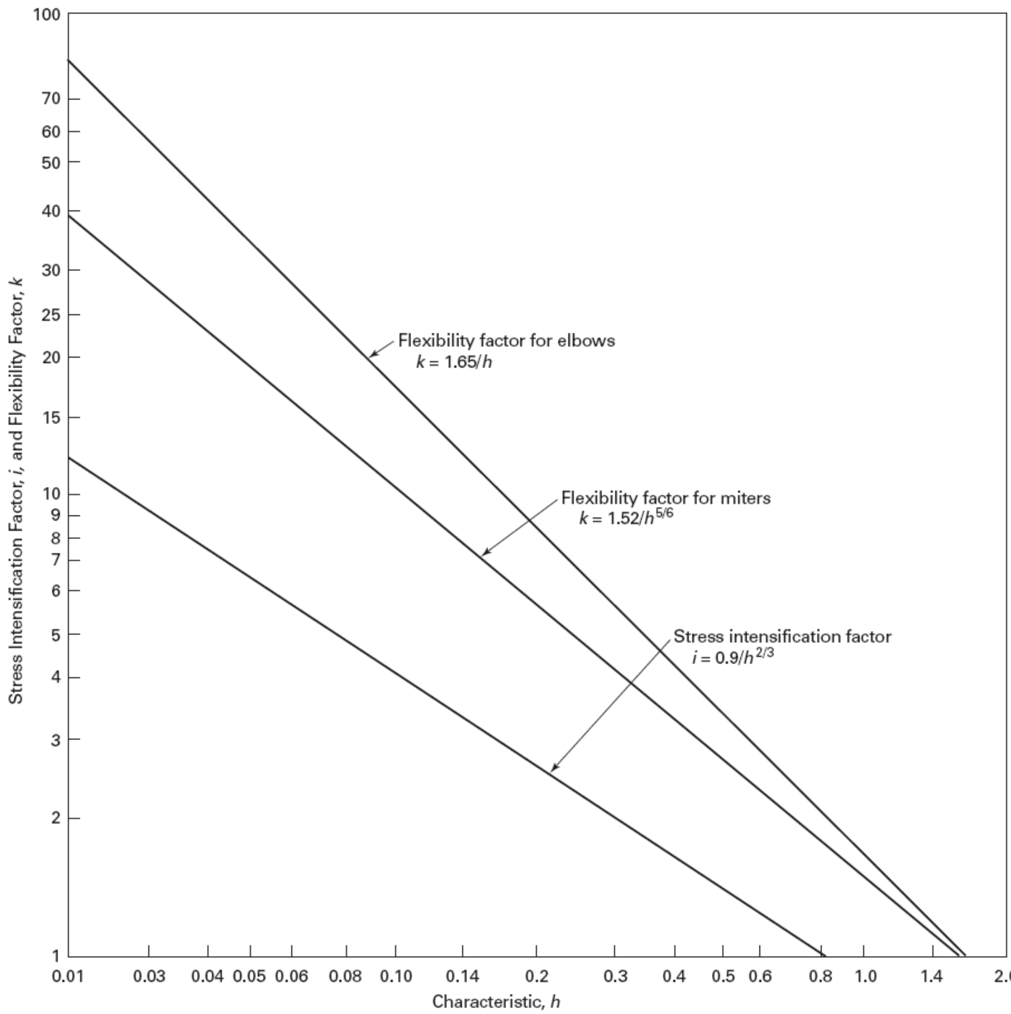
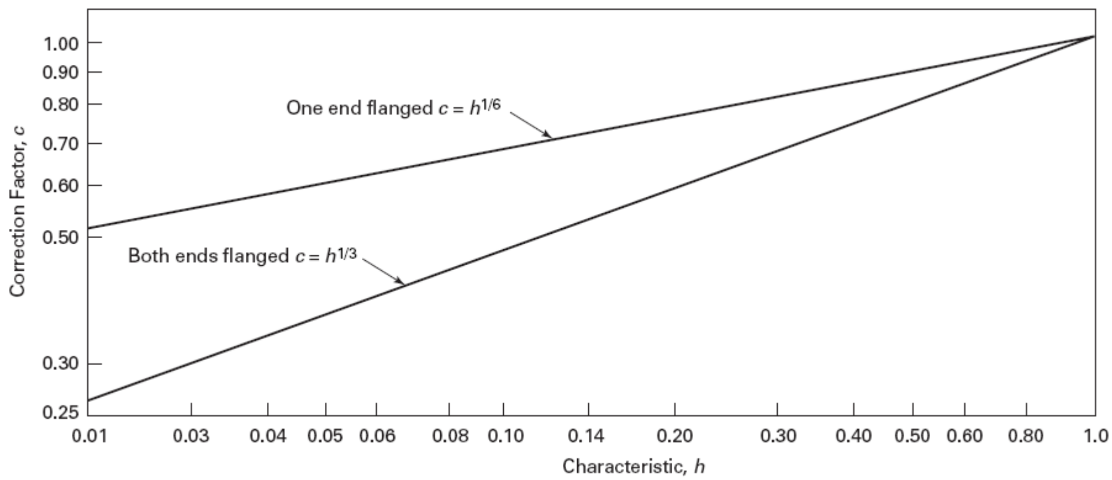


Chart D-2 Correction Factor, c



Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with I = 1.0 for bends from paras. IP-3.2.1 and IP-3.3.1 respectively.

$$P_a = \frac{2SEM_f t_a}{D - 2Yt_a}$$

where

P_a = allowable pressure

S = stress value for material from Table IX-1A in Appendix IX

E = quality factor from Table IX-2 or Table IX-3A in Appendix IX

M_f = material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C in Appendix IX.

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

d = inside diameter

Y = coefficient from Table IP-3.2.1, valid for $t_a < D/6$ for Ferritic and Austenitic steels. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE for all available materials.

$Y = \frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$ for all material types.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4a) and Eq. (4b) from para. IP-3.3.3.

$$P_a = minimum\left[\frac{SEM_f t_a (R - r)}{r(R - r/2)}, \frac{SEM_f t_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{r t_a}\right)}\right]$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. IP-3.3.3 as

$$P_a = \frac{SEM_f t_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{r t_a}\right)}$$

For widely spaced miter bends with θ > 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. IP-3.3.3 as

$$P_a = \frac{SEM_f t_a^2}{r\left(t_a + 1.25 \tan\theta \sqrt{r t_a}\right)}$$

where
r = mean radius of pipe = $(D - t_n)/2$
R = effective bend radius of the miter (see para. IP-3.3.3 (d) of code for definition) [an input in CAEPIPE for miters]
θ = angle of miter cut (see para. IP-3.3.3 of code for definition)

Sustained Stress

As per para. IP-6.2, the stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b), (23c) and (23d) from para. 320.2 of ASME B31.3 (2022) and compared against the allowable as stated in para. IP-2.2.10(c).

All paragraph numbers cited below are from the ASME B31.3 (2022) code, unless otherwise specified.

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \le S_h M_f$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = I_a\left[\frac{P\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10
D = outside diameter
t_S = wall thickness used for sustained stress calculation after deducting corrosion allowance from the nominal thickness
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 320.1
d = corroded inside diameter = $D - 2t_S$
A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 320.2
I_a = longitudinal force index = 1.0
F_a = longitudinal force due to sustained loads (pressure and weight)
R = axial force due to weight alone, where weight is computed using nominal thickness.
I_i = sustained in-plane moment index = $0.75i_i$ or 1.0, whichever is greater
I_o = sustained out-of-plane moment index = $0.75i_o$ or 1.0, whichever is greater
I_t = sustained torsional moment index = 1.0
M_i = in-plane bending moment due to sustained loads, e.g., pressure and weight
M_o = out-of-plane bending moment due to sustained loads, e.g., pressure and weight
M_t = torsional moment due to sustained loads, e.g., pressure and weight
Z_m = corroded section modulus as per para. 320.1
S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10}) from Table IX-1A in Appendix IX
i_i and i_o = in-plane and out-of-plane index from ASME B31J (2017) respectively

M_f = material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C in Appendix IX.

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. IP-2.2.11).

All paragraph numbers cited below are from the ASME B31.3 (2022) code, unless otherwise specified.

For temp ≤ 427^0 C or 800^0 F

$S_{LO} \leq 1.33 S_h M_f$ as per para. IP-2.2.11(a)

For temp > 427^0 C or 800^0 F *(see Note 2 below)*

$S_{LO} \leq 0.9 W S_y M_f$ as per IP-2.2.11(a)

where
$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b), (23c) and (23d) with applicable loads as per para. 302.3.6 (a).

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = I_a\left[\frac{\left(P_{peak} - P\right)\pi d^2/4}{A_p} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P

P = maximum of CAEPIPE input pressures P1 through P10
R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for other materials as per para. IP-2.2.11(a)
Z_m = corroded section modulus as per para. 320.1
M_f = material performance factor from Tables IX-5B and IX-5C in Appendix IX.
I_i and I_o = in-plane and out-of-plane index from ASME B31J (2017) respectively.

Notes:

1. When the field Yield strength is left BLANK or NOT input, then CAEPIPE will compute the Yield Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 1.5 (=3/2). This is because; the allowable stress for material below creep is generally 2/3 of Yield Strength.

2. The allowable stress equations for (S_{LO}) are taken from para. IP-2.2.11, ignoring the "wrongly-worded" last statement given in that paragraph namely *"At temperatures warmer than 427 deg. C (800 deg.F), use 1.33.Sh.M_f"*

Expansion Stress

The stress (S_E) due to thermal expansion is calculated according to Equation 17 of Paragraph 319.4.4 of the ASME B31.3 (2022) code, as referenced in Paragraphs IP-6.1 and IP-2.2.10(d). All paragraph numbers cited below are from the ASME B31.3 (2022) code, unless otherwise specified.

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \le S_A$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.
i_a= axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ for other components as per ASME B31J (2017)
F_a = range of axial force between any two thermal conditions being evaluated
i_i = in-plane stress intensification factor (SIF) as per ASME B31J (2017); shall not be < 1.0
i_o = out-of-plane SIF as per ASME B31J (2017); shall not be < 1.0
i_t = torsional SIF as per ASME B31J (2017); shall not be < 1.0
M_i = in-plane bending moment range between any two conditions being evaluated
M_o = out-of-plane bending moment range between any two conditions being evaluated
M_t = torsional moment range between any two conditions being evaluated
Z = un-corroded section modulus as per para. 319.3.5 and para. 319.4.4 (a)
$S_A = f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)
f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $20(N)^{-0.333}$ <= f_m & f >= 0.15
f_m = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths <= 75 ksi) and at metal temperatures <=700° F; otherwise $f_m = 1.0$

N = equivalent number of full displacement cycles expected during service of piping. This full displacement cycles (N) shall be increased by a factor of 10 for carbon and low alloy steels and other materials that are susceptible to Hydrogen Embrittlement (HE) as per para. IP-2.2.10(d), **irrespective of their design temperatures**.

S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

when S_h is greater than S_L, the allowable stress range may be calculated as

$S_A = f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d). This equation can be re-written as

$S_A = f(1.25S_C + 0.25S_h) + f(S_h - S_L)$ (see **Note 3** below)

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout > Options > Analysis > Code tab.

Notes:

1. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).

2. Refer to the end of this appendix for the details of "Thickness and Section Modulus used for weight, allowable pressure and stress calculations".

3. Para. 302.3.5 provides maximum value of S_c and S_h as 138 MPa (20 ksi). The reason for this criterion is explicitly stated in Note 2 of para. 102.3.5 (b) (1) of ASME B31.1 (2022) as given here *"For materials with a minimum tensile strength of over 70 ksi (480 MPa), eqs. (1a) and (1b) shall be calculated using Sc or Sh values no greater than 20 ksi (140 MPa), unless otherwise justified."*

   Compliance to this criterion is checked using the value entered under Tensile Strength field of CAEPIPE Material property input. If this Tensile Strength field is NOT entered or left BLANK, then CAEPIPE will compute the Tensile Strength of the material by multiplying the Allowable Stress at the minimum temperature (at which the material properties are entered in CAEPIPE stress model) with a factor of 3.5. This is because, the allowable stress for material below creep is generally 1/3.5 of Tensile Strength as stated in Section 1-100 of Mandatory Appendix 1 of ASME Section II, Part D.

   For example, if the allowable stress is 22,000 psi for a high strength material at the minimum temperature of -20 deg. F, then the Tensile Strength would be 22,000 x 3.5 = 77,000 psi. So, in this case, CAEPIPE will internally set the values of both S_c and S_h as 20,000 psi as Tensile Strength is greater than 70,000 psi.

   In addition, if the option "Use Liberal allowable stresses" is turned ON through Layout Window > Options > Analysis > Code, then if the left over Sustained stress (= S_h - S_L) is positive, CAEPIPE will multiply this positive left over Sustained stress by the Stress range reduction factor (f) and add that resulting value to the Expansion allowable stress computed using the above equation (1a).

4. Para. 319.2.1(c), implies that wind sway at a piping support (e.g., piping supported from a tall slender tower) could be considered as an imposed thermal displacement at that

support. Since CAEPIPE allows up to 10 thermal loads, the question arises "under which thermal load should this wind sway to be included". Hence, we recommend that wind sway is to be input as a part of "wind displacement under occasional stress condition".

Notes on Material Library for B3112-2023.mat supplied with CAEPIPE:

1. Material library for ASME B31.12 (2023) [B3112-2023.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix IX of ASME B31.12 (2023).
2. **Coefficient of Thermal Expansion:** Coefficient of Thermal Expansion data are entered by referring to the values provided in Table C-1 of Appendix C of ASME B31.3 (2022).
3. **Modulus of Elasticity:** Modulus of Elasticity data are entered by referring to the values provided in Table C-6 of Appendix C of ASME B31.3 (2022).
4. **Longitudinal Joint Factor:** Longitudinal Joint Factors are entered by referring to the values specified in Table IX-3A of ASME B31.12 (2023).

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure

[Sl. Nos. 1 & 2 below are from Table IP-3.2.1 and Sl. Nos. 3, 4 & 5 are from Table 304.1.1 of ASME B31.3 (2022)]

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Carbon Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as "CS" (from Table IX-5B)

Sl. No.	Specified Min. Yield Strength (ksi)	Materials Performance Factor (M_f) System Design Pressure, psig					
		<=1000	2000	3000	4000	5000	6000
1.	<= 52	1.000	0.948	0.912	0.884	0.860	0.839
2.	<= 56	0.930	0.881	0.848	0.824	0.800	0.778
3.	<= 65	0.839	0.796	0.766	0.745	0.724	0.706
4.	<= 80	0.715	0.678	0.645	0.633	0.618	0.600

Low and Intermediate Alloy Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as "AS" (from Table IX-5C)

Sl. No.	Specified Min. Tensile Strength (ksi)	Materials Performance Factor (M_f)						
		System Design Pressure, psig						
		0.000	1000	2000	3000	4000	5000	6000
1.	<= 35	1.000	0.918	0.881	0.875	0.836	0.815	0.800
2.	<= 45	0.791	0.724	0.696	0.675	0.660	0.642	0.630
3.	<= 60	0.655	0.601	0.577	0.561	0.547	0.533	0.524
4.	<= 65	0.580	0.532	0.511	0.497	0.485	0.472	0.464

Note:

For materials not covered by Tables given above, Material Performance Factor (M_f) is taken as 1.00.

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with I = 1.0 for bends from paras. IP-3.2.1 and IP-3.3.1.respectively.

$$P_a = \frac{2SEM_f t_a}{D - 2Yt_a}$$

where

P_a= allowable pressure

S = stress value for material from Table IX-1A

E = quality factor from Table IX-2 or Table IX-3A

M_f= material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

d= inside diameter

Y= coefficient from Table IP-3.2.1, valid for $t_a < D/6$ for Ferritic and Austenitic steels. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE for all available materials.

$Y = \frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$ for all material types.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4b) from para. IP-3.3.3.

$$P_a = \frac{SEM_f t_a (R - r)}{r(R - r/2)}$$

For widely spaced miter bends with θ<= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. IP-3.3.3 as

$$P_a = \frac{SEM_f t_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{rt_a}\right)}$$

For widely spaced miter bends with θ> 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. IP-3.3.3 as

$$P_a = \frac{SEM_f t_a^2}{r\left(t_a + 1.25 \tan\theta \sqrt{r t_a}\right)}$$

where

r = mean radius of pipe = (D- t_n)/2

R = effective bend radius of the miter (see para. IP-3.3.3 (d) of code for definition) [an input in CAEPIPE for miters]

θ = angle of miter cut (see para. IP-3.3.3 of code for definition)

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) from para. 320.2 of ASME B31.3 (2018) and compared against the allowable provided in para. IP-2.2.10.

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \le S_h M_f$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

For branch (Leg 3 in Fig. 319.4.4B) of ASME B31.3 (2018),

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_S = wall thickness used for sustained stress calculation obtained by deducting corrosion allowance from the nominal thickness

t_S = nominal thickness - corrosion allowance in CAEPIPE, as per para. 320.1 of ASME B31.3 (2018)

A_p = <u>corroded</u> cross-sectional area of the pipe computed using t_s as per para. 320.1of ASME B31.3 (2018)

I_a =longitudinal force index = 1.0

F_a = longitudinal force due to sustained loads such as pressure and weight

R = axial force due to weight alone, where weight is computed using nominal thickness.

I_i = sustained in-plane moment index = $0.75 i_i$ or 1.0, whichever is greater.

I_o = sustained out-of-plane moment index = $0.75 i_o$ or 1.0, whichever is greater.

where, i_i and i_o are taken from Appendix D of ASME B31.3 (2018) [reprinted at the end of this Section] or from B31J (2017) when the option "Use B31J for SIFs and Flexibility Factors" is Turned ON.

I_t = torsional moment index = 1.0

M_i = in-plane bending moment due to sustained loads such as pressure and weight

M_o = out-of-plane bending moment due to sustained loads such as pressure and weight

M_t = torsional moment due to sustained loads such as pressure and weight

Z_m = corroded section modulus as per para. 320.1 of ASME B31.3 (2018)

Z_e = effective corroded section modulus for branch as per para.320.2 of ASME B31.3 (2018) when Appendix D of ASME B31.3 is used to compute Stress Intensification Factors (SIFs) (or) corroded section modulus when B31J is used to compute to compute SIFs.

M_f = material performance factor that addresses loss of material properties associated withhydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. IP-2.2.11).

For temp ≤ 427^0 C or 800^0 F(see Note 1 below)

$$S_{LO} \leq 1.33 S_h M_f$$

For temp > 427^0 C or 800^0 F

$$S_{LO} \leq 0.9 W S_y M_f$$

where

$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) of ASME B31.3 (2018) with applicable loads.

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = \left[\frac{(P_{peak} - P)D}{4t_s} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

For branch (Leg 3 in Fig. 319.4.4B) of ASME B31.3 (2018)

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P
P = maximum of CAEPIPE input pressures P1 through P10

R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t = torsional moment due to occasional loads such as earthquake or wind
S_y = yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for other materials as per para. IP-2.2.11(a)
Z_m = corroded section modulus as per para. 320.1 of ASME B31.3 (2018)
Z_e= effective corroded section modulus for branch as per para.320.2 of ASME B31.3 (2018) when Appendix D of ASME B31.3 is used to compute Stress Intensification Factors (SIFs) (or) corroded section modulus when B31J is used to compute to compute SIFs.

Note 1:

The allowable stress equations for (S_{LO})are taken from para. 302.3.6 of ASME B31.3 (2018), as the sentence "At temperatures warmer than 427 deg. C (800 deg.F), use 1.33.Sh.M_f" in para. IP-2.2.11 of ASME B31.12 (2019) code seems to be incorrectly worded.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. IP-6.1.5. The Axial Stress term (S_a) is included in Expansion Stress calculation as per Eq. 17 of para. 319.4.4 of ASME B31.3 (2018) code.

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

For branch (Leg 3 in Fig. IP-6.1.5-2)

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_e}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A =un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D as per IP-6.1.4 (e).
i_a=axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o \; or \; i$ for other components as listed in Appendix D of B31.3 (2018)
F_a=range of axial force due to displacement strains between any two thermal conditions being evaluated
i_i= in-plane stress intensification factor from Appendix D of ASME B31.3 (2018) or from B31J (2017) when the option "Use B31J for SIFs and Flexibility Factors" is Turned ON. $i_i$shallnot be less than 1.0.
i_o=out-of-plane stress intensification factor Appendix D of ASME B31.3 (2018) or from B31J (2017) when the option "Use B31J for SIFs and Flexibility Factors" is Turned ON. $i_o$shallnot be less than 1.0.
i_t=torsional stress intensification factor = 1.0
M_i=in-plane bending moment
M_o=out-of-plane bending moment
M_t=torsional moment
Z=un-corroded section modulus as per IP-6.1.4 (e)
Z_e=un-corroded effective section modulus as per IP-6.1.4 (e)

S_A=$f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. IP-2.2.10 (d)
f=stress range reduction factor from Eq. (1c) of para. IP-2.2.10 (d) = $6N^{-0.2}$
where f ≥ 0.15 and f ≤ 1.0 (see Note 1 below)
S_C=basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h=basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis
When S_h is greater than Sustained Stress S_L, the allowable stress range may be calculated as
$S_A \;\; = \;\; f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. IP-2.2.10 (d).

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout > Options > Analysis > Code tab.

Notes:

1. As per para. IP-2.2.10 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.
2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. IP-6.1.5 (d)(1).
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Notes on Material Library for B3112-2019.mat supplied with CAEPIPE:

5. Material library for ASME B31.12 (2019) [B3112-2019.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix IX of ASME B31.12 (2019).
6. **Coefficient of Thermal Expansion:** Coefficient of Thermal Expansion data are entered by referring to the values provided in Table C-1 of Appendix C of ASME B31.3 (2018).
7. **Modulus of Elasticity:** Modulus of Elasticity data are entered by referring to the values provided in Table C-6 of Appendix C of ASME B31.3 (2018).
8. **Longitudinal Joint Factor:** Longitudinal Joint Factor are entered by referring to the values specified in Table IX-3A of ASME B31.12 (2019).

Stress Intensification Factor (SIF) values for B31.12 (2019) are referred from Appendix D of B31.3 (2018). The same is provided below for details.

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

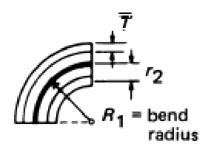
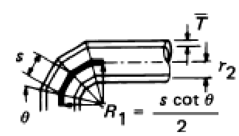
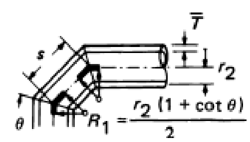
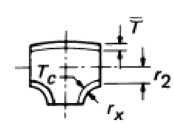
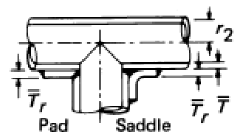
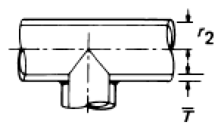
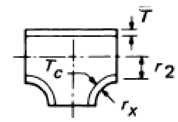
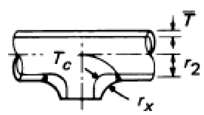
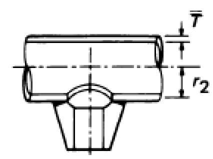
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2 (1 + \tan \theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1 \frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5} r_2}$	

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\overline{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$, $T_c < 1.5\ \overline{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\overline{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1\ \frac{\overline{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\ \frac{\overline{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

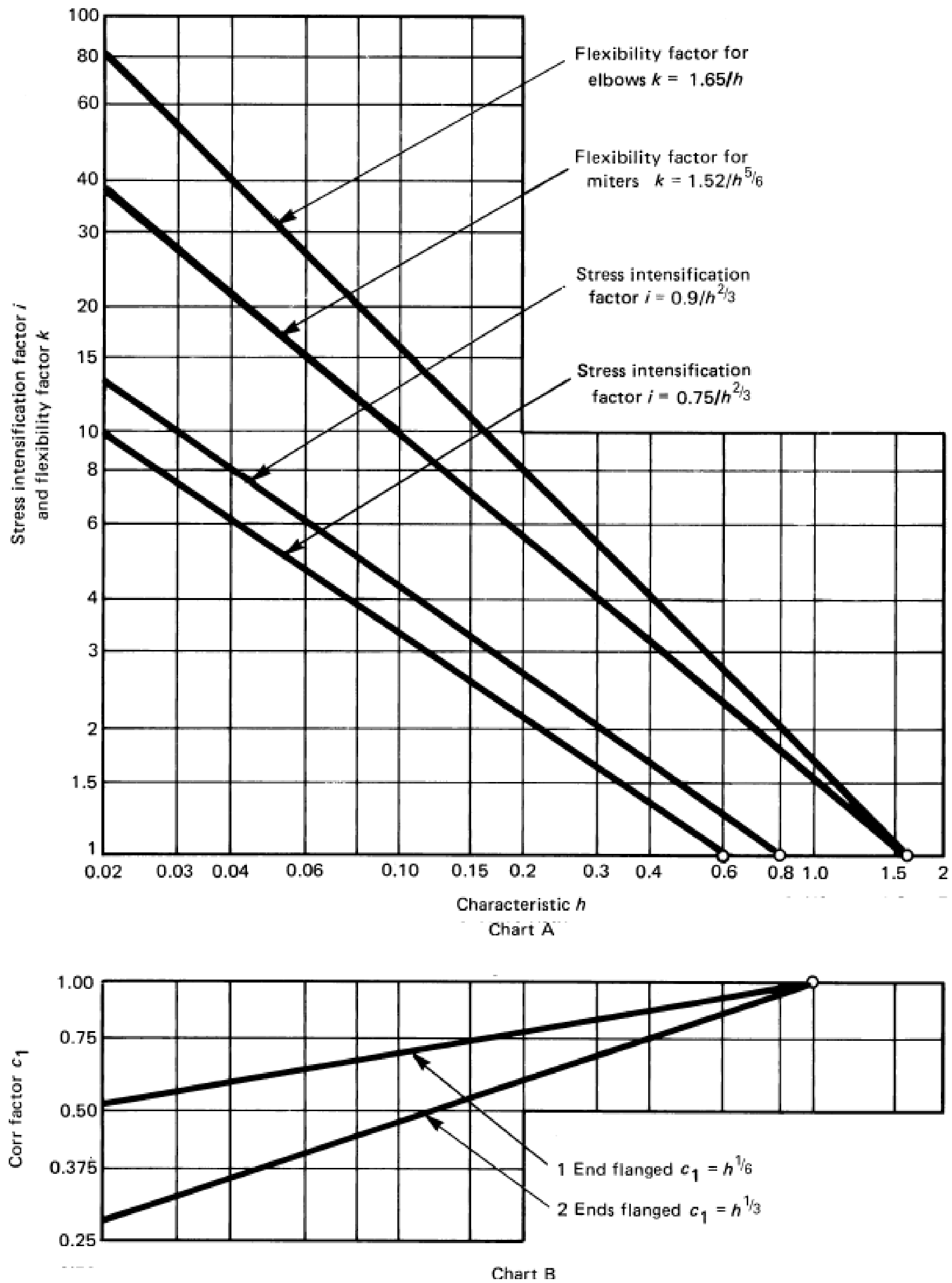


Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd) (14)

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\overline{T} \leq 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\overline{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\overline{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5\overline{T}$, a flexibility characteristic of $4.4\ \overline{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\overline{T}_r$ is $> 1\frac{1}{2}\ \overline{T}$, use $h = 4\ \overline{T}/r_2$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure

[Sl. Nos. 1 & 2 below are from Table IP-3.2.1 and Sl. Nos. 3, 4 & 5 are from Table 304.1.1 of ASME B31.3 (2018)]

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Carbon Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as "CS" (from Table IX-5B)

Sl. No.	Specified Min. Yield Strength (ksi)	System Design Pressure, psig					
		<=1000	2000	3000	4000	5000	6000
1.	<= 52	1.000	0.948	0.912	0.884	0.860	0.839
2.	<= 56	0.930	0.881	0.848	0.824	0.800	0.778
3.	<= 65	0.839	0.796	0.766	0.745	0.724	0.706
4.	<= 80	0.715	0.678	0.645	0.633	0.618	0.600

Low and Intermediate Alloy Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as "AS" (from Table IX-5C)

Sl. No.	Specified Min. Tensile Strength (ksi)	System Design Pressure, psig						
		0.000	1000	2000	3000	4000	5000	6000
1.	<= 35	1.000	0.918	0.881	0.875	0.836	0.815	0.800
2.	<= 45	0.791	0.724	0.696	0.675	0.660	0.642	0.630
3.	<= 60	0.655	0.601	0.577	0.561	0.547	0.533	0.524
4.	<= 65	0.580	0.532	0.511	0.497	0.485	0.472	0.464

Note:
For materials not covered by Tables given above, Material Performance Factor (M_f) is taken as 1.00.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. PL-3.7.1.

$$P = \frac{2SEt_nFTH_f}{D}$$

where

P = allowable pressure

S = specified minimum yield strength from para. PL-3.7.1 (a)

E = longitudinal joint factor (input as material property), obtained from Table IX-3B of Appendix IX

t_n = nominal pipe thickness

D = nominal outside diameter of pipe

F = construction location design factor, obtained from Table PL-3.7.1-1 (for Option A) and Table PL-3.7.1-2 (for Option B)

T = temperature derating factor, obtained from Table PL-3.7.1.3

H_f = material performance factor from Mandatory Appendix IX, Table IX-5A. H_f given in Table IX-5A is applied only for Design Factors corresponding to Option A – Prescriptive Design Method. For Design Factors corresponding to Option B – Performance-based Design Method, H_f is set as 1.0 internally. Design Factor can be selected in CAEPIPE through Layout Window > Options > Analysis > Code.

Stress due to Sustained & Occasional Loads [Unrestrained (above ground) Piping]

The sum of longitudinal stress due to internal pressure and due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, occasional loads such as seismic or wind, etc. is calculated according to paras. PL-2.6.5 (a) and PL-2.6.5 (b) along with paras. PL-2.6.2 (b), PL-2.6.2 (d), PL-2.6.2 (e) and PL-2.6.2 (f). Wind and Seismic is not considered to act concurrently.

Note:

The “include axial force in stress calculations” option is turned ON by default for ASME B31.12 PL in CAEPIPE.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

For other Fittings and Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO}} = \mathbf{S_L} + \left|\frac{(\mathbf{P_{peak}} - \mathbf{P})\mathbf{D}}{\mathbf{4t_n}} + \frac{\mathbf{R}}{\mathbf{A}}\right|_{\mathbf{occasional}} + \left[\frac{\sqrt{(\boldsymbol{M_i})^2 + (\boldsymbol{M_o})^2 + (\boldsymbol{M_t})^2}}{\mathbf{Z}}\right]_{\mathbf{occasional}} \leq \mathbf{0.75ST}$$

For other Fittings and Components

$$S_{LO(fc)} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where
P = maximum operating pressure = max (P_1 through P_{10})
P_{peak} = Peak pressure factor x P
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor from Appendix E of ASME B31.8 (2022); the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor from Appendix E of ASME B31.8 (2022); the product $0.75i_o$ shall not be less than 1.0
M_i = in-plane bending moment due to weight and external loads
M_o= out-of-plane bending moment due to weight and external loads
M_t= torsional moment due to weight and external loads
Z = un-corroded section modulus; for reduced outlets, effective section modulus
R = axial force component for external loads (other than due to thermal expansion and pressure)
A = un-corroded pipe metal cross-section area
S = specified minimum yield strength from para. PL-3.7.1 (a)
T= temperature derating factor, obtained from Table PL-3.7.1-3

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with paras. PL-2.5.3 (g) and PL-2.5.4 (b).

Expansion Stress [Unrestrained (above ground) Piping]

The stress (S_E) due to thermal expansion is calculated from para. PL-2.6.7, which in turn, refers to para. IP-2.2.10.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$

M_i = in-plane bending moment due to thermal expansion
M_o = out-of-plane bending moment due to thermal expansion
M_t = torsional moment due to thermal expansion
Z = un-corroded section modulus; for reduced outlets, effective section modulus
$S_A = f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)
f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) of ASME B31.3 (2022) = $20(N)^{-0.333}$ <= f_m & f >= 0.15
f_m = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths <= 75 ksi) and at metal temperatures <=700° F; otherwise $f_m = 1.0$
N = equivalent number of full displacement cycles expected during service of piping. This full displacement cycles (N) shall be increased by a factor of 10 for carbon and low alloy steels and other materials that are susceptible to Hydrogen Embrittlement (HE) as per para. IP-2.2.10(d), **irrespective of their design temperatures**.
S_L = sustained stress computed as per equation given above
S_C = 0.33SuT at the minimum installed or operating temperature
S_h = 0.33SuT at the maximum installed or operating temperature

where
S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and
S_y = specified minimum yield strength as per para. PL-3.7.1 (a)
T = temperature derating factor from Table PL-3.7.1.3

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [= min(T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with paras. PL-2.5.3 (g) and PL-2.5.4 (b).

Sustained, Thermal & Occasional Stress [Restrained (buried) Piping]

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. PL-2.6.3 (a), PL-2.6.3 (b) along with paras. PL-2.6.2 (a), PL-2.6.2 (c), PL-2.6.2 (d), PL-2.6.2 (e) and PL-2.6.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per PL-2.6.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.
where
$S_p = 0.3S_H = 0.3\frac{PD}{2t_n}$ = longitudinal stress due to internal pressure in restrained pipeline

S_H = hoop stress = $\frac{PD}{2t_n}$ as per para. PL-2.6.2 (a)

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha_m(T_m - T_i)$ (see Note 1 below)

S_X = stress due to axial loading (other than thermal expansion and pressure) $= \frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads (other than thermal expansion)

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}$$

For other Fittings and Components.

$$S_B = \frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}$$

As per para PL-2.6.3 (a), note that S_B,S_L, S_T or S_X can be positive or negative

where
P = maximum operating pressure = max(P1 through P10)
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment due to weight and other external loads (other than thermal expansion)
M_o = out-of-plane bending moment due to weight and other external loads (other than thermal expansion)
M_t = torsional moment due to weight and other external loads (other than thermal expansion)
R = axial force from weight and external loads (other than due to thermal expansion and pressure)
A = un-corroded pipe metal cross-sectional area (i.e., before deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. PL-3.7.1 (a)
T = Temperature derating factor from Table PL-3.7.1-3
E = Young's modulus at ambient temperature, i.e., at T_{ref} in CAEPIPE
T_i = installation temperature = T_{ref} in CAEPIPE (see Note 1 below)
T_m = warmest or coldest operating temperature (see Note 1 below)
α_m = coefficient of thermal expansion at T_0 in CAEPIPE (see Note 1 below)

Note 1:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress S_T due to thermal expansion as follows.

For a change in temperature from T_{ref} to T_1, $S_{T1} = -E\alpha_1(T_1 - T_{ref})$

For a change in temperature from T_{ref} to T_2, $S_{T2} = -E\alpha_2(T_2 - T_{ref})$

For a change in temperature from T_1 to T_2, $S_{T1->T2} = S_{T2} - S_{T1}$

Please note, that negative (-) sign is added in the above equations as the soil is restraining the thermal expansion / contraction of the buried pipe due to friction at the soil-to-pipe interface.

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE as per para. PL-2.6.4. To be conservative, S_{eq1} and S_{eq2} given below are in line with para. 833.4 of ASME B31.8 (2022).

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where

S_{eq} = equivalent combined stress

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

Notes:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix in accordance with paras. PL-2.5.3 (g) and PL-2.5.4 (b).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
3. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, turn ON the analysis option "Combine stresses as per Max. Distortion Energy Theory" through Layout Window > Options > Analysis > Code.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i*

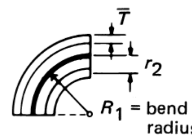
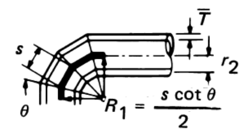
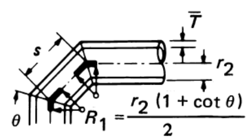
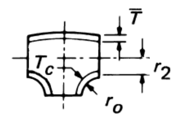
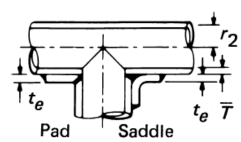
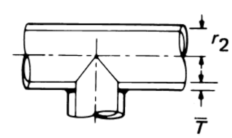
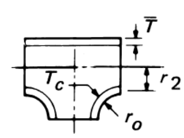
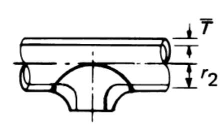
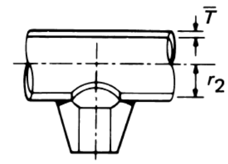
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1), (2)] Out-Plane, i_o	Stress Intensification Factor, i [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Illustration
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^{\,2}}$	
Closely spaced miter bend $s < r_2\,(1 + \tan\theta)$ [Notes (1), (2), (3), (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\,\frac{\bar{T}s}{r_2^{\,2}}$	
Single miter bend or widely spaced miter bend $s \geq r_2\,(1 + \tan\theta)$ [Notes (1), (2), (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\,\frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq d/8$ $T_c \geq 1.5\bar{T}$ [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$\frac{\left(\bar{T} + \frac{1}{2}t_e\right)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5\,\bar{T}$ [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_0}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq d/8$ $T_c \geq 1.5\bar{T}$ [Notes (1), (2), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, *k*	Stress Intensification Factor, *i* [Notes (1), (2)] Out-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, *h*	Illustration
Branch welded-on fitting (integrally reinforced) in accordance with MSS SP-97 [Notes (1), (2), (9), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\overline{T}}{r_2}$	

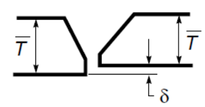
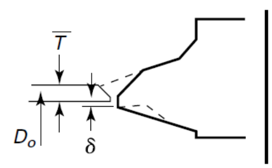
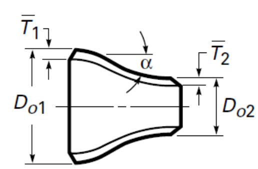
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Illustration
Butt weld [Notes (1), (12)]			
$\overline{T}$ ≥ 0.237 in. (6.02 mm), δ_{max} ≤ 1/16 in. (1.59 mm), and $\delta_{avg}/\overline{T}$ ≤ 0.13	1	1.0	
$\overline{T}$ ≥ 0.237 in. (6.02 mm), δ_{max} ≤ 1/8 in. (3.18 mm), and $\delta_{avg}/\overline{T}$ = any value	1	1.9 max. or [0.9 + 2.7($\delta_{avg}/\overline{T}$)], but not less than 1.0	
$\overline{T}$ ≤ 0.237 in. (6.02 mm), δ_{max} ≤ 1/16 in. (1.59 mm), and $\delta_{avg}/\overline{T}$ ≤ 0.33			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{\overline{T}} + 3.6\frac{\delta}{\overline{T}}$	
Concentric reducer per ASME B16.9 [Notes (1), (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_{o2}}{\overline{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14), (15)]	1	2.1 max. or 2.1 $\overline{T}/C_x$ but not less than 1.3	
Lap joint flange (with vASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

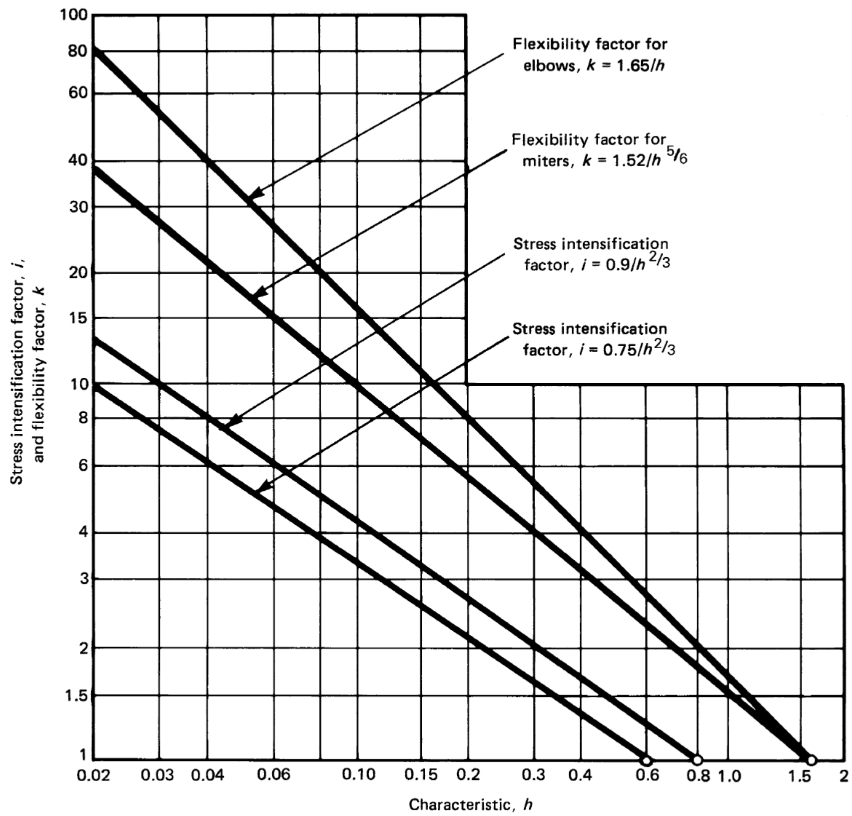


Chart A

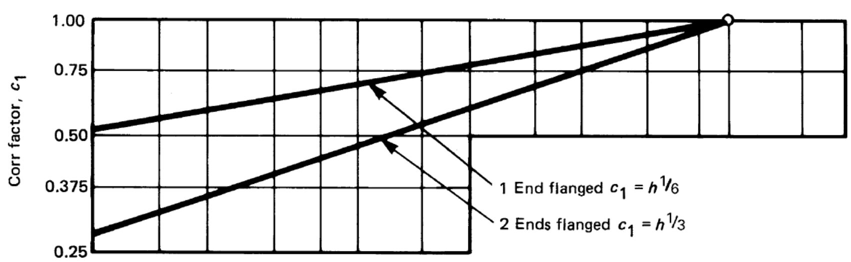


Chart B

GENERAL NOTE: The stress intensification and flexibility factors from ASME B31J may be used instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of in-plane (i_i) and out-plane (i_o) stress intensification factors shall be used in calculating stresses in accordance with para. 833.2 or para. A842.2.2. Alternatively, stress intensification factors and branch connection flexibility factors may be developed using ASME B31J, Nonmandatory Appendix A.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES:
(1) The nomenclature is as follows:

D_O = outside diameter, in. (mm)
d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_O = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\overline{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, k, applies to bending in any plane. The flexibility factors, k, and stress intensification factors, i, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends and to the intersection point for tees. The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed h.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the table, divide k by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide i by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where
E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + {}^1\!/_4$, respectively.

(7) When $t_e > 1\frac{1}{2}T$, use $h = 4.05T/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + {}^1\!/_4$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + {}^1\!/_4$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the nominal wall thicknesses are between $0.875\overline{T}$ and $1.10\overline{T}$ for an axial distance of $\sqrt{D_0\overline{T}}$. D_0 and $\overline{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met:
(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.
(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.
(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES: (Cont'd)

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\left(S_b A_b - P A_p\right)$$

where

A_b = total area of flange bolts, in.^{2} (mm^3)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. PL-3.7.1.

$$P = \frac{2SEt_nFTH_f}{D}$$

where
P = allowable pressure
S = specified minimum yield strength from para. PL-3.7.1 (a)
E = longitudinal joint factor (input as material property), obtained from Table IX-3B of Appendix IX
t_n = nominal pipe thickness
D = nominal outside diameter of pipe
F = construction location design factor, obtained from Table PL-3.7.1-1 (for Option A) and Table PL-3.7.1-2 (for Option B)
T = temperature derating factor, obtained from Table PL-3.7.1.3
H_f = material performance factor from Mandatory Appendix IX, Table IX-5A. H_f given in Table IX-5A is applied only for Design Factors corresponding to Option A – Prescriptive Design Method. For Design Factors corresponding to Option B – Performance-based Design Method, H_f is set as 1.0 internally. Design Factor can be selected in CAEPIPE through Layout Window > Options > Analysis > Code.

Stress due to Sustained & Occasional Loads [Unrestrained (above ground) Piping]

The sum of longitudinal stress due to internal pressure and due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, occasional loads such as seismic or wind, etc. is calculated according to paras. PL-2.6.5 (a) and PL-2.6.5 (b) along with paras. PL-2.6.2 (b), PL-2.6.2 (d), PL-2.6.2 (e) and PL-2.6.2 (f). Wind and Seismic is not considered to act concurrently.

Note:

The "include axial force in stress calculations" option is turned ON by default for ASME B31.12 PL in CAEPIPE.

Sustained Stress S_L:

For Pipes and Long Radius Bends

$$S_L = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

For other Fittings and Components.

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{R}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \leq 0.75ST$$

Sustained + Occasional Stress S_{LO}:

For Pipes and Long Radius Bends

$$\mathbf{S_{LO}} = \mathbf{S_L} + \left|\frac{(\mathbf{P_{peak}} - \mathbf{P})\mathbf{D}}{\mathbf{4t_n}} + \frac{\mathbf{R}}{\mathbf{A}}\right|_{\mathbf{occasional}} + \left[\frac{\sqrt{(\boldsymbol{M_i})^2 + (\boldsymbol{M_o})^2 + (\boldsymbol{M_t})^2}}{\mathbf{Z}}\right]_{\mathbf{occasional}} \leq \mathbf{0.75ST}$$

For other Fittings and Components

$$S_{LO(fc)} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.75ST$$

where
P = maximum operating pressure = max (P_1 through P_{10})
P_{peak} = Peak pressure factor x P
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o= out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment due to weight and external loads
M_o= out-of-plane bending moment due to weight and external loads
M_t= torsional moment due to weight and external loads
Z = un-corroded section modulus; for reduced outlets, effective section modulus
R = axial force component for external loads (other than due to thermal expansion and pressure)
A = un-corroded pipe metal cross-section area
S = specified minimum yield strength from para. PL-3.7.1 (a)
T= temperature derating factor, obtained from Table PL-3.7.1-3

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with paras. PL-2.5.3 (g) and PL-2.5.4 (b).

Expansion Stress [Unrestrained (above ground) Piping]

The stress (S_E) due to thermal expansion is calculated from para.PL-2.6.7, which. In turn, refers to para. IP-2.2.10.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq S_A$$

where
S_b = resultant bending stress = $\frac{\sqrt{(i_iM_i)^2+(i_oM_o)^2}}{Z}$
S_t = torsional stress = $\frac{M_t}{2Z}$
M_i = in-plane bending moment due to thermal expansion

M_o= out-of-plane bending moment due to thermal expansion
M_t= torsional moment due to thermal expansion
Z = un-corroded section modulus; for reduced outlets, effective section modulus
$S_A = f[1.25(S_C + S_h) - S_L]$, which is eq. (1b) in para. IP-2.2.10 (d)
f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles, where $f \leq 1.0$ (eq. 1(c) from para. PL-2.2.10 (d)). See Note 2 below.
S_L = sustained stress computed as per equation given above
S_C = 0.33SuT at the minimum installed or operating temperature
S_h = 0.33SuT at the maximum installed or operating temperature
where
S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and
S_y = specified minimum yield strength as per para. PL-3.7.1 (a)
T = temperature derating factor from Table PL-3.7.1.3

Note:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [= min(T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with paras. PL-2.5.3 (g) and PL-2.5.4 (b).
2. As per para. IP-2.2.10 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.

Sustained, Thermal & Occasional Stress [Restrained (buried) Piping]

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. PL-2.6.3 (a), PL-2.6.3 (b) along with paras. PL-2.6.2 (a), PL-2.6.2 (c), PL-2.6.2 (d), PL-2.6.2 (e) and PL-2.6.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per PL-2.6.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.
where

$S_p = 0.3S_H = 0.3\frac{PD}{2t_n}$ = longitudinal stress due to internal pressure in restrained pipeline

S_H = hoop stress = $\frac{PD}{2t_n}$ as per para. PL-2.6.2 (a)

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha_m(T_m - T_i)$ (see Note 1 below)

S_X = stress due to axial loading (other than thermal expansion and pressure) $= \frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads (other than thermal expansion)

For Pipes and Long Radius Bends

$$S_B = \frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z}$$

For other Fittings and Components.

$$S_B = \frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}$$

As per para PL-2.6.3 (a), note that S_B,S_L, S_T *or* S_X can be positive or negative

where

P = maximum operating pressure = max(P1 through P10)
D = outside diameter
t_n = nominal thickness
i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
i_o = out-of-plane stress intensification factor; the product $0.75i_o$shall not be less than 1.0
M_i = in-plane bending moment due to weight and other external loads (other than thermal expansion)
M_o = out-of-plane bending moment due to weight and other external loads (other than thermal expansion)
M_t = torsional moment due to weight and other external loads (other than thermal expansion)
R = axial force from weight and external loads (other than due to thermal expansion and pressure)
A = un-corroded pipe metal cross-sectional area (i.e., before deducting for corrosion)
Z = un-corroded section modulus; for reduced outlets, effective section modulus
S = Specified Minimum Yield Strength (SMYS) from para. PL-3.7.1 (a)
T = Temperature derating factor from Table PL-3.7.1-3
E = Young's modulus at ambient temperature, i.e., at T_{ref} in CAEPIPE
T_i = installation temperature = T_{ref} in CAEPIPE (see Note 1 below)
T_m = warmest or coldest operating temperature (see Note 1 below)
α_m = coefficient of thermal expansion at T_0 in CAEPIPE (see Note 1 below)

Note 1:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress S_T due to thermal expansion as follows.

For a change in temperature from T_{ref} to T_1, $S_{T1} = -E\alpha_1(T_1 - T_{ref})$

For a change in temperature from T_{ref} to T_2, $S_{T2} = -E\alpha_2(T_2 - T_{ref})$

For a change in temperature from T_1 to T_2, $S_{T1-.>T2} = S_{T2} - S_{T1}$

Please note, that negative (-) sign is added in the above equations as the soil is restraining the thermal expansion / contraction of the buried pipe due to friction at the soil-to-pipe interface.

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE as per para. PL-2.6.4. To be conservative, S_{eq1} and S_{eq2} given below are in line with para. 833.4 of ASME B31.8.

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where

S_{eq} = equivalent combined stress

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

Notes:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10},T_{ref})] is used to form the stiffness matrix in accordance with paras. PL-2.5.3 (g) and PL-2.5.4 (b).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
3. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, turn ON the analysis option "Combine stresses as per Max. Distortion Energy Theory" through Layout Window > Options > Analysis > Code.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i*

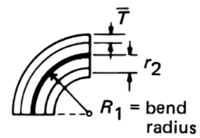
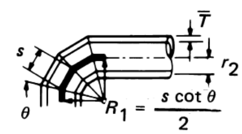
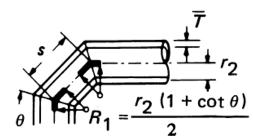
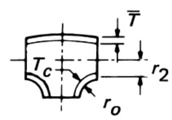
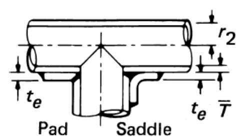
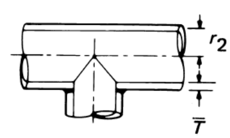
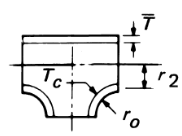
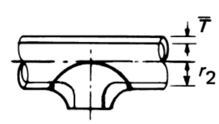
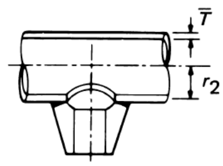
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1), (2)] Out-Plane, i_o	Stress Intensification Factor, i [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Illustration
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^{\,2}}$	
Closely spaced miter bend $s < r_2\,(1 + \tan\theta)$ [Notes (1), (2), (3), (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\,\frac{\bar{T}s}{r_2^{\,2}}$	
Single miter bend or widely spaced miter bend $s \geq r_2\,(1 + \tan\theta)$ [Notes (1), (2), (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\,\frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq d/8$, $T_c \geq 1.5\bar{T}$ [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$\frac{\left(\bar{T} + \frac{1}{2}t_e\right)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$, $T_c < 1.5\,\bar{T}$ [Notes (1), (2), (6)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_0}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq d/8$, $T_c \geq 1.5\bar{T}$ [Notes (1), (2), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}\,i_o + \frac{1}{4}$	$4.4\frac{\bar{T}}{r_2}$	

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1), (2)] Out-Plane, i_o	Stress Intensification Factor, i [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Illustration
Branch welded-on fitting (integrally reinforced) in accordance with MSS SP-97 [Notes (1), (2), (9), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\bar{T}}{r_2}$	

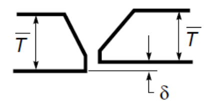
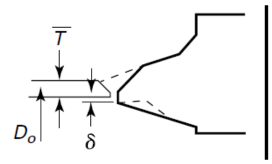
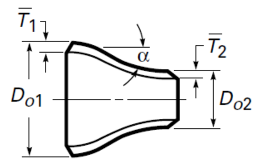
Description	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Butt weld [Notes (1), (12)] $\bar{T} \geq$ 0.237 in. (6.02 mm), $\delta_{max} \leq$ ¹⁄₁₆ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
$\bar{T} \geq$ 0.237 in. (6.02 mm), $\delta_{max} \leq$ ⅛ in. (3.18 mm), and $\delta_{avg}/\bar{T}$ = any value $\bar{T} \leq$ 0.237 in. (6.02 mm), $\delta_{max} \leq$ ¹⁄₁₆ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$	1	1.9 max. or [$0.9 + 2.7(\delta_{avg}/\bar{T})$], but not less than 1.0	
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{\bar{T}} + 3.6\frac{\delta}{\bar{T}}$	
Concentric reducer per ASME B16.9 [Notes (1), (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14), (15)]	1	2.1 max. or $2.1\,\bar{T}/C_x$ but not less than 1.3	
Lap joint flange (with vASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

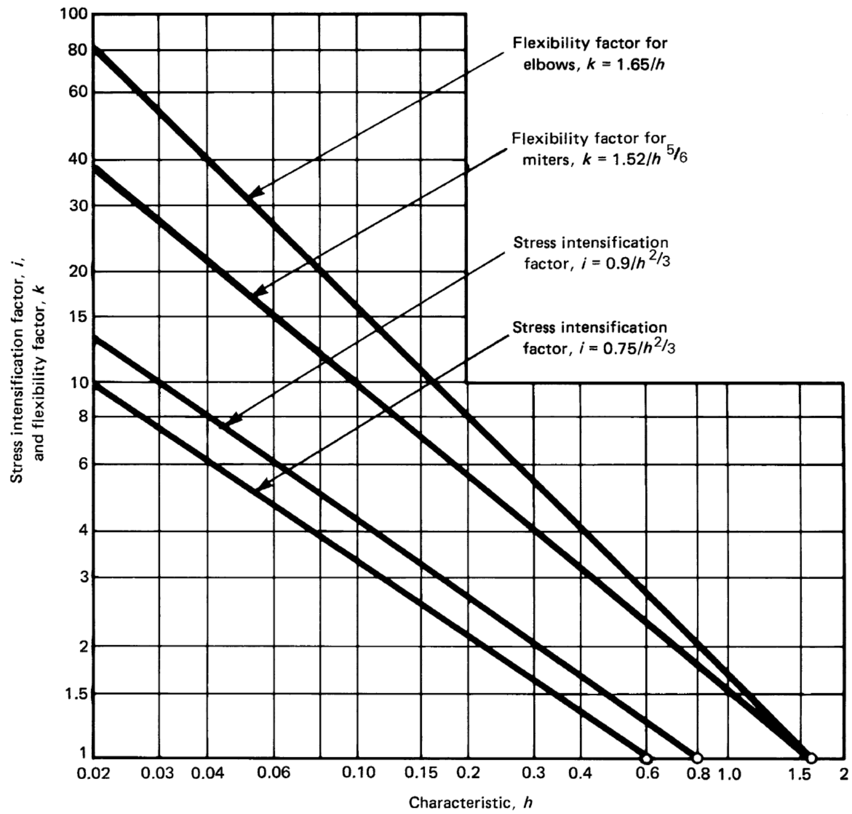


Chart A

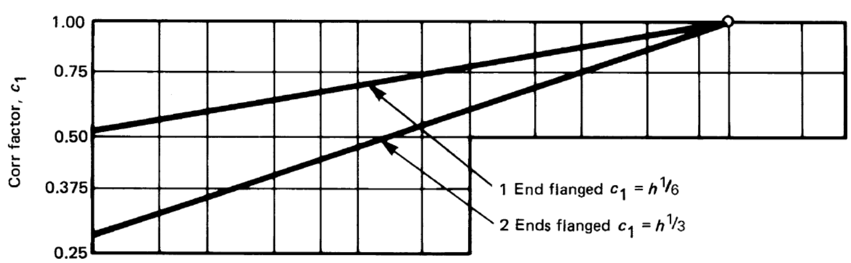


Chart B

GENERAL NOTE: The stress intensification and flexibility factors from ASME B31J may be used instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of in-plane (i_i) and out-plane (i_o) stress intensification factors shall be used in calculating stresses in accordance with para. 833.2 or para. A842.2.2. Alternatively, stress intensification factors and branch connection flexibility factors may be developed using ASME B31J, Nonmandatory Appendix A.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES:

(1) The nomenclature is as follows:

D_o = outside diameter, in. (mm)
d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_o = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\overline{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, k, applies to bending in any plane. The flexibility factors, k, and stress intensification factors, i, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends and to the intersection point for tees. The values of k and i can be read directly from Chart A by entering with the characteristic, h, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed h.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the table, divide k by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide i by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where
E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}T$, use $h = 4.05T/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the nominal wall thicknesses are between $0.875\overline{T}$ and $1.10\overline{T}$ for an axial distance of $\sqrt{D_o\overline{T}}$. D_o and $\overline{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met:
(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.
(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.
(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

Table E-1
Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES: (Cont'd)

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\left(S_b A_b - P A_p\right)$$

where

A_b = total area of flange bolts, in.^{2} (mm^3)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with I = 1.0 for bends from paras. IP-3.2.1 and IP-3.3.1.respectively.

$$P_a = \frac{2SEM_f t_a}{D - 2Yt_a}$$

where

P_a= allowable pressure

S = stress value for material from Table IX-1A

E = quality factor from Table IX-2 or Table IX-3A

M_f= material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

d= inside diameter

Y= coefficient from Table IP-3.2.1, valid for $t_a < D/6$ for Ferritic and Austenitic steels. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE for all available material.

$Y = \frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$ for all material types.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4b) from para. IP-3.3.3.

$$P_a = \frac{SEM_f t_a (R - r)}{r(R - r/2)}$$

For widely spaced miter bends with θ<= 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. IP-3.3.3 as

$$P_a = \frac{SEM_f t_a^2}{r\left(t_a + 0.643 \tan\theta \sqrt{rt_a}\right)}$$

For widely spaced miter bends with θ> 22.5 deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. IP-3.3.3 as

$$P_a = \frac{SEM_f t_a^2}{r\left(t_a + 1.25 \tan\theta \sqrt{r t_a}\right)}$$

where

r= mean radius of pipe = (D- t_n)/2

R = effective bend radius of the miter (see para. IP-3.3.3 (d) of code for definition) [an input in CAEPIPE for miters]

θ= angle of miter cut

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b), (23c) and (23d) from para. 320.2 of ASME B31.3 (2014) and compared against the allowable provided in para. IP-2.2.10.

$$S_L = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2} \leq S_h M_f$$

where

$$S_a = \left[\frac{I_a F_a}{A_p}\right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p}\right]_{Sustained}$$

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Sustained}$$

For branch (Leg 3 in Fig. 319.4.4B)of ASME B31.3 (2014),

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e}\right]_{Sustained}$$

$$S_t = \left[\frac{I_t M_t}{2Z_m}\right]_{Sustained}$$

P= maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_S=wall thickness used for sustained stress calculation obtained by deducting corrosion allowance from the nominal thickness

t_S= nominal thickness - corrosion allowance in CAEPIPE, as per para. 320.1ofASME B31.3 (2014)

A_p=corroded cross-sectional area of the pipe computed using t_s as per para. 320.1ofASME B31.3 (2014)

I_a= longitudinal force index = 1.0

F_a= longitudinal force due to sustained loads such as pressure and weight

R= axial force due to weight alone, where weight is computed using nominal thickness.

I_i= sustained in-plane moment index = $0.75 i_i$ or 1.0, whichever is greater.

I_o= sustained out-of-plane moment index = $0.75 i_o$ or 1.0, whichever is greater.

where, i_i and i_o are taken from Appendix D of ASME B31.3 (2014) [reprinted at the end of this Section].

I_t= torsional moment index = 1.0

M_i=in-plane bending moment due to sustained loads such as pressure and weight

M_o=out-of-plane bending moment due to sustained loads such as pressure and weight

M_t=torsional moment due to sustained loads such as pressure and weight

Z_m=corroded section modulus as per para. 320.1ofASME B31.3 (2014)

Z_e=effective corroded section modulus for branch as per para.320.2 of ASME B31.3 (2014)

M_f=material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. IP-2.2.11).

For temp ≤ 427⁰ C or 800⁰ F

$$S_{LO} \leq 1.33 S_h M_f$$

For temp > 427⁰ C or 800⁰ F

$$S_{LO} \leq 0.9 W S_y M_f$$

where

$S_{LO} = S_L + S_O$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b), (23c) and (23d) of ASME B31.3 (2014) with applicable loads.

$$S_O = \sqrt{(|S_{ao}| + S_{bo})^2 + (2S_{to})^2}$$

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{Occasional} = \left[\frac{(P_{peak} - P)D}{4t_s} + \frac{R}{A_p}\right]_{Occasional}$$

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_m}\right]_{Occasional}$$

For branch (Leg 3 in Fig. 319.4.4B)of ASME B31.3 (2014)

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_e}\right]_{Occasional}$$

$$S_{to} = \left[\frac{I_t M_t}{2Z_m}\right]_{Occasional}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P

R = axial force due to occasional loads such as earthquake or wind
M_i = in-plane bending moment due to occasional loads such as earthquake or wind
M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind
M_t= torsional moment due to occasional loads such as earthquake or wind
S_y= yield strength at maximum temperature, i.e., max (T_{ref}, T_1 through T_{10})
W = 1.0 for Austenetic stainless steel and 0.8 for other materials as per para. IP-2.2.11(a)
Z_m = corroded section modulus as per para. 320.1ofASME B31.3 (2014)
Z_e = effective corroded section modulus for branch as per para. 320.2ofASME B31.3 (2014)

Note 1:

The allowable stress equations for (S_{LO})are taken from para. 302.3.6 of ASME B31.3 (2014), as the sentence "At temperatures warmer than 427 deg. C (800 deg.F), use 1.33.Sh.M_f" in para. IP-2.2.11 of ASME B31.12 (2014) code seems to be incorrectly worded.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. IP-6.1.5

$$S_E = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where

$$S_a = \left[\frac{i_a F_a}{A}\right]_{Expansion}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]_{Expansion}$$

For branch (Leg 3 in Fig. IP-6.1.5-2)

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_e}\right]_{Expansion}$$

$$S_t = \left[\frac{i_t M_t}{2Z}\right]_{Expansion}$$

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D as per IP-6.1.4 (e).
i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o \; or \; i$ for other components as listed in Appendix D of B31.3 (2014)
F_a = range of axial force due to displacement strains between any two thermal conditions being evaluated
i_i = in-plane stress intensification factor from Appendix D of ASME B31.3 (2014) shallnot be less than 1.0
i_o = out-of-plane stress intensification factor Appendix D of ASME B31.3 (2014) shall not be less than 1.0

i_t = torsional stress intensification factor = 1.0
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torsional moment
Z = un-corroded section modulus as per IP-6.1.4 (e)
Z_e = un-corroded effective section modulus as per IP-6.1.4 (e)

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. IP-2.2.10 (d)
f = stress range reduction factor from Eq. (1c) of para. IP-2.2.10 (d) = $6N^{-0.2}$
where f ≥ 0.15 and f ≤ 1.0 (see Note 1 below)
S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than Sustained Stress S_L, the allowable stress range may be calculated as
S_A = $f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. IP-2.2.10 (d).

This is specified as an analysis option "Use liberal allowable stresses", in the menu Layout > Options > Analysis > Code tab.

Notes:

4. As per para. IP-2.2.10 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.
5. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. IP-6.1.5 (d)(1).
6. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Notes on Material Library for B3112-2014.mat supplied with CAEPIPE:

Material library for ASME B31.12 (2014) [B3112-2014.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix IX of ASME B31.12 (2014).

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

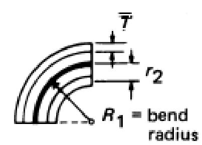
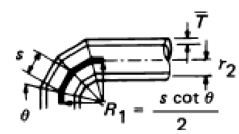
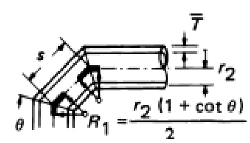
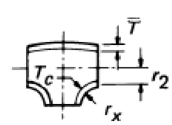
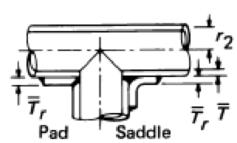
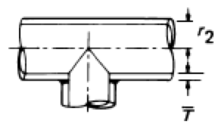
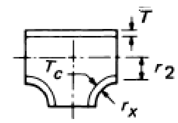
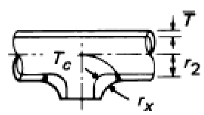
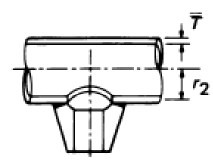
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2(1 + \tan\theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2(1 + \tan\theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5}r_2}$	

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\overline{T}}{r_2}$	
Extruded welding tee with $r_x \ge 0.05\ D_b$, $T_c < 1.5\ \overline{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1+\frac{r_x}{r_2}\right)\frac{\overline{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\overline{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\overline{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

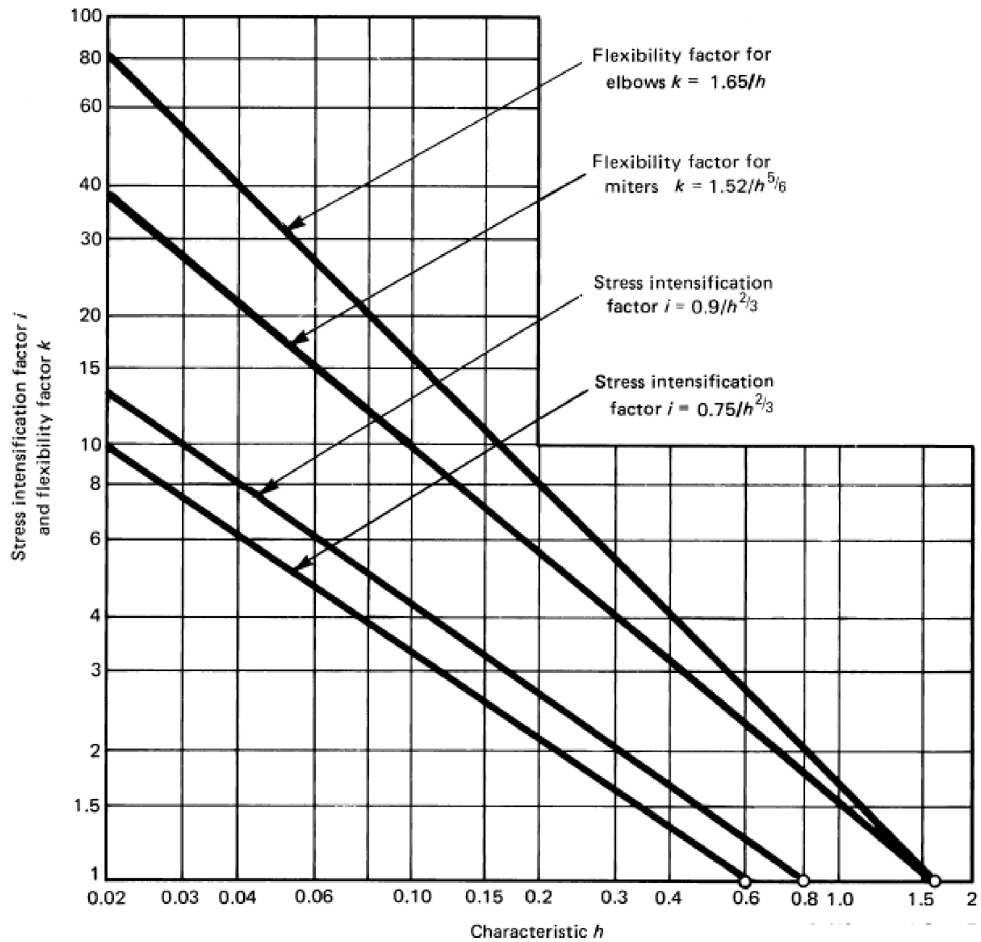


Chart A

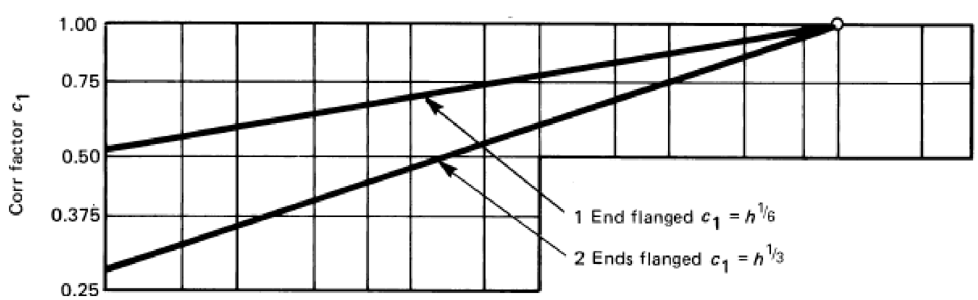


Chart B

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd) (14)

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\overline{T} \leq 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\overline{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\overline{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5\overline{T}$, a flexibility characteristic of $4.4\ \overline{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\overline{T}_r$ is $> 1\frac{1}{2}\ \overline{T}$, use $h = 4\ \overline{T}/r_2$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure

[Sl. Nos. 1 & 2 below are from Table IP-3.2.1 and Sl. Nos. 3, 4 & 5 are from Table 304.1.1 of ASME B31.3 (2014)]

Sl. No.	Material Type	Values of 'Y' for Temperature, Deg F (Deg C)							
		900 (482) and below	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677) and above
1.	Ferritic Steels (FS)	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
2.	Austenitic Steel (AS)	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
3.	Nickel Alloys (NA)	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7
4.	Gray Iron / Cast Iron (CI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	Material Types other than those stated from Sl. Nos. 1 to 4.	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Carbon Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as "CS" (from Table IX-5B)

Sl. No.	Specified Min. Yield Strength (ksi)	System Design Pressure, psig					
		<=1000	2000	3000	4000	5000	6000
1.	<= 52	1.000	0.948	0.912	0.884	0.860	0.839
2.	<= 56	0.930	0.881	0.848	0.824	0.800	0.778
3.	<= 65	0.839	0.796	0.766	0.745	0.724	0.706
4.	<= 80	0.715	0.678	0.645	0.633	0.618	0.600

Low and Intermediate Alloy Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as "AS" (from Table IX-5C)

Sl. No.	Specified Min. Tensile Strength (ksi)	System Design Pressure, psig						
		0.000	1000	2000	3000	4000	5000	6000
1.	<= 35	1.000	0.918	0.881	0.875	0.836	0.815	0.800
2.	<= 45	0.791	0.724	0.696	0.675	0.660	0.642	0.630
3.	<= 60	0.655	0.601	0.577	0.561	0.547	0.533	0.524
4.	<= 65	0.580	0.532	0.511	0.497	0.485	0.472	0.464

Note:
For materials not covered by Tables given above, Material Performance Factor (M_f) is taken as 1.00.

- Implemented as an optional feature for B31.5 and B31.8 codes. This feature can be turned ON or OFF through Layout Frame > Options > Analysis.

- When B31J is applied, it will allow users to select and specify among those Branch SIF types defined in B31J for the Piping Code selected for analysis.

- When B31J is applied, CAEPIPE will calculate SIFs as per B31J and report Torsional, In-plane and Out-of-plane SIFs in Element Forces and Moments results irrespective of whether they are being used or not in Code Compliance as per the Piping Code selected for Analysis. For Example, CAEPIPE will not include Torsional Moment and Torsional SIF while calculating Sustained and Occasional Stresses as per ASME B31.5 (2022).

- For Equal TEEs, the Run and Branch should be differentiated in CAEPIPE model by defining the Branch OD slightly less than the Run OD through CAEPIPE Sections input. Otherwise, CAEPIPE will use the equations corresponding to Run pipe even for Branch pipe.

- ASME B31.3 (2022) includes the term Axial SIF in Stress Calculations. On the other hand, B31J is silent about the Axial SIF for various components. Hence, CAEPIPE will use the Axial SIF values as stated in the respective text portions of ASME B31.3 (2022) code while computing stresses.

- As per para 402.6.1 of ASME B31.4 (2022), Torsion moment is not included in the equation for Sustained Stress for Restrained piping. In line with this ASME B31.4 (2022) code, CAEPIPE will not use Torsion Moment and Torsion SIF while calculating Sustained Stress for Restrained pipe.

- For ASME B31.5 (2022), paras. 502.3.2(d), 502.3.3(a), 519.4.5 and 519.3.5 do not include Torsional moment in computing Stresses. Accordingly, CAEPIPE will not include Torsional Moment and Torsional SIF while calculating Stresses as per ASME B31.5 (2022) even when the option B31J is turned ON.

- For ASME B31.8 (2022), para. 833.2 (e) states that the nominal Bending Stress for Fittings and Components as M_R/Z, where M_R is the resultant intensified moment across the fittings or components with Stress Intensification Factor (SIF) as 0.75i, where 0.75i cannot be less than 1.0.

  On the other hand, for Pipe and Long Radius Bends, para.833.2 (d) of the Code states that the nominal Bending Stress as M/Z, where M is the bending moment across the pipe cross section without SIF being considered. In other words, the moments are NOT intensified for Pipe and Long Radius Bends.

- As ASME B31.8 (2022) does not include SIF for Pipe and Long Radius Bends in Sustained Stress equation, SIF calculated as per B31J will NOT be included in Sustained Stress calculation for Pipes and Long Radius bends at this time even when the option B31J is turned ON. However, the SIF calculated as per B31J will be displayed in the Element Forces and Moments results, but will not be used.

- When B31J is turned ON, In-plane and Out-of-plane Flexibility Factors for Bends, Miter bends and TEEs will be calculated as per B31J and included by CAEPIPE in the corresponding element stiffness matrices. Similarly, CAEPIPE will calculate the Torsion Flexibility Factors as per B31J and include them in the element stiffness matrices irrespective of whether the code includes or excludes Torsional Moment and Torsional SIF in Stress equations.

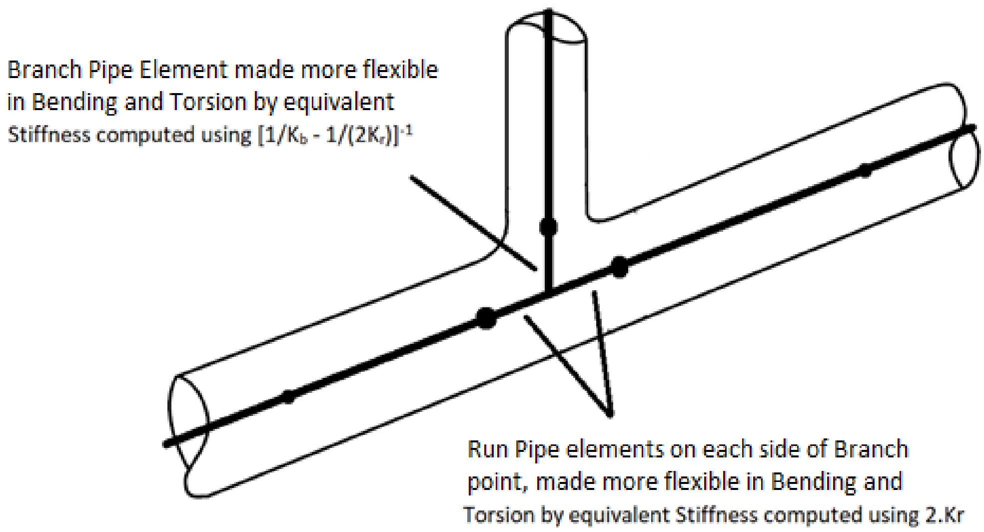
- As it is not possible to identify the number of Flanges or Rigids at Run Pipe ends located within 0.1D^1.4/T^0.4 from Branch intersection node using CAEPIPE (required for applying the correction factor while computing Flexibility Factors as per B31J), a provision is made in the Branch SIF definition to manually input the no. of Flanges or Rigids that fall within the distance given by B31J.

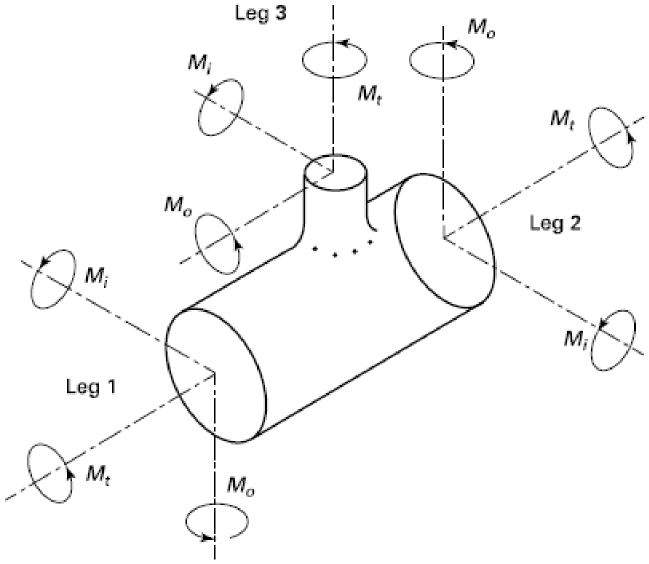
- When the bend angle is 90 degree and the thickness of the bend is equal to the thickness of the matching pipe, as per B31J (2023) the K_i and K_o should be calculated from 1.3/h. This is NOT implemented in CAEPIPE at this time.

- Flexibility Factors computed for TEEs as per B31J are always applied to both ends of the first elements belonging to Leg 1, Leg 2 and Leg 3 that are connected at the Branch node as shown in Figure 1-1 of B31J.

  CAEPIPE includes a feature to automatically refine the elements connected to the Branch node as given detailed to compute and apply Flexibility Factors for Run (Leg 1 and Leg 2) and Branch Pipe (Leg 3).

  a. Two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Split Factor x Run Pipe OD, where the Run Split Factor can be input by the user.
  b. One (1) node on Branch Pipe at a distance equal to Branch Split Factor x Run Pipe OD from the Branch SIF node, where the Branch Split Factor can be input by the user.





Moment	Flexibility Factor, k	Stiffness, in.-lb/rad (N·mm/rad)	Stiffness, in.-lb/rad (N·mm/rad)	
M_{i3} (Leg 3)	k_{ib}	M_{ib} /θ_{ib}	$(E)(I_b)/(k_{ib}\ d)$	K_b
M_{o3} (Leg 3)	k_{ob}	M_{ob} /θ_{ob}	$(E)(I_b)/(k_{ob}\ d)$	
M_{t3} (Leg 3)	k_{tb}	M_{tb} /θ_{tb}	$(E)(I_b)/(k_{tb}\ d)$	
$M_{i1,2}$ (Legs 1, 2)	k_{ir}	M_{ir} /θ_{ir}	$(E)(I_r)/(k_{ir}\ D)$	K_r
$M_{o1,2}$ (Legs 1, 2)	k_{or}	M_{or} /θ_{or}	$(E)(I_r)/(k_{or}\ D)$	
$M_{t1,2}$ (Legs 1, 2)	k_{tr}	M_{tr} /θ_{tr}	$(E)(I_r)/(k_{tr}\ D)$	

Changes between ASME B31J (2017) and ASME B31J (2023) are summarized below for easy reference.

Item #1	**For Table 1-1, Sketch 1.1, Equations for SIF In-plane and Out-of-plane for Pipe Bend or Welding Elbow:** The division sign, which was mistakenly omitted in B31J (2017), has now been included in B31J (2023).
ASME B31J (2017)	SIF in plane, i_i — $0.9h^{2/3}$ SIF out of plane, i_o — $0.75h^{2/3}$
ASME B31J (2023)	SIF In-plane, i_i — $0.9/h^{2/3}$ SIF Out-of-plane, i_o — $0.75/h^{2/3}$
Remarks	Although the division sign was omitted in B31J (2017), the CAEPIPE implementation was **correct** since Version 8.00, as it included the division. As a result, there will be no change in SIF values for Pipe Bend or Welding Elbows in a stress layout analyzed using both earlier and current versions of CAEPIPE.

Item #2	**Run in-plane SIF for Sketch 2.2 (Reinforced Fabricated TEE).** The exponent value for (d/D) has been updated from 0.54 to 1.0, and the sign in front of 0.34 has been changed to negative, as shown below.
ASME B31J (2017)	Run SIF in plane, i_{ir} — $[R/(T + 0.5t_p)]^{0.45}\ (d/D)^{0.54}\ (t/T)^{0.34} \geq 1.5$
ASME B31J (2023)	Run SIF in plane, i_{ir} — $[R/(T + 0.5t_p)]^{0.45}\ (d/D)^{1.0}\ (t/T)^{-0.34} \geq 1.5$
Remarks	Modifications shown above are implemented in CAEPIPE starting with Version 13.10. As a result, the calculated Run in-plane SIF value for Reinforced Fabricated Tee may differ from those produced by earlier versions of CAEPIPE.

Item #3	**Branch in-plane SIF for Sketch 2.2 (Reinforced Fabricated TEE):** The extra bracket that was mistakenly included in B31J (2017) has been removed in the B31J (2023) edition.
ASME B31J (2017)	Branch SIF in plane, i_{ib} — $[3.33(d/D) - 5.49(d/D)^2 + 2.94(d/D)^3](TR^{2/3})(T + 0.5t_p)]^{-5/3}\ (t/T)^{0.3}$
ASME B31J (2023)	Branch SIF in plane, i_{ib} — $[3.33(d/D) - 5.49(d/D)^2 + 2.94(d/D)^3](TR^{2/3})(T + 0.5t_p)^{-5/3}\ (t/T)^{0.3}$
Remarks	Although an extra bracket was displayed in B31J (2017), the CAEPIPE implementation was **correct** since Version 8.00, as it was done without the additional bracket. Hence, there will be no change in Branch in-plane SIF values for Reinforced Fabricated Tee modeled in a stress layout analyzed using both earlier and current versions of CAEPIPE.

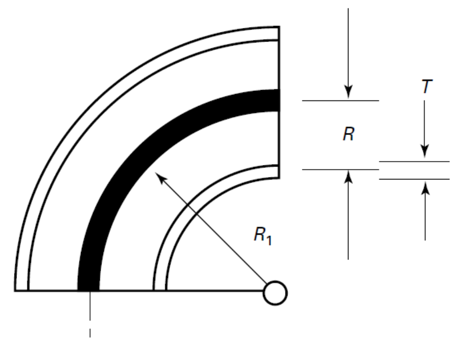
Item #4	**Branch out-of-plane SIF for Sketch 2.2 (Reinforced Fabricated TEE):** The extra bracket that was mistakenly included in B31J (2017) has been removed in the B31J (2023) edition.
ASME B31J (2017)	Branch SIF out of plane, i_{ob} — $[2.86(d/D) + 2.4(d/D)^2 - 4.34(d/D)^3](TR^{2/3})(T + 0.5t_p)]^{-5/3}\ (t/T)^{0.3}$ (when $t/T < 0.85$, use $t/T = 0.85$)
ASME B31J (2023)	Branch SIF out of plane, i_{ob} — $[2.86(d/D) + 2.4(d/D)^2 - 4.34(d/D)^3](TR^{2/3})(T + 0.5t_p)^{-5/3}\ (t/T)^{0.3}$ (when $t/T < 0.85$, use $t/T = 0.85$)
Remarks	Although an extra bracket was displayed in B31J (2017), the CAEPIPE implementation was **correct** since Version 8.00, as it was done without the additional bracket. Hence, there will be no change in Branch out-of-plane SIF values for Reinforced Fabricated Tee modeled in a stress layout analyzed using both earlier and current versions of CAEPIPE.

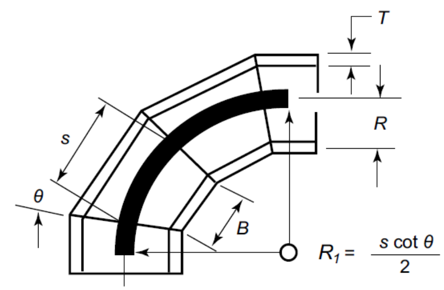
Item #5	**Run in-plane SIF for Sketch 2.3 (Fabricated TEE).** The exponent value for (d/D) has been updated from 0.5 to 1.0 as shown below.
ASME B31J (2017)	Run SIF in plane, i_{ir} | $1.2(d/D)^{0.5}\ (R/T)^{0.4}\ (t/T)^{-0.35} \geq 1.5$
ASME B31J (2023)	Run SIF in plane, i_{ir} | $1.2(d/D)^{1.0}\ (R/T)^{0.4}\ (t/T)^{-0.35} \geq 1.5$
Remarks	Modification shown above is implemented in CAEPIPE starting with Version 13.10. As a result, the calculated Run in-plane SIF value for Fabricated Tee may differ from those produced by earlier versions of CAEPIPE.

Item #6	**Branch out-of-plane SIF for Sketch 2.3 (Fabricated TEE).** When t/T < 0.85, use t/T = 0.85 has been updated to when t/T < 0.6, use t/T = 0.6 as shown below.
ASME B31J (2017)	Branch SIF out of plane, i_{ob} | $[0.038 + 2(d/D) + 2(d/D)^2 - 3.1(d/D)^3](R/T)^{2/3}\ (t/T)$ (when $t/T < 0.85$, use $t/T = 0.85$)
ASME B31J (2023)	Branch SIF out of plane, i_{ob} | $[0.038 + 2(d/D) + 2(d/D)^2 - 3.1(d/D)^3](R/T)^{2/3}\ (t/T)$ (when $t/T < 0.6$ use $t/T = 0.6$)
Remarks	Modification shown above is implemented in CAEPIPE starting with Version 13.10. As a result, the calculated Run in-plane SIF value for Fabricated Tee may differ from those produced by earlier versions of CAEPIPE.

Item #7	**Run in-plane SIF for Sketch 2.4 (Extruded Outlet):** Sign in front of 0.52 has been changed to negative, as shown below.
ASME B31J (2017)	Run SIF in plane, i_{ir} | $1.45(1 + r_x/R)^{-2/3}\ (R/T)^{0.35}\ (d/D)^{0.72}\ (t/T)^{0.52}$
ASME B31J (2023)	Run SIF in plane, i_{ir} | $1.45(1 + r_x/R)^{-2/3}\ (R/T)^{0.35}\ (d/D)^{0.72}\ (t/T)^{-0.52}$
Remarks	Modification shown above is implemented in CAEPIPE starting with Version 13.10. As a result, the calculated Run in-plane SIF value for Extruded Outlet may differ from those produced by earlier versions of CAEPIPE.

Table 1-1
Flexibility and Stress Intensification Factors

Term	Equation	Sketch
1.1 Pipe Bend or Welding Elbow Meeting ASME B16.9 [Notes (1)–(4)]		
Flexibility characteristic, h	TR_1/R^2	
Flexibility factor in plane, k_i	$1.65/h$	
Flexibility factor out of plane, k_o	$1.65/h$	
SIF in plane, i_i	$0.9/h^{2/3}$	
SIF out of plane, i_o	$0.75/h^{2/3}$	
SIF torsional, i_t	1	

Term	Equation	Sketch
1.2 Closely Spaced Miter Bend, $s < R\ (1 + \tan\theta)$ [Notes (1), (2), (4)]		
Flexibility characteristic, h	$sT \cot\theta/(2R^2)$	
Flexibility factor in plane, k_i	$1.52/h^{5/6}$	
Flexibility factor out of plane, k_o	$1.52/h^{5/6}$	
SIF in plane, i_i	$0.9/h^{2/3}$	
SIF out of plane, i_o	$0.9/h^{2/3}$	
SIF torsional, i_t	1	

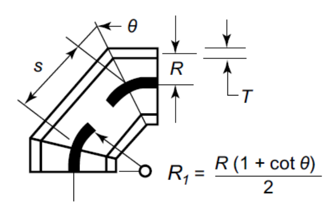
Term	Equation	Sketch
1.3 Widely Spaced Miter Bend, $s \geq R\ (1 + \tan\theta)$ [Notes (1), (4), (5)]		
Flexibility characteristic, h	$T\ (1 + \cot\theta)/(2R)$	
Flexibility factor in plane, k_i	$1.52/h^{5/6}$	
Flexibility factor out of plane, k_o	$1.52/h^{5/6}$	
SIF in plane, i_i	$0.9/h^{2/3}$	
SIF out of plane, i_o	$0.9/h^{2/3}$	
SIF torsional, i_t	1	

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

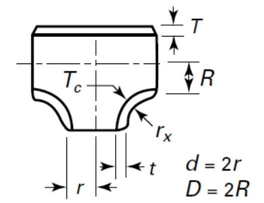
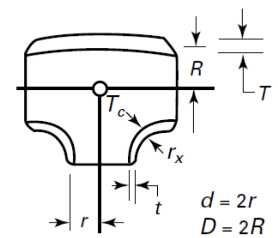
Term	Equation	Sketch
2.1 Welding Tee Meeting ASME B16.9 [Notes (1), (6), (7)]		
Run in-plane flexibility factor, k_{ir}	$0.18(R/T)^{0.8}\ (d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.08(R/T)^{0.91}\ (d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[1.91(d/D) - 4.32(d/D)^{2} + 2.7(d/D)^{3}](R/T)^{0.77}\ (d/D)^{0.47}\ (t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$[0.34(d/D) - 0.49(d/D)^{2} + 0.18(d/D)^{3}](R/T)^{1.46}\ (t/T)$	
Branch torsional flexibility factor, k_{tb}	$[1.08(d/D) - 2.44(d/D)^{2} + 1.52(d/D)^{3}](R/T)^{0.77}\ (d/D)^{1.61}\ (t/T)$	
Run SIF in plane, i_{ir}	$0.98(R/T)^{0.35}\ (d/D)^{0.72}\ (t/T)^{-0.52}$	
Run SIF out of plane, i_{or}	$0.61(R/T)^{0.29}\ (d/D)^{1.95}\ (t/T)^{-0.53}$	
Run SIF torsional, i_{tr}	$0.34(R/T)^{2/3}\ (d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{ib}	$0.33(R/T)^{2/3}\ (d/D)^{0.18}\ (t/T)^{0.7}$	
Branch SIF out of plane, i_{ob}	$0.42(R/T)^{2/3}\ (d/D)^{0.37}\ (t/T)^{0.37}$	
Branch SIF torsional, i_{tb}	$0.42(R/T)^{2/3}\ (d/D)^{1.1}\ (t/T)^{1.1}$	

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

Term	Equation	Sketch
2.2 Reinforced Fabricated Tee (When $t_p > 1.5T$, Use $t_p = 1.5T$) [Notes (1), (7)]		
Run in-plane flexibility factor, k_{ir}	$0.21[R/(T + 0.5t_p)]^{0.97} (t/T)^{-0.65} (d/D)^{6.2}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.12[R/(T + 0.5t_p)]^{1.39} (t/T)^{-0.74} (d/D)^{8.5}$	
Branch in-plane flexibility factor, k_{ib}	$[1.29(d/D) - 2.73(d/D)^2 + 1.62(d/D)^3][R/(T + 0.5t_p)]^{1.2} (t/T)^{0.56} (d/D)^{0.33}$	
Branch out-of-plane flexibility factor, k_{ob}	$[0.84(d/D) - 1.27(d/D)^2 + 0.5(d/D)^3][R/(T + 0.5t_p)]^{1.69} (t/T)^{0.68} (d/D)^{0.21}$	
Branch torsional flexibility factor, k_{tb}	$1.1[R/(T + 0.5t_p)]^{0.5} (d/D)^{5.42}$	
Run SIF in plane, i_{ir}	$[R/(T + 0.5t_p)]^{0.45} (d/D)^{1.0} (t/T)^{-0.34} \geq 1.5$	
Run SIF out of plane, i_{or}	$[1.29(d/D) - 2.87(d/D)^2 + 2.39(d/D)^3](t/T)^{-0.25}[R/(T + 0.5t_p)]^{0.35}$	
Run SIF torsional, i_{tr}	$0.36[R/(T + 0.5t_p)]^{2/3} (t/T)^{-0.6} (d/D)^{1.4}$	
Branch SIF in plane, i_{ib}	$[3.33(d/D) - 5.49(d/D)^2 + 2.94(d/D)^3](TR^{2/3})(T + 0.5t_p)^{-5/3} (t/T)^{0.3}$	
Branch SIF out of plane, i_{ob}	$[2.86(d/D) + 2.4(d/D)^2 - 4.34(d/D)^3](TR^{2/3})(T + 0.5t_p)^{-5/3} (t/T)^{0.3}$ (when $t/T < 0.85$, use $t/T = 0.85$)	
Branch SIF torsional, i_{tb}	$0.642(d/D)^2 (TR^{2/3})(T + 0.5t_p)^{-5/3} (t/T)^{0.3}$	

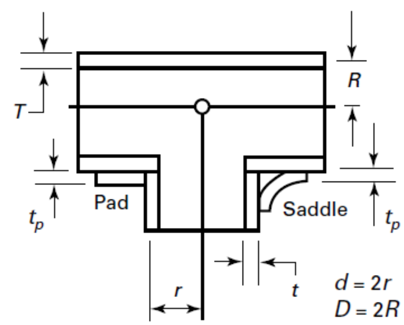
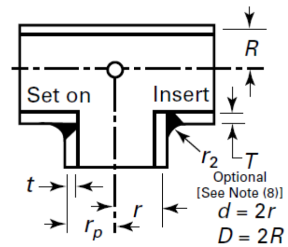
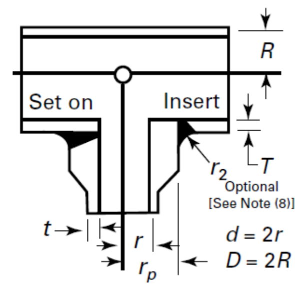


Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

Term	Equation	Sketch
2.3 Fabricated Tee [Notes (1), (7), (8)]		
Run in-plane flexibility factor, k_{ir}	$1.23(R/T)^{0.47}\ (t/T)^{-0.47}\ (d/D)^{5.3}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$(R/T)^{0.78}\ (t/T)^{-0.8}\ (d/D)^{7.8}$	
Branch in-plane flexibility factor, k_{ib}	$[3.15(d/D) - 6.4(d/D)^2 + 4(d/D)^3](R/T)^{0.83}\ (t/T)^{0.49}\ (d/D)^{-0.2}$	
Branch out-of-plane flexibility factor, k_{ob}	$[2.05(d/D) - 2.94(d/D)^2 + 1.1(d/D)^3](R/T)^{1.4}\ (t/T)^{0.6}\ (d/D)^{0.12}$	
Branch torsional flexibility factor, k_{tb}	$0.95(R/T)^{0.83}\ (d/D)^{5.42}$	
Run SIF in plane, i_{ir}	$1.2(d/D)^{1.0}\ (R/T)^{0.4}\ (t/T)^{-0.35} \geq 1.5$	
Run SIF out of plane, i_{or}	$[(d/D) - 2.7(d/D)^2 + 2.62(d/D)^3](R/T)^{0.43}\ (t/T)^{-0.7}$ (when $d/D < 0.5$, use $d/D = 0.5$; when $t/T < 0.5$, use $t/T = 0.5$)	
Run SIF torsional, i_{tr}	$1.2\ (R/T)^{0.46}\ (t/T)^{-0.45}\ (d/D)^{1.37}$ (when $t/T < 0.15$, use $t/T = 0.15$)	
Branch SIF in plane, i_{ib}	$[0.038 + 1.45(d/D) - 2.39(d/D)^2 + 1.34(d/D)^3](R/T)^{0.76}\ (t/T)^{0.74}$ (when $t/T < 1$, use $t/T = 1$)	
Branch SIF out of plane, i_{ob}	$[0.038 + 2(d/D) + 2(d/D)^2 - 3.1(d/D)^3](R/T)^{2/3}\ (t/T)$ (when $t/T < 0.6$ use $t/T = 0.6$)	
Branch SIF torsional, i_{tb}	$0.45(R/T)^{0.8}\ (t/T)^{0.29}\ (d/D)^2$	





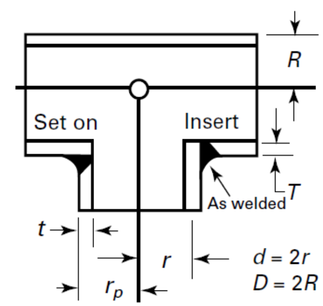


Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

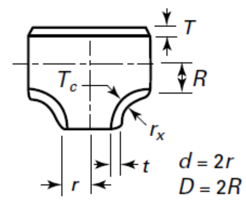
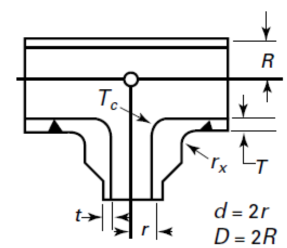
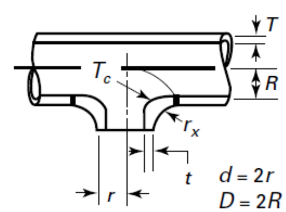
Term	Equation	Sketch
2.4 Extruded Outlet With $r_x \geq 0.05d_o$ and $T < T_c < 1.5T$ [Notes (1), (7), (9)]		
Run in-plane flexibility factor, k_{ir}	$0.18(R/T)^{0.8}\ (d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.08(R/T)^{0.91}\ (d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[1.91(d/D) - 4.32(d/D)^2 + 2.7(d/D)^3](R/T)^{0.77}\ (d/D)^{0.47}\ (t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$[0.34(d/D) - 0.49(d/D)^2 + 0.18(d/D)^3](R/T)^{1.46}\ (t/T)$	
Branch torsional flexibility factor, k_{tb}	$[1.08(d/D) - 2.44(d/D)^2 + 1.52(d/D)^3](R/T)^{0.77}\ (d/D)^{1.79}\ (t/T)$	
Run SIF in plane, i_{ir}	$1.45(1 + r_x/R)^{-2/3}\ (R/T)^{0.35}\ (d/D)^{0.72}\ (t/T)^{-0.52}$	
Run SIF out of plane, i_{or}	$0.58(1 + r_x/R)^{-2/3}\ (R/T)^{2/3}\ (d/D)^{2.69}$	
Run SIF torsional, i_{tr}	$0.55(1 + r_x/R)^{-2/3}\ (R/T)^{2/3}\ (d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{ib}	$0.56(1 + r_x/R)^{-2/3}\ (R/T)^{2/3}\ (d/D)^{0.68}$	
Branch SIF out of plane, i_{ob}	$0.85(1 + r_x/R)^{-2/3}\ (R/T)^{2/3}\ (d/D)^{0.5}$	
Branch SIF torsional, i_{tb}	$0.71(1 + r_x/R)^{-2/3}\ (R/T)^{2/3}\ (d/D)^{2}$	
2.5 Welded-in Contour Insert (When r_x Is Not Provided, Use $r_x = 0$) [Notes (1), (6), (7)]		
Run in-plane flexibility factor, k_{ir}	$0.18(R/T)^{0.84}\ (d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.1(R/T)^{0.91}\ (d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[2.36(d/D) - 5.33(d/D)^2 + 3.33(d/D)^3](R/T)^{0.77}\ (d/D)^{0.47}\ (t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$(1 + r_x/R)[0.67(d/D) - 0.97(d/D)^2 + 0.36(d/D)^3](R/T)^{1.46}\ (t/T)$	
Branch torsional flexibility factor, k_{tb}	$[1.05(d/D) - 2.36(d/D)^2 + 1.49(d/D)^3](R/T)^{0.77}\ (d/D)^{1.61}\ (t/T)$	
Run SIF in plane, i_{ir}	$(R/T)^{0.35}\ (d/D)^{0.72}\ (t/T)^{-0.52}$	
Run SIF out of plane, i_{or}	$0.72(R/T)^{0.29}\ (d/D)^{1.95}\ (t/T)^{-0.53}$	
Run SIF torsional, i_{tr}	$0.36(R/T)^{2/3}\ (d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{ib}	$0.35(R/T)^{2/3}\ (d/D)^{0.18}\ (t/T)^{0.7}$	
Branch SIF out of plane, i_{ob}	$0.48(R/T)^{2/3}\ (d/D)^{0.37}\ (t/T)^{0.37}$	
Branch SIF torsional, i_{tb}	$0.44(R/T)^{2/3}\ (d/D)^{1.1}\ (t/T)^{1.1}$	

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

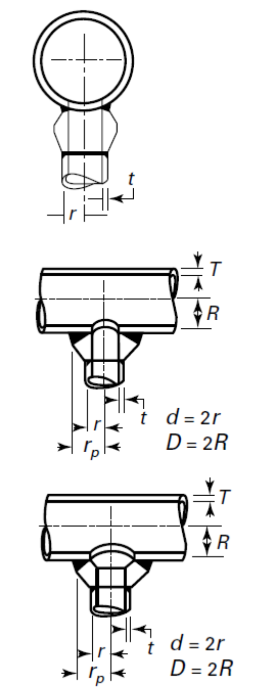
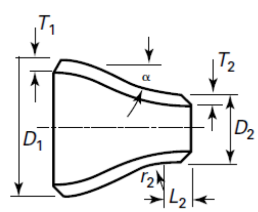
Term	Equation	Sketch
2.6 Integrally Reinforced Branch Welded-on Fittings [Notes (1), (7), (10)]		
Run in-plane flexibility factor, k_{ir}	$0.5(R/T)^{0.5}\ (d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.1(R/T)(d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[0.55(d/D) - 1.13(d/D)^2 + 0.69(d/D)^3](R/T)(t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$[1.03(d/D) - 1.55(d/D)^2 + 0.59(d/D)^3](R/T)^{1.4}\ (t/T)(d/D)^{0.33}$	
Branch torsional flexibility factor, k_{tb}	$[0.37(d/D) - 0.75(d/D)^2 + 0.46(d/D)^3](R/T)(t/T)(d/D)^{1.2}$	
Run SIF in plane, i_{ir}	$(R/T)^{0.43}\ (d/D)^{0.5} \geq 1.5$	
Run SIF out of plane, i_{or}	$[0.02 + 0.88(d/D) - 2.56(d/D)^2 + 2.58(d/D)^3](R/T)^{0.43}$	
Run SIF torsional, i_{tr}	$1.3(R/T)^{0.45}\ (d/D)^{1.37}$	
Branch SIF in plane, i_{ib}	$[0.08 + 1.28(d/D) - 2.35(d/D)^2 + 1.45(d/D)^3](R/T)^{0.81}\ (t/T)(r/r_p)$	
Branch SIF out of plane, i_{ob}	$[1.83(d/D) - 1.07(d/D)^3]\ (R/T)^{0.82}\ (t/T)(r/r_p)^{1.18}$	
Branch SIF torsional, i_{tb}	$0.77(R/T)^{2/3}\ (t/T)\ (d/D)^2\ (r/r_p)$	
3.1 Concentric or Eccentric Reducer Meeting ASME B16.9 [Note (11)]		
SIF in plane, i_i	$0.6 + 0.003(\alpha T_2/T_1)^{0.8}\ (D_2\ /T_2)^{0.25}\ (D_2/r_2)$	
SIF out of plane, i_o	$0.6 + 0.003(\alpha T_2/T_1)^{0.8}\ (D_2/T_2)^{0.25}\ (D_2\ /r_2)$	
SIF torsional, i_t	$0.3 + 0.0015(\alpha T_2/T_1)^{0.8}\ (D_2\ /T_2)^{0.25}\ (D_2/r_2)$	

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

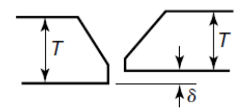
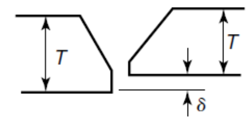
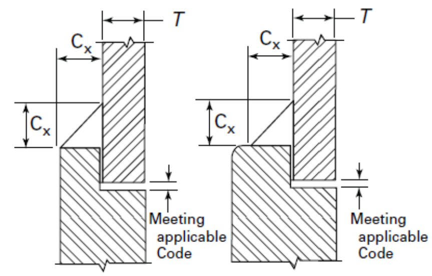
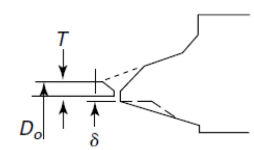
Term	Equation	Sketch
4.1 Butt Weld, $T \geq 6$ mm (0.237 in.), $\delta_{max} \leq 1.5$ mm ($^1\!/_{16}$ in.), and $\delta_{avg}/T \leq 0.13$ [Note (12)]		
SIF in plane, i_i	1.0	
SIF out of plane, i_o	1.0	
SIF torsional, i_t	1.0	
4.2 Butt Weld, $T \geq 6$ mm (0.237 in.), $\delta_{max} \leq 3$ mm ($^1\!/_8$ in.), and δ_{avg}/T = Any Value OR $T < 6$ mm (0.237 in.), $\delta_{max} \leq 1.5$ mm ($^1\!/_{16}$ in.), and $\delta_{avg}/T \leq 0.33$ [Note (12)]		
SIF in plane, i_i	1.9 max. or $0.9 + 2.7(\delta_{avg}/T)$ but not less than 1.0	
SIF out of plane, i_o	1.9 max. or $0.9 + 2.7(\delta_{avg}/T)$ but not less than 1.0	
SIF torsional, i_t	$0.45 + 1.35(\delta_{avg}/T)$ but not less than 1.0	
4.3 Fillet-Welded Joint or Socket-Welded Flange Meeting ASME B16.5 or Socket-Welded Fitting Meeting ASME B16.11 [Note (13)]		
SIF in plane, i_i	1.3	
SIF out of plane, i_o	1.3	
SIF torsional, i_t	1.3	
4.4 Tapered Transition in Accordance With Applicable Code Sections and ASME B16.25		
SIF in plane, i_i	1.9 max. or $1.3 + 0.0036(D_o/T) + 3.6(\delta/T)$	
SIF out of plane, i_o	1.9 max. or $1.3 + 0.0036(D_o/T) + 3.6(\delta/T)$	
SIF torsional, i_t	1.3	
4.5 Weld Neck Flange		
SIF in plane, i_i	1.0	...
SIF out of plane, i_o	1.0	
SIF torsional, i_t	1.0	

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

Term	Equation	Sketch
4.6 Single Welded Slip-on Flange		
SIF in plane, i_i	1.3	...
SIF out of plane, i_o	1.3	
SIF torsional, i_t	1.3	
4.7 Double Welded Slip-on Flange		
SIF in plane, i_i	1.2	...
SIF out of plane, i_o	1.2	
SIF torsional, i_t	1.2	
4.8 Lap Joint Flange (With ASME B16.9 Lap Joint Stub)		
SIF in plane, i_i	1.6	...
SIF out of plane, i_o	1.6	
SIF torsional, i_t	1.6	
5.1 Threaded Pipe Joint or Threaded Flange in Accordance With Acceptable Code Detail		
SIF in plane, i_i	2.3	...
SIF out of plane, i_o	2.3	
SIF torsional, i_t	2.3	

GENERAL NOTES:
(a) The following symbols are used in this table:
A_p = metal area of pipe cross section, in.^{2} (mm^2)
B = length of miter segment at crotch, in. (mm)
b = branch subscript corresponding to Leg 3 in Figure 1-1
c = factor for rigid ends adjacent to bends, miters, and branch connections in sketches 1.1, 1.2, and 2.1 through 2.6
C_x = minimum socket weld leg length, in. (mm)
D = mean diameter of matching pipe found from ($D_o - T$), in. (mm); for sketches 2.1 through 2.6, the mean diameter of the matching run pipe
d = mean diameter of matching branch pipe found from ($d_o - t$), in. (mm)
d' = effective branch diameter used with Figure 1-3, illustrations (a), (b), and (c), in. (mm)
D_1, D_2 = outside diameter of matching pipe at large and small ends of reducer, respectively, in. (mm)
D_i = inside diameter of matching run pipe found from ($D_o - 2T$), in. (mm)
d_i = inside diameter of matching branch pipe found from ($d_o - 2t$), in. (mm)
D_o = outside diameter of matching pipe, in. (mm)
d_o = outside diameter of the matching branch pipe, in. (mm); for sketches 2.1 through 2.6, the outside diameter of the matching run pipe
E = modulus of elasticity, psi (kPa)
h = flexibility characteristic for elbows and bends
i = stress intensification factor (SIF)
I_b, I_r = matching branch and run pipe moment of inertia used in Table 1-2, in.^{4} (mm^4)
k = flexibility factor with respect to the plane and component indicated [see Rodabaugh (1994) for a more detailed definition of flexibility factor as it applies to straight and curved pipe and branch connections]
L_1 = length of taper or thicker branch section in Figure 1-2, in. (mm)
L_2 = length of the cylindrical portion at the small end of the reducer in sketch 3.1, in. (mm)
M = moment on branch or run legs shown in Figure 1-1, in.-lb (N·mm)

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

GENERAL NOTES: (Cont'd)

N_c = number of flanges or other rigid components adjacent to the run pipe end of a branch connection (1 or 2)
P = gage pressure, psi (MPa)
R = mean radius of matching pipe found from $(D_o - T)/2$, in. (mm)
r = mean radius of matching branch pipe found from $(d_o - t)/2$ for sketches 2.1 through 2.6, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_2 = radii used with Figure 1-3 and in sketch 3.1, in. (mm)
r_i = inside radius used with Figure 1-3, in. (mm)
r_p = radius to outside edge of fitting for sketches 2.3 and 2.6 measured in longitudinal plane, in. (mm)
r_x = external crotch radius of welding tee in accordance with ASME B16.9, extruded outlet and welded-in contour insert (see sketches 2.1, 2.4, and 2.5), measured in the plane containing the centerline axes of the run and branch, in. (mm)
s = miter spacing at centerline, in. (mm)
SIF = stress intensification factor
T = nominal wall thickness of matching pipe or the average wall thickness of the fitting, if available, for welding elbows in sketch 1.1; nominal wall thickness of pipe or the average wall thickness of the fitting, if available, for pipe bends in sketch 1.1; nominal wall thickness of pipe for miter bends in sketches 1.2 and 1.3; nominal wall thickness of matching run pipe for tees in sketches 2.1 and 2.4; nominal wall thickness of run pipe for tees in sketches 2.2, 2.3, 2.5, and 2.6; nominal wall thickness of pipe for weld joints in sketches 4.1 through 4.4
t = nominal wall thickness of matching branch pipe, in. (mm)
t' = effective branch thickness used with Figure 1-3, illustrations (a), (b), and (c), in. (mm)
T_1, T_2 = nominal wall thickness of matching pipe at the large and small ends of the reducer, respectively, in. (mm)
T_c = crotch thickness in sketches 2.1, 2.4, and 2.5 measured at the center of the crotch and in the plane shown, in. (mm)
t_n = local branch pipe thickness used with Figure 1-3, illustrations (a) and (b), in. (mm)
t_p = reinforcement pad or saddle thickness, in. (mm)
y = large end of taper used with Figure 1-3, illustration (c), and found from $(L_1 \tan \theta_n)$, in. (mm)
Z = section modulus of pipe, in.^{3} (mm^3) [see Note (7)]
Z_b = section modulus of matching branch pipe, in.^{3} (mm^3) [see Note (7)]
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg
θ_n = angle used with Figure 1-3, illustration (c), deg
θ_{ib}, θ_{ob}, θ_{tb}, θ_{ir}, θ_{or}, θ_{tr} = rotations at branch or run legs shown in Figure 1-1, rad

(b) Stress intensification and flexibility factor data in this table shall be used in the absence of more directly applicable data. Their validity has been demonstrated for $D/T \leq 100$. Other limits are provided as needed below.

(1) Flexibility and stress intensification factors shall not be less than 1.0.

(2) Stress intensification factors may be used without flexibility factors.

(3) Stress intensification and flexibility factors in this table have been developed from fatigue tests of representative commercially available matching product forms with assemblies manufactured from ductile ferrous materials and from numerical analysis using finite elements. Caution should be exercised when applying these rules for certain nonferrous materials (e.g., copper and aluminum alloys) for other than low-cycle applications.

(4) Corrugated straight pipe or corrugated or creased bends should be designed using the principles found in ASME B31.3, Nonmandatory Appendix X; standards from the Expansion Joint Manufacturers Association; or similar standards.

(c) The highest in-plane or out-of-plane stress intensification factor shall be used when only a single stress intensification factor is needed. Flexibility factors should always be used with the orientation specified. For sketches 3.1 through 5.1, the in-plane and out-of-plane orientations must be orthogonal to each other and to the pipe axis.

(d) Where sustained stress or moment factors are required by the applicable Code (e.g., ASME B31.1, ASME B31.3), and in lieu of more applicable data, for components of sketches 1.1 through 1.3 and sketches 3.1 through 5.1, the directional sustained stress or moment multiplier can be taken as the component stress intensification factor. For components of sketches 2.1 through 2.6, the directional sustained stress or moment multiplier can be conservatively taken as the smaller of (1) and either (2) or (3) below.

(1) 0.75 times the applicable stress intensification factor

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

GENERAL NOTES: (Cont'd)

(2) (t/T) times the square root of the applicable stress intensification factor when $t/T > 1$

(3) the square root of the applicable stress intensification factor when $t/T \le 1$

The sustained stress or moment factors should always be used with the section modulus of the matching pipe and should not be less than 1.0.

When the D_o/T ratio for any component is greater than 50, the sustained stress or moment factor should be divided by $(1.3 - 0.006D_o/T)$.

(e) For piping components such as valves, strainers, eccentric reducers, reducing elbows, unions, nonstandard fittings or attachments not covered in Table 1-1, suitable stress intensification factors can be found by comparison of their significant geometry with similar components in Table 1-1. Relationships can be developed using engineering judgment, supplemented by detailed stress analysis, e.g., finite element method or correlation with documented test results.

NOTES:

(1) Stress intensification and flexibility factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and may be read from Figure 1-4. Stress intensification factors for sketches 2.1 through 2.6 apply to the intersection point for Legs 1 and 2 as shown in Figures 1-1 and 1-6. Stress intensification factors apply to the intersection point for branch Leg 3 in Figures 1-1 and 1-6 when $d_o/D_o > 0.5$, and to the branch centerline at the surface of the run pipe when $d_o/D_o \le 0.5$. Flexibility factors for sketches 2.1 through 2.6 shall be applied as shown in Figures 1.1 and 1.6 for all d_o/D_o.

(2) Where flanges or other rigid components are attached to one or both ends, the in-plane and out-of-plane values of k and i shall be multiplied by the factor c from Figure 1-5, entering with the computed h.

(3) When the bend angle is 90 deg and the thickness of the bend is equal to the thickness of the matching pipe, the flexibility factors k_i and k_o may be found from $1.3/h$ and adjusted by the factor c from Figure 1-5 where applicable.

(4) In large-diameter thin-wall elbows and bends, pressure can affect the magnitudes of k and i. To correct values from this table, divide k by

$$\left[1 + 6\left(\frac{P}{E}\right)\left(\frac{R}{T}\right)^{7/3}\left(\frac{R_1}{R}\right)^{1/3}\right]$$

and divide i by

$$\left[1 + 3.25\left(\frac{P}{E}\right)\left(\frac{R}{T}\right)^{5/2}\left(\frac{R_1}{R}\right)^{2/3}\right]$$

For consistency, use kPa and mm for SI and psi and in. for U.S. customary notation. Stress intensification factors shall be used with the section modulus of the matching pipe or the section modulus of the bend, whichever is smaller.

(5) Sketch 1.3 includes single miter joints.

(6) Sidewall thinning, undulations, creases, tool marks, and boring discontinuities can reduce fatigue life. Sketch 2.1 stress intensification factors are based on components free of these defects. Sketch 2.3 stress intensification factors may be used as an alternative. When sketch 2.1 stress intensification factors are used

(a) if $r_x \ge (1/8)(d_o)$ and $T_c \ge 1.5T$, the factors k and i may be divided by 1.26, and

(b) if $t/T < 0.6$, use $t/T = 0.6$ for all branch k and i factors

(7) The flexibility and stress intensification factors apply only if the following conditions are satisfied:

(a) the branch pipe axis is normal to within 5 deg of the surface of the run pipe unless otherwise noted

(b) $R/T \le 50$

(c) $d/D \le 1$

(d) $r/t \le 50$

(e) the matching run pipe thickness, T, and diameter, D, are maintained for at least two run pipe diameters on each side of the branch centerline

(f) for sketches 2.1, 2.4, and 2.5, $t/T \le 1.2$ and $T_c/T \ge 1.1$

When a Table 1-2 flexibility factor is less than or equal to 1.0, the stiffness associated with that flexibility factor shall be rigid. Flexibility factors k_{ib}, k_{ob}, and k_{tb} in sketches 2.1 through 2.6 shall be multiplied by the factor c from Table 1-3 when flanges or other rigid components are adjacent to one or more of the run pipe ends. A flange or other rigid component is adjacent to the run pipe end when the length of any straight run pipe between the branch and the flange or rigid component is less than $0.1D^{1.4}/T^{0.4}$. Stress intensification factors i_{ib}, i_{ob}, i_{tb}, i_{ir}, i_{or}, and i_{tr} and

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

NOTES: (Cont'd)

flexibility factors k_{ib}, k_{ob}, k_{tb}, k_{ir}, k_{or}, and k_{tr} in sketches 2.1, 2.2, 2.4, 2.5, and 2.6 shall not be greater than the corresponding stress intensification and flexibility factors for sketch 2.3 and Figure 1-3, illustration (d), calculated using matching branch and run pipe dimensions and $r_2 = 0$. Stress intensification factors i_{ib}, i_{ob}, i_{tb}, i_{ir}, i_{or}, and i_{tr} and flexibility factors k_{ib}, k_{ob}, k_{tb}, k_{ir}, k_{or}, and k_{tr} in sketches 2.2, 2.3, 2.4, 2.5, and 2.6 shall not be less than the corresponding stress intensification and flexibility factors for sketch 2.1 calculated using $T_c = 1.1T$.

If $i_{ob} < i_{ib}$ for any of sketches 2.1 through 2.6, then use $i_{ob} = i_{ib}$. If $i_{ir} < i_{or}$ for any of sketches 2.1 through 2.6, then use $i_{ir} = i_{or}$. Stress intensification factors i_{ib}, i_{ob}, i_{ir}, i_{or}, and i_{tr} from this table can be used for sketches 2.2, 2.3, 2.5, and 2.6 when the branch pipe axis is in the same plane as the run pipe axis and is normal to within 45 deg of the surface of the run pipe, provided $D/T < 50$ and $d/D \leq 0.6$; in the absence of more applicable data, i_{tb} can be taken equal to i_{ob}. The stress intensification factor i_{ob} in sketch 2.3 shall be multiplied by the larger of $[0.75(t/T) - 0.89(t/T)^2 + 0.18](D/T)^{0.34}$ or 1.0 when $t/T \leq 0.85$, $d/D < 1$, and $D/T \geq 25$.

The stress intensification factor i_{ob} in sketch 2.2 shall be multiplied by the larger of $[1.07(t/T) - 1.08(t/T)^2 + 0.026](D/T)^{0.34}$ or 1.0 when $t/T \leq 0.85$, $d/D < 1$, and $D/T \geq 25$.

The designer must be satisfied that the branch connection pressure rating is greater than or equal to that of the matching run pipe. Branch connection stress intensification factors shall be used with the section modulus of the matching pipe. The section modulus shall be calculated using the following equation for the run:

$$Z = \left(\frac{\pi}{32}\right)\left(\frac{D_o^4 - D_i^4}{D_o}\right)$$

and by the following equation for the branch:

$$Z_b = \left(\frac{\pi}{32}\right)\left(\frac{d_o^4 - d_i^4}{d_o}\right)$$

(8) The in-plane, out-of-plane, and torsional stress intensification factors for both the branch and the run may be multiplied by the factor 0.7 for the geometries shown in Figure 1-3 when the outer radius, r_2, is provided and is not less than the smallest of $T/2$, $t/2$, $(r_p - r_i)/2$, or $(t + y)/2$. For Figure 1-3, illustrations (a), (b), and (c), the following hold:

(a) Flexibility and stress intensification factors shall be calculated by replacing the parameters t/T with t'/T and d/D with d'/D.

(b) Stress intensification factors i_{ib}, i_{ob}, and i_{tb} and flexibility factors k_{ib}, k_{ob}, and k_{tb} shall also be multiplied by $(t/t')(d/d')^2$.

(c) Calculate t' as follows:

(-1) For Figure 1-3, illustrations (a) and (b)

$$\begin{aligned} t' &= t_n \text{ if } L_1 \geq 0.5(2rt_n)^{1/2} \\ &= t \text{ if } L_1 < 0.5(2rt_n)^{1/2} \end{aligned}$$

(-2) For Figure 1-3, illustration (c)

$$\begin{aligned} t' &= t + (2/3)y \text{ if } \theta_n \leq 30 \text{ deg} \\ &= t + 0.385L_1 \text{ if } \theta_n > 30 \text{ deg} \end{aligned}$$

(d) Calculate d' as follows:

$$d' = d - t + t'$$

(e) Stress intensification factors i_{ib}, i_{ob}, i_{ir}, and i_{tr} shall not be less than 1.5.

(9) When r_x is not provided, use $r_x = 0.05d_o$. If $r_x \geq r$, use $r_x = r$. When $t/T < 0.6$, use $t/T = 0.6$ for all branch k and i factors. Sidewall thinning, undulations, creases, tool marks, and boring discontinuities can reduce fatigue life. Sketch 2.4 stress intensification factors are based on components free of these defects. Sketch 2.3 stress intensification factors may be used as an alternative.

(10) When r/r_p is not available, a value of 0.85 may be used. If $r/r_p < 0.6$, then use $r/r_p = 0.6$. For size-on-size branch connections when $D/T < 40$, i_{ob} may be multiplied by 0.75. When the weld sizes and actual dimensions of the fitting are available, r_p can be taken as the distance along the surface of the run pipe from the branch centerline to the toe of the attachment fillet weld in the longitudinal plane. When $d/D > 0.8$, the geometry of commercially available fittings varies considerably from manufacturer to manufacturer. More applicable data from the manufacturer should be used when available. Results from tests where $D/T < 40$ should not be extrapolated to branch connections where $D/T > 40$.

Table 1-1
Flexibility and Stress Intensification Factors (Cont'd)

NOTES: (Cont'd)
(11) The flexibility and stress intensification factors apply only if the following conditions are satisfied:
(a) 5 deg < α < 60 deg
(b) 5 < D_2/T_2 < 80
(c) the wall thickness is not less than T_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than T_2
(d) 0.08 < r_2 /D_2 < 0.7
(e) 1 < T_1/T_2 < 2.12
(f) if $L_2 < (D_2T_2)^{0.5}$, the stress intensification factors should be multiplied by $[2 - L_2/(D_2T_2)^{0.5}]$
The maximum stress intensification factor need not be greater than 2.0 but shall in no case be less than 1.0. Reducers with $D_2/T_2 \le 55$ can be modeled as a step change in diameter and thickness from D_2, T_2 to D_1, T_1 at the middle of the reducer, or with any more applicable geometry. When $D_2/T_2 > 55$, consideration should be given to adding flexibility to the beam model to more accurately represent the stiffness of the reducer. For eccentric reducers, the dimensions shown in sketch 3.1 are to be taken at the location on the circumference where α is the maximum. When r_2 is not given, use $r_2 = 0.1D_1$. When L_2 is not given, use $L_2 = 0.1D_2$. When α is not given, use α equal to the smaller of $60(D_1/D_2 - 1)$ or 60.
(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between 0.875T and 1.10T for an axial distance of $(D_oT)^{1/2}$. D_o and T are the nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.
(13) For welds to socket-welded flanges and fittings, the stress intensification factor is based on the following:
(a) the assumption that the pipe and fitting are matched in accordance with ASME B16.11 or that socket-welded pipe, flanges, and other fittings greater than NPS 2 meet the fabrication requirements of the applicable Code.
(b) the weld is made as shown in sketch 4.3.
(c) the pipe wall thickness is greater than the lesser of schedule 40 or standard weight.
(d) the weld size C_x is in accordance with the applicable Code. For pipe whose wall thickness is thinner than the lesser of schedule 40 or standard weight, the stress intensification factor for all directions shall be equal to 2.1 unless otherwise justified. Blending the toe of the fillet weld with no undercut smoothly into the pipe wall, as shown in Figure 1-7, illustrations (b) and (d), has been shown to improve the fatigue performance of the weld. Large-diameter socket-welded and slip-on flanges with welds smaller than those required by the applicable Code may induce stresses not considered by the stress intensification factors.

Table 1-2
Moment-Rotation Relationships for Sketches 2.1 Through 2.6 of Table 1-1

Moment (Figure 1-1)	Flexibility Factor, k	Stiffness, in.-lb/rad (N·mm/rad)	Stiffness, in.-lb/rad (N·mm/rad)
M_{i3} (Leg 3)	k_{ib}	M_{ib}/θ_{ib}	$(E)(I_b)/(k_{ib}d)$
M_{o3} (Leg 3)	k_{ob}	M_{ob}/θ_{ob}	$(E)(I_b)/(k_{ob}d)$
M_{t3} (Leg 3)	k_{tb}	M_{tb}/θ_{tb}	$(E)(I_b)/(k_{tb}d)$
$M_{i1,2}$ (Legs 1, 2)	k_{ir}	M_{ir}/θ_{ir}	$(E)(I_r)/(k_{ir}D)$
$M_{o1,2}$ (Legs 1, 2)	k_{or}	M_{or}/θ_{or}	$(E)(I_r)/(k_{or}D)$
$M_{t1,2}$ (Legs 1, 2)	k_{tr}	M_{tr}/θ_{tr}	$(E)(I_r)/(k_{tr}D)$

GENERAL NOTE: The moment-rotation relationships in this table are developed by independently applying moments to the respective run or branch leg. Simultaneous run and branch moment-rotation interaction must be accommodated by the model.

Table 1-3
Flanged End Correction Coefficients for Sketches 2.1 Through 2.6 of Table 1-1

Flexibility Factor	Flexibility Factor Multiplier, c
k_{ib}	$1 - 0.032\ N_c^{1.345}\ (D/T)^{0.431}\ (d/D)^{0.903}$
k_{ob}	$1 - 0.07\ N_c^{0.61}\ (D/T)^{0.44}\ (d/D)^{0.339}$
k_{tb}	$1 - 0.003\ N_c^{3.962}\ (D/T)^{0.548}\ (d/D)^{0.693}$

Figure 1-1
Orientations for Sketches 2.1 Through 2.6 of Table 1-1

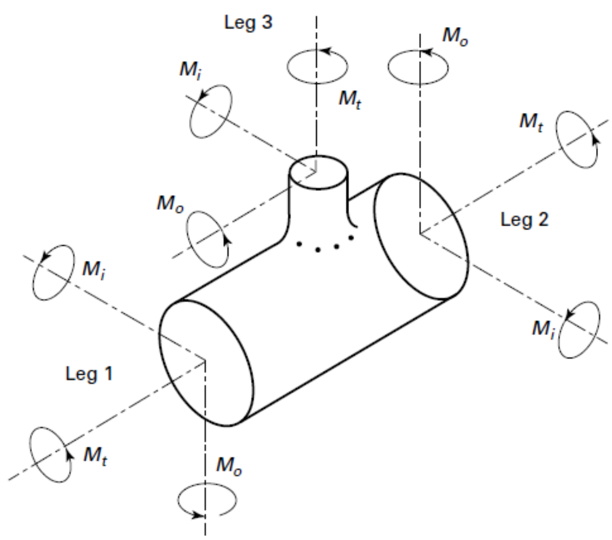


Figure 1-2
Orientations for Bends

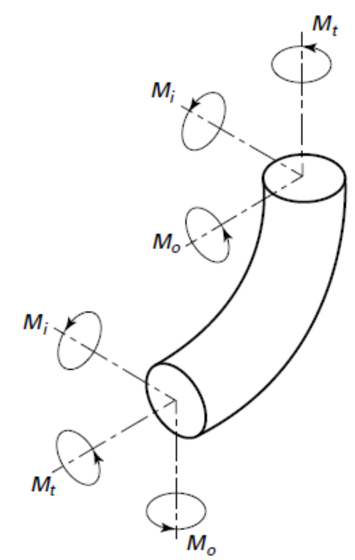


Figure 1-3
Branch Dimensions

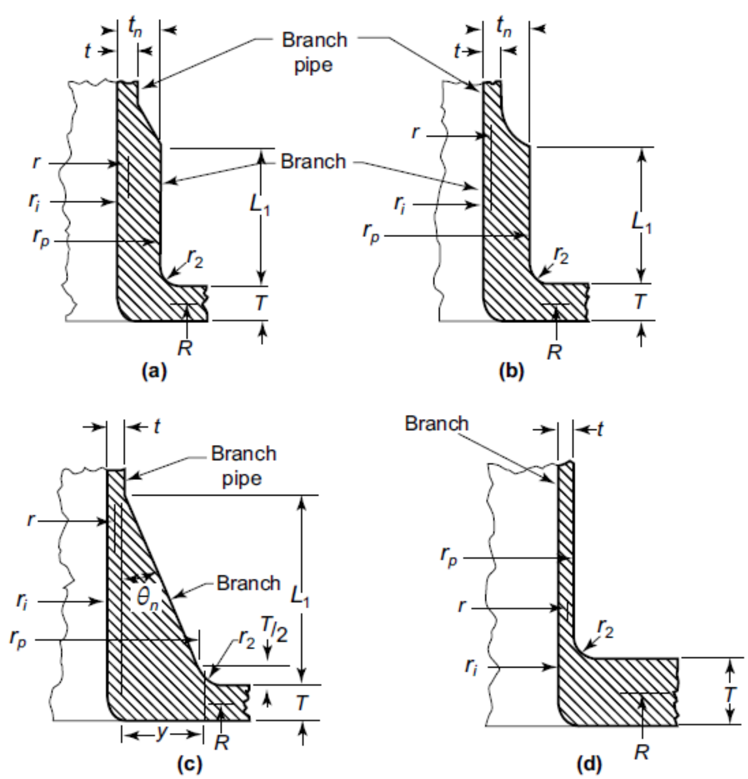


Figure 1-4
Flexibility and Stress Intensification Factors for Bends and Miters

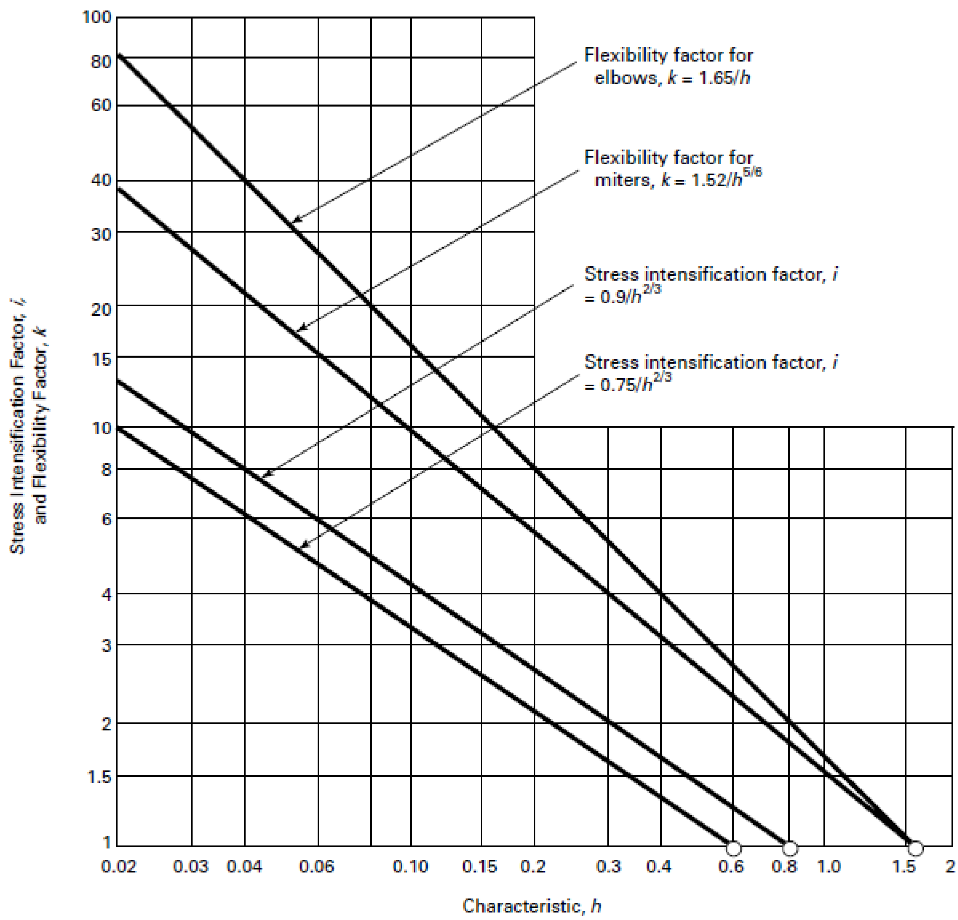


Figure 1-5
Flanged End Corrections for Bends and Miters

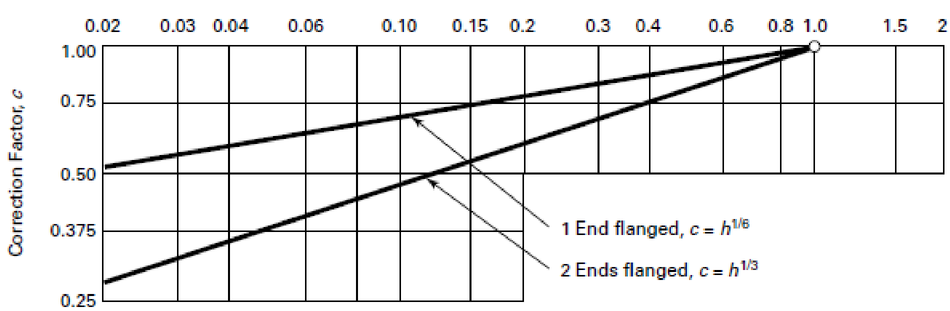
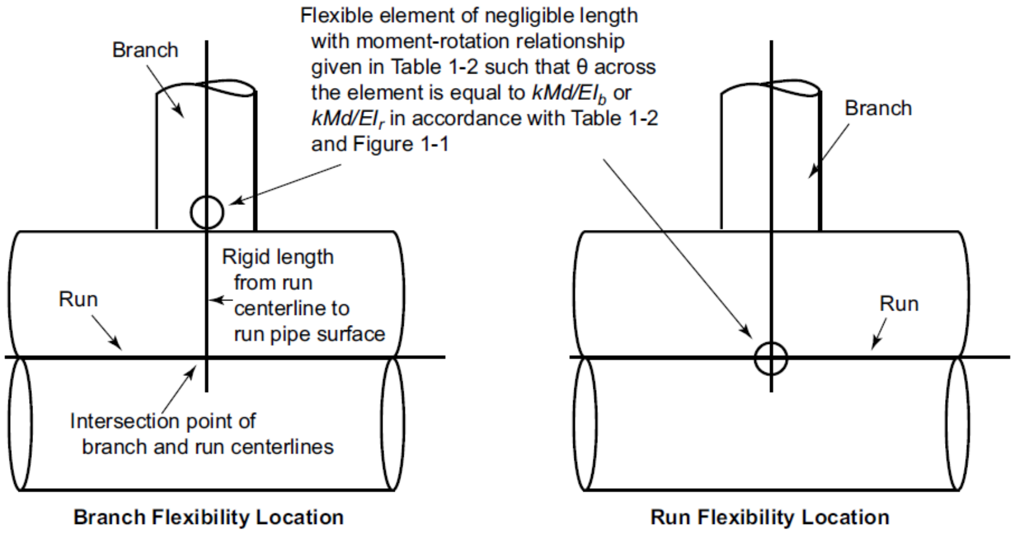
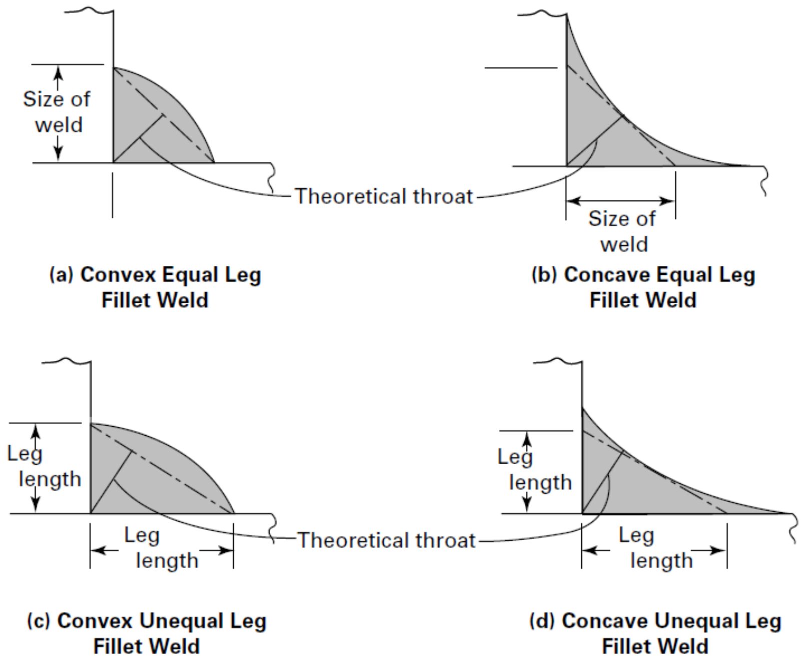


Figure 1-6
Flexibility Element Locations



GENERAL NOTE: See Figure 1-1 for flexibility orientations.

Figure 1-7
Fillet Weld Contours



- Implemented as an optional feature for B31.4, B31.5, B31.8 and B31.12 codes. This feature can be turned ON or OFF through Layout Frame > Options > Analysis.

- Turning on the Option B31J will allow users to select and specify among those Branch SIF types defined in B31J for all the above codes.

- When B31J is turned ON, CAEPIPE will calculate SIFs as per B31J and report Torsional, In-plane and Out-of-plane SIFs in Element Forces and Moments results irrespective of whether they are being used or not in Code Compliance as per the Piping Code selected for Analysis. For Example, CAEPIPE will not include Torsional Moment and Torsional SIF while calculating Sustained Stress as per ASME B31.5 (2016).

- For Equal TEEs, the Run and Branch should be differentiated in CAEPIPE model by defining the Branch OD slightly less than the Run OD through CAEPIPE Sections input. Otherwise, CAEPIPE will use the equations corresponding to Run pipe even for Branch pipe.

- ASME B31.3 (2020) includes the term Axial SIF in Stress Calculations. On the other hand, B31J is silent about the Axial SIF for various components. Hence, CAEPIPE will use the Axial SIF values as stated in the respective text portions of B31.3 (2016) while computing stresses irrespective of whether the option B31J is turned ON or OFF.

- As per para 402.6.1 of ASME B31.4 (2019), Torsion moment is not included in the equation for Sustained Stress for Restrained piping. In line with the code, CAEPIPE will not use Torsion Moment and Torsion SIF while calculating Sustained Stress for Restrained pipe even with the option B31J turned ON.

- For ASME B31.5 (2019), paras. 502.3.2(d), 502.3.3 (a), 519.4.5 and 519.3.5 do not include Torsional moment in computing Stresses. Accordingly, CAEPIPE will not include Torsional Moment and Torsional SIF while calculating Stresses as per ASME B31.5 (2016) even when the option B31J is turned ON.

- For ASME B31.8 (2020), para. 833.2 (e) states that the nominal Bending Stress for Fittings and Components as M_R/Z, where M_R is the resultant intensified moment across the fittings or components with Stress Intensification Factor (SIF) as 0.75i.

  On the other hand, for Pipe and Long Radius Bends, para.833.2 (d) of the Code states that the nominal Bending Stress as M/Z, where M is the bending moment across the pipe cross section without SIF being considered. In other words, the moments are NOT intensified for Pipe and Long Radius Bends.

- As ASME B31.8 (2020) does not include SIF for Pipe and Long Radius Bends in Sustained Stress equation, SIF calculated as per B31J will NOT be included in Sustained Stress calculation for Pipes and Long Radius bends at this time when the option B31J is selected. On the other hand, the SIF calculated as per B31J will be displayed in the Element Forces and Moments results.

- When B31J is turned ON, In-plane and Out-of-plane Flexibility Factors for Bends, Miter bends and TEEs will be calculated as per B31J and included by CAEPIPE in the corresponding element stiffness matrices. Similarly, CAEPIPE will calculate the Torsion Flexibility Factors as per B31J and include them in the element stiffness matrices irrespective of whether the code includes or excludes Torsional Moment and Torsional SIF in Stress equations.

- As it is not possible to identify the number of Flanges or Rigids at Run Pipe ends located within 0.1D^1.4/T^0.4 from Branch intersection node using CAEPIPE (required for applying the correction factor while computing Flexibility Factors as per B31J), a provision is made in the Branch SIF definition to input the no. of Flanges or Rigids that fall within the distance given by B31J.

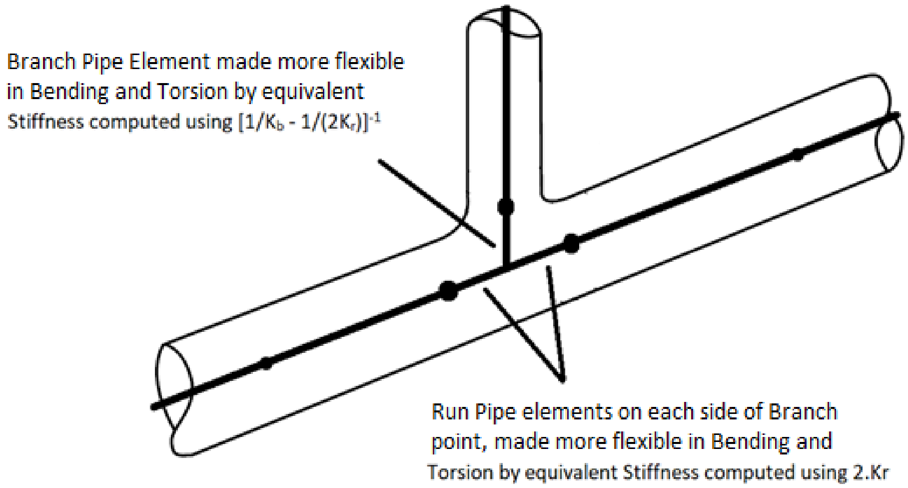
- When the bend angle is 90 degree and the thickness of the bend is equal to the thickness of the matching pipe, the Ki and Ko should be calculated from 1.3/h. This is not implemented in CAEPIPE software at this time.

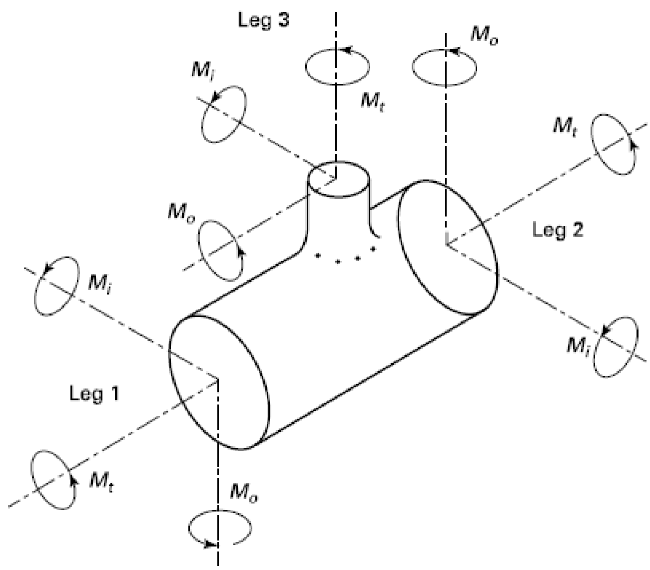
- Flexibility Factors computed for TEEs as per B31J are always applied to both ends of the first elements belonging to Leg 1, Leg 2 and Leg 3 that are connected at the Branch nodeas shown in Figure 1-1 of B31J.

  CAEPIPE includes a feature “Layout Frame > Edit > Refine Branches for B31J” to refine the elements connected to the Branch node to compute and apply Flexibility Factors for Run (Leg 1 and Leg 2) and BranchPipe (Leg 3) as stated above.

  When the above command is used, CAEPIPE will add the following.

  c. Two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Split Factor x Run Pipe OD, where the Run Split Factor can be input by the user.
  d. One (1) node on Branch Pipe at a distance equal to Branch Split Factor x Run Pipe OD from the Branch SIF node, where the Branch Split Factor can be input by the user.





Moment	Flexibility Factor, k	Stiffness, in.-lb/rad (N·mm/rad)	Stiffness, in.-lb/rad (N·mm/rad)	
M_{i3} (Leg 3)	k_{ib}	M_{ib}/θ_{ib}	$(E)(I_b)/(k_{ib}\ d)$	K_b
M_{o3} (Leg 3)	k_{ob}	M_{ob}/θ_{ob}	$(E)(I_b)/(k_{ob}\ d)$	
M_{t3} (Leg 3)	k_{tb}	M_{tb}/θ_{tb}	$(E)(I_b)/(k_{tb}\ d)$	
$M_{i1,2}$ (Legs 1, 2)	k_{ir}	M_{ir}/θ_{ir}	$(E)(I_r)/(k_{ir}\ D)$	K_r
$M_{o1,2}$ (Legs 1, 2)	k_{or}	M_{or}/θ_{or}	$(E)(I_r)/(k_{or}\ D)$	
$M_{t1,2}$ (Legs 1, 2)	k_{tr}	M_{tr}/θ_{tr}	$(E)(I_r)/(k_{tr}\ D)$	

Table 1-1 Flexibility and Stress Intensification Factors

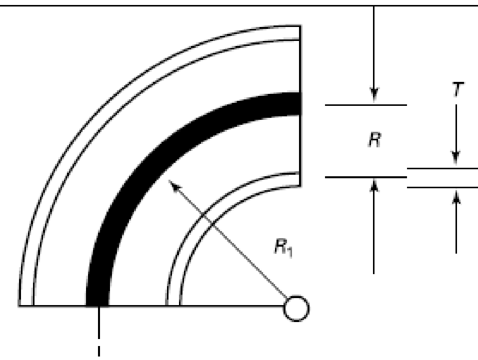
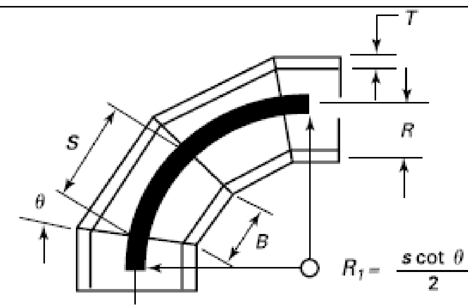
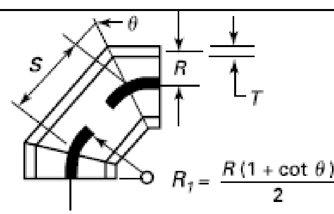
Term	Equation	Sketch
1.1 Pipe Bend or Welding Elbow Meeting ASME B16.9 [Notes (1), (2), (3), (4)]		
Flexibility characteristic, k	TR_1/R^2	
Flexibility factor in plane, k_i	$1.65/k$	
Flexibility factor out of plane, k_o	$1.65/k$	
SIF in plane, i_i	$0.9k^{2/3}$	
SIF out of plane, i_o	$0.75k^{2/3}$	
SIF torsional, i_t	1	
1.2 Closely Spaced Miter Bend, $s < R\,(1 + \tan\theta)$ [Notes (1), (2), (4)]		
Flexibility characteristic, k	$sT\cot\theta/(2R^2)$	
Flexibility factor in plane, k_i	$1.52/k^{5/6}$	
Flexibility factor out of plane, k_o	$1.52/k^{5/6}$	
SIF in plane, i_i	$0.9/k^{2/3}$	
SIF out of plane, i_o	$0.9/k^{2/3}$	
SIF torsional, i_t	1	
1.3 Widely Spaced Miter Bend, $s \geq R\,(1 + \tan\theta)$ [Notes (1), (4), (5)]		
Flexibility characteristic, k	$T\,(1 + \cot\theta)/(2R)$	
Flexibility factor in plane, k_i	$1.52/k^{5/6}$	
Flexibility factor out of plane, k_o	$1.52/k^{5/6}$	
SIF in plane, i_i	$0.9/k^{2/3}$	
SIF out of plane, i_o	$0.9/k^{2/3}$	
SIF torsional, i_t	1	

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

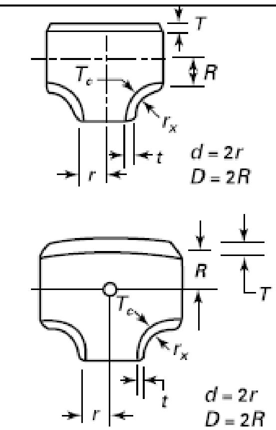
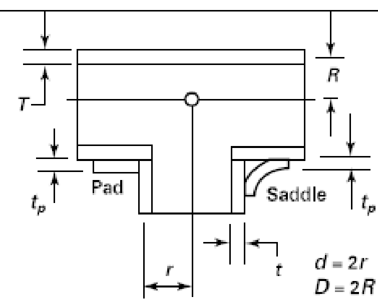
Term	Equation	Sketch
2.1 Welding Tee Meeting ASME B16.9 [Notes (1), (6), (7)]		
Run in-plane flexibility factor, k_{ir}	$0.18(R/T)^{0.8}(d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.08(R/T)^{0.81}(d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[1.91(d/D) - 4.32(d/D)^2 + 2.7(d/D)^3](R/T)^{0.77}(d/D)^{0.47}(t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$[0.34(d/D) - 0.49(d/D)^2 + 0.18(d/D)^3](R/T)^{1.46}(t/T)$	
Branch torsional flexibility factor, k_{tb}	$[1.08(d/D) - 2.44(d/D)^2 + 1.52(d/D)^3](R/T)^{0.77}(d/D)^{1.61}(t/T)$	
Run SIF in plane, i_{ir}	$0.98(R/T)^{0.35}(d/D)^{0.72}(t/T)^{-0.52}$	
Run SIF out of plane, i_{or}	$0.61(R/T)^{0.29}(d/D)^{1.35}(t/T)^{-0.53}$	
Run SIF torsional, i_{tr}	$0.34(R/T)^{2/3}(d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{ib}	$0.33(R/T)^{2/3}(d/D)^{0.18}(t/T)^{0.7}$	
Branch SIF out of plane, i_{ob}	$0.42(R/T)^{2/3}(d/D)^{0.37}(t/T)^{0.37}$	
Branch SIF torsional, i_{tb}	$0.42(R/T)^{2/3}(d/D)^{1.1}(t/T)^{1.1}$	
2.2 Reinforced Fabricated Tee (When t_p > 1.5T, Use t_p = 1.5T) [Notes (1), (7)]		
Run in-plane flexibility factor, k_{ir}	$0.21[R/(T + 0.5t_p)]^{0.87}(t/T)^{-0.65}(d/D)^{6.2}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.12[R/(T + 0.5t_p)]^{1.39}(t/T)^{-0.74}(d/D)^{2.5}$	
Branch in-plane flexibility factor, k_{ib}	$[1.29(d/D) - 2.73(d/D)^2 + 1.62(d/D)^3][R/(T + 0.5t_p)]^{1.2}(t/T)^{0.56}(d/D)^{0.33}$	
Branch out-of-plane flexibility factor, k_{ob}	$[0.84(d/D) - 1.27(d/D)^2 + 0.5(d/D)^3][R/(T + 0.5t_p)]^{1.63}(t/T)^{0.63}(d/D)^{0.21}$	
Branch torsional flexibility factor, k_{tb}	$1.1[R/(T + 0.5t_p)]^{0.5}(d/D)^{5.42}$	
Run SIF in plane, i_{ir}	$[R/(T + 0.5t_p)]^{0.45}(d/D)^{0.54}(t/T)^{0.34} \geq 1.5$	
Run SIF out of plane, i_{or}	$[1.29(d/D) - 2.87(d/D)^2 + 2.39(d/D)^3](t/T)^{-0.25}[R/(T + 0.5t_p)]^{0.35}$	
Run SIF torsional, i_{tr}	$0.36[R/(T + 0.5t_p)]^{2/3}(t/T)^{-0.6}(d/D)^{1.4}$	
Branch SIF in plane, i_{ib}	$[3.33(d/D) - 5.49(d/D)^2 + 2.94(d/D)^3](TR^{2/3})(T + 0.5t_p)^{-5/3}(t/T)^{0.3}$	
Branch SIF out of plane, i_{ob}	$[2.86(d/D) + 2.4(d/D)^2 - 4.34(d/D)^3](TR^{2/3})(T + 0.5t_p)^{-5/3}(t/T)^{0.3}$ (when t/T < 0.85, use t/T = 0.85)	
Branch SIF torsional, i_{tb}	$0.642(d/D)^2(TR^{2/3})(T + 0.5t_p)^{-5/3}(t/T)^{0.3}$	

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

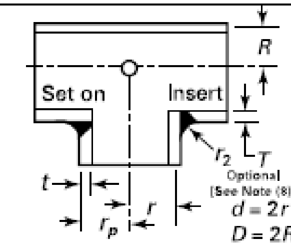
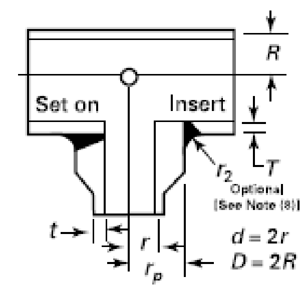
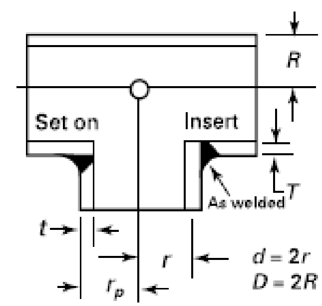
Term	Equation	Sketch
2.3 Fabricated Tee [Notes (1), (7), (8)]		
Run in-plane flexibility factor, k_{ir}	$1.23(R/T)^{0.47}(t/T)^{-0.47}(d/D)^{5.3}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$(R/T)^{0.78}(t/T)^{-0.8}(d/D)^{7.8}$	
Branch in-plane flexibility factor, k_{ib}	$[3.15(d/D) - 6.4(d/D)^2 + 4(d/D)^3](R/T)^{0.83}(t/T)^{0.49}(d/D)^{-0.2}$	
Branch out-of-plane flexibility factor, k_{ob}	$[2.05(d/D) - 2.94(d/D)^2 + 1.1(d/D)^3](R/T)^{1.4}(t/T)^{0.6}(d/D)^{0.12}$	
Branch torsional flexibility factor, k_{tb}	$0.95(R/T)^{0.89}(d/D)^{5.42}$	
Run SIF in plane, i_{ir}	$1.2(d/D)^{0.5}(R/T)^{0.4}(t/T)^{-0.35} \geq 1.5$	
Run SIF out of plane, i_{or}	$[(d/D) - 2.7(d/D)^2 + 2.62(d/D)^3](R/T)^{0.49}(t/T)^{-0.7}$ (when $d/D < 0.5$, use $d/D = 0.5$; when $t/T < 0.5$, use $t/T = 0.5$)	
Run SIF torsional, i_{tr}	$1.2(R/T)^{0.46}(t/T)^{-0.45}(d/D)^{1.37}$ (when $t/T < 0.15$, use $t/T = 0.15$)	
Branch SIF in plane, i_{ib}	$[0.038 + 1.45(d/D) - 2.39(d/D)^2 + 1.34(d/D)^3](R/T)^{0.76}(t/T)^{0.74}$ (when $t/T < 1$, use $t/T = 1$)	
Branch SIF out of plane, i_{ob}	$[0.038 + 2(d/D) + 2(d/D)^2 - 3.1(d/D)^3](R/T)^{2/3}(t/T)$ (when $t/T < 0.85$, use $t/T = 0.85$)	
Branch SIF torsional, i_{tb}	$0.45(R/T)^{0.8}(t/T)^{0.29}(d/D)^2$	

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

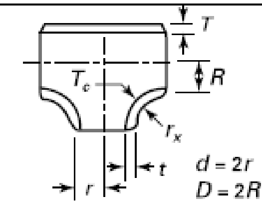
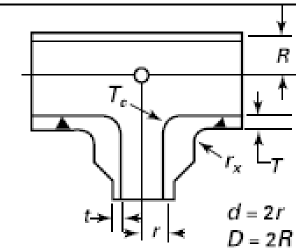
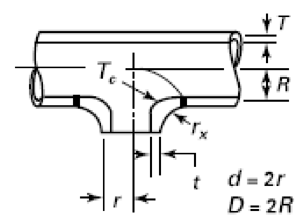
Term	Equation	Sketch
2.4 Extruded Outlet With $r_x \geq 0.05d_o$ and $T < T_c < 1.5T$ [Notes (1), (7), (9)]		
Run in-plane flexibility factor, k_{ir}	$0.18(R/T)^{0.8}(d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.08(R/T)^{0.81}(d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[1.91(d/D) - 4.32(d/D)^2 + 2.7(d/D)^3](R/T)^{0.77}(d/D)^{0.47}(t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$[0.34(d/D) - 0.49(d/D)^2 + 0.18(d/D)^3](R/T)^{1.46}(t/T)$	
Branch torsional flexibility factor, k_{tb}	$[1.08(d/D) - 2.44(d/D)^2 + 1.52(d/D)^3](R/T)^{0.77}(d/D)^{1.79}(t/T)$	
Run SIF in plane, i_{ir}	$1.45(1 + r_x/R)^{-2/3}(R/T)^{0.35}(d/D)^{0.72}(t/T)^{0.52}$	
Run SIF out of plane, i_{or}	$0.58(1 + r_x/R)^{-2/3}(R/T)^{2/3}(d/D)^{2.69}$	
Run SIF torsional, i_{tr}	$0.55(1 + r_x/R)^{-2/3}(R/T)^{2/3}(d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{ib}	$0.56(1 + r_x/R)^{-2/3}(R/T)^{2/3}(d/D)^{0.68}$	
Branch SIF out of plane, i_{ob}	$0.85(1 + r_x/R)^{-2/3}(R/T)^{2/3}(d/D)^{0.5}$	
Branch SIF torsional, i_{tb}	$0.71(1 + r_x/R)^{-2/3}(R/T)^{2/3}(d/D)^{2}$	
2.5 Welded-in Contour Insert (When r_x Is Not Provided, Use $r_x = 0$) [Notes (1), (6), (7)]		
Run in-plane flexibility factor, k_{ir}	$0.18(R/T)^{0.84}(d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.1(R/T)^{0.91}(d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[2.36(d/D) - 5.33(d/D)^2 + 3.33(d/D)^3](R/T)^{0.77}(d/D)^{0.47}(t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$(1 + r_x/R)[0.67(d/D) - 0.97(d/D)^2 + 0.36(d/D)^3](R/T)^{1.46}(t/T)$	
Branch torsional flexibility factor, k_{tb}	$[1.05(d/D) - 2.36(d/D)^2 + 1.49(d/D)^3](R/T)^{0.77}(d/D)^{1.61}(t/T)$	
Run SIF in plane, i_{ir}	$(R/T)^{0.35}(d/D)^{0.72}(t/T)^{-0.52}$	
Run SIF out of plane, i_{or}	$0.72(R/T)^{0.29}(d/D)^{1.95}(t/T)^{-0.53}$	
Run SIF torsional, i_{tr}	$0.36(R/T)^{2/3}(d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{ib}	$0.35(R/T)^{2/3}(d/D)^{0.18}(t/T)^{0.7}$	
Branch SIF out of plane, i_{ob}	$0.48(R/T)^{2/3}(d/D)^{0.37}(t/T)^{0.37}$	
Branch SIF torsional, i_{tb}	$0.44(R/T)^{2/3}(d/D)^{1.1}(t/T)^{1.1}$	

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

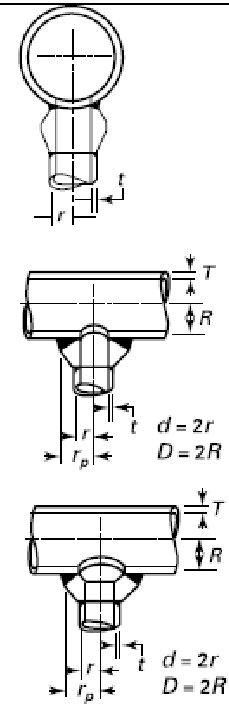
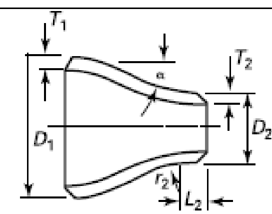
Term	Equation	Sketch
2.6 Integrally Reinforced Branch Welded-on Fittings [Notes (1), (7), (10)]		
Run in-plane flexibility factor, k_{ir}	$0.5(R/T)^{0.5}(d/D)^{5}$	
Run out-of-plane flexibility factor, k_{or}	1	
Run torsional flexibility factor, k_{tr}	$0.1(R/T)(d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{ib}	$[0.55(d/D) - 1.13(d/D)^{2} + 0.69(d/D)^{3}](R/T)(t/T)$	
Branch out-of-plane flexibility factor, k_{ob}	$[1.03(d/D) - 1.55(d/D)^{2} + 0.59(d/D)^{3}](R/T)^{1.4}(t/T)(d/D)^{0.33}$	
Branch torsional flexibility factor, k_{tb}	$[0.37(d/D) - 0.75(d/D)^{2} + 0.46(d/D)^{3}](R/T)(t/T)(d/D)^{1.2}$	
Run SIF in plane, i_{ir}	$(R/T)^{0.43}(d/D)^{0.2} \geq 1.5$	
Run SIF out of plane, i_{or}	$[0.02 + 0.88(d/D) - 2.56(d/D)^{2} + 2.58(d/D)^{3}](R/T)^{0.43}$	
Run SIF torsional, i_{tr}	$1.3(R/T)^{0.45}(d/D)^{1.37}$	
Branch SIF in plane, i_{ib}	$[0.08 + 1.28(d/D) - 2.35(d/D)^{2} + 1.45(d/D)^{3}](R/T)^{0.81}(t/T)(r/r_p)$	
Branch SIF out of plane, i_{ob}	$[1.83(d/D) - 1.07(d/D)^{3}](R/T)^{0.82}(t/T)(r/r_p)^{1.18}$	
Branch SIF torsional, i_{tb}	$0.77(R/T)^{2/3}(t/T)(d/D)^{2}(r/r_p)$	
3.1 Concentric or Eccentric Reducer Meeting ASME B16.9 [Note (11)]		
SIF in plane, i_i	$0.6 + 0.003(\alpha T_2/T_1)^{0.8}(D_2/T_2)^{0.25}(D_2/r_2)$	
SIF out of plane, i_o	$0.6 + 0.003(\alpha T_2/T_1)^{0.8}(D_2/T_2)^{0.25}(D_2/r_2)$	
SIF torsional, i_t	$0.3 + 0.0015(\alpha T_2/T_1)^{0.8}(D_2/T_2)^{0.25}(D_2/r_2)$	

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

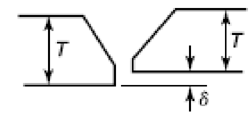
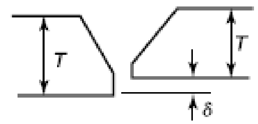
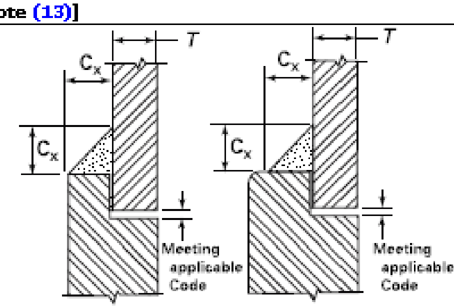
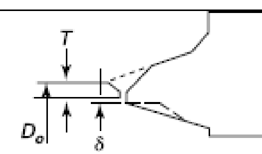
Term	Equation	Sketch
4.1 Butt Weld, $T \geq$ 6 mm (0.237 in.), $\delta_{max} \leq$ 1.5 mm (1/16 in.), and $\delta_{avg}/T \leq$ 0.13 [Note (12)]		
SIF in plane, i_i	1.0	
SIF out of plane, i_o	1.0	
SIF torsional, i_t	1.0	
4.2 Butt Weld, $T \geq$ 6 mm (0.237 in.), $\delta_{max} \leq$ 3 mm (1/8 in.), and δ_{avg}/T = Any Value OR $T <$ 6 mm (0.237 in.), $\delta_{max} \leq$ 1.5 mm (1/16 in.), and $\delta_{avg}/T \leq$ 0.33 [Note (12)]		
SIF in plane, i_i	1.9 max. or $0.9 + 2.7(\delta_{avg}/T)$ but not less than 1.0	
SIF out of plane, i_o	1.9 max. or $0.9 + 2.7(\delta_{avg}/T)$ but not less than 1.0	
SIF torsional, i_t	$0.45 + 1.35(\delta_{avg}/T)$ but not less than 1.0	
4.3 Fillet-Welded Joint or Socket-Welded Flange Meeting ASME B16.5 or Socket-Welded Fitting Meeting ASME B16.11 [Note (13)]		
SIF in plane, i_i	1.3	
SIF out of plane, i_o	1.3	
SIF torsional, i_t	1.3	
4.4 Tapered Transition in Accordance With Applicable Code Sections and ASME B16.25		
SIF in plane, i_i	1.9 max. or $1.3 + 0.0036(D_o/T) + 3.6(\delta/T)$	
SIF out of plane, i_o	1.9 max. or $1.3 + 0.0036(D_o/T) + 3.6(\delta/T)$	
SIF torsional, i_t	1.3	
4.5 Weld Neck Flange		
SIF in plane, i_i	1.0	...
SIF out of plane, i_o	1.0	
SIF torsional, i_t	1.0	

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

Term	Equation	Sketch
4.6 Single Welded Slip-on Flange		
SIF in plane, i_i	1.3	...
SIF out of plane, i_o	1.3	
SIF torsional, i_t	1.3	
4.7 Double Welded Slip-on Flange		
SIF in plane, i_i	1.2	...
SIF out of plane, i_o	1.2	
SIF torsional, i_t	1.2	
4.8 Lap Joint Flange (With ASME B16.9 Lap Joint Stub)		
SIF in plane, i_i	1.6	...
SIF out of plane, i_o	1.6	
SIF torsional, i_t	1.6	
5.1 Threaded Pipe Joint or Threaded Flange in Accordance With Acceptable Code Detail		
SIF in plane, i_i	2.3	...
SIF out of plane, i_o	2.3	
SIF torsional, i_t	2.3	

GENERAL NOTES:
(a) The following symbols are used in this table:

A_p = metal area of pipe cross section, in.^{2} (mm^2)
B = length of miter segment at crotch, in. (mm)
b = branch subscript corresponding to Leg 3 in Figure 1-1
c = factor for rigid ends adjacent to bends, miters, and branch connections in Sketches 1.1, 1.2, and 2.1 through 2.6
C_x = minimum socket weld leg length, in. (mm)
D = mean diameter of matching pipe found from (D_o − T), in. (mm); for Sketches 2.1 through 2.6, the mean diameter of the matching run pipe
d = mean diameter of matching branch pipe found from (d_o − t), in. (mm)
d' = effective branch diameter used with Figure 1-3, illustrations (a), (b), and (c), in. (mm)
D_1, D_2 = outside diameter of matching pipe at large and small ends of reducer, respectively, in. (mm)
D_i = inside diameter of matching run pipe found from (D_o − $2T$), in. (mm)
d_i = inside diameter of matching branch pipe found from (d_o − $2t$), in. (mm)
D_o = outside diameter of matching pipe, in. (mm)
d_o = outside diameter of the matching branch pipe, in. (mm); for Sketches 2.1 through 2.6, the outside diameter of the matching run pipe
E = modulus of elasticity, psi (kPa)
i = stress intensification factor (SIF)
I_b, I_r = matching branch and run pipe moment of inertia used in Table 1-2, in.^{4} (mm^4)
k = flexibility factor with respect to the plane and component indicated (see Nonmandatory Appendix B, Ref. [1] for a more detailed definition of flexibility factor as it applies to straight and curved pipe and branch connections)
L_1 = length of taper or thicker branch section in Figure 1-2, in. (mm)
L_2 = length of the cylindrical portion at the small end of the reducer in Sketch 3.1, in. (mm)
M = moment on branch or run legs shown in Figure 1-1, in.-lb (N·mm)

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

GENERAL NOTES (Cont'd):

N_c = number of flanges or other rigid components adjacent to the run pipe end of a branch connection (1 or 2)
P = gage pressure, psi (MPa)
R = mean radius of matching pipe found from $(D_o - T)/2$, in. (mm)
r = mean radius of matching branch pipe found from $(d_o - t)/2$ for Sketches 2.1 through 2.6, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_2 = radii used with Figure 1-3 and in Sketch 3.1, in. (mm)
r_i = inside radius used with Figure 1-3, in. (mm)
r_p = radius to outside edge of fitting for Sketches 2.3 and 2.6 measured in longitudinal plane, in. (mm)
r_x = external crotch radius of welding tee in accordance with ASME B16.9, extruded outlet and welded-in contour insert (Sketches 2.1, 2.4, and 2.5), measured in the plane containing the centerline axes of the run and branch, in. (mm)
s = miter spacing at centerline, in. (mm)
SIF = stress intensification factor
T = nominal wall thickness of matching pipe or the average wall thickness of the fitting, if available, for welding elbows in Sketch 1.1; nominal wall thickness of pipe or the average wall thickness of the fitting, if available, for pipe bends in Sketch 1.1; nominal wall thickness of pipe for miter bends in Sketches 1.2 and 1.3; nominal wall thickness of matching run pipe for tees in Sketches 2.1 and 2.4; nominal wall thickness of run pipe for tees in Sketches 2.2, 2.3, 2.5, and 2.6; nominal wall thickness of pipe for weld joints in Sketches 4.1 through 4.4
t = nominal wall thickness of matching branch pipe, in. (mm)
t' = effective branch thickness used with Figure 1-3, illustrations (a), (b), and (c), in. (mm)
T_1, T_2 = nominal wall thickness of matching pipe at the large and small ends of the reducer, respectively, in. (mm)
T_c = crotch thickness in Sketches 2.1, 2.4, and 2.5 measured at the center of the crotch and in the plane shown, in. (mm)
t_n = local branch pipe thickness used with Figure 1-3, illustrations (a) and (b), in. (mm)
t_p = reinforcement pad or saddle thickness, in. (mm)
y = large end of taper used with Figure 1-3, illustration (c), and found from $(L_1 \tan \theta_n)$, in. (mm)
Z = section modulus of pipe, in.^{3} (mm^3) [see Note (7)]
Z_b = section modulus of matching branch pipe, in.^{3} (mm^3) [see Note (7)]
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg
θ_n = angle used with Figure 1-3, illustration (c), deg
θ_{ib}, θ_{ob}, θ_{tb}, θ_{ir}, θ_{or}, θ_{tr} = rotations at branch or run legs shown in Figure 1-1, rad

(b) Stress intensification and flexibility factor data in this table shall be used in the absence of more directly applicable data. Their validity has been demonstrated for $D/T \le 100$. Other limits are provided as needed below.

(1) Flexibility and stress intensification factors shall not be less than 1.0.
(2) Stress intensification factors may be used without flexibility factors.
(3) Stress intensification and flexibility factors in this table have been developed from fatigue tests of representative commercially available matching product forms with assemblies manufactured from ductile ferrous materials and from numerical analysis using finite elements. Caution should be exercised when applying these rules for certain nonferrous materials (e.g., copper and aluminum alloys) for other than low-cycle applications.
(4) Corrugated straight pipe or corrugated or creased bends should be designed using the principles found in ASME B31.3 Nonmandatory Appendix X, standards from the Expansion Joint Manufacturers Association, or similar standards.

(c) The highest in-plane or out-of-plane stress intensification factor shall be used when only a single stress intensification factor is needed. Flexibility factors should always be used with the orientation specified. For Sketches 3.1 through 5.1, the in-plane and out-of-plane orientations must be orthogonal to each other and to the pipe axis.

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

GENERAL NOTES (Cont'd):

(d) Where sustained stress or moment factors are required by the applicable Code (e.g., ASME B31.1, ASME B31.3), and in lieu of more applicable data, for components of Sketches 1.1, 1.3, 2.1, and 2.2, the directional sustained stress or moment multiplier can be taken as the component stress intensification factor. For all components of Sketch 1.2, the directional sustained stress or moment multiplier can be conservatively taken as the smaller of (1) and either (2) or (3) below

(1) 0.75 times the applicable stress intensification factor

(2) (t/T) times the square root of the applicable stress intensification factor when $t/T > 1$

(3) the square root of the applicable stress intensification factor when $t/T \le 1$

The sustained stress or moment factors should always be used with the section modulus of the matching pipe and should not be less than 1.0.

NOTES:

(1) Stress intensification and flexibility factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and may be read from Figure 1-4. Stress intensification factors for Sketches 2.1 through 2.6 apply to the intersection point for Legs 1 and 2 as shown in Figures 1-1 and 1-6. Stress intensification factors apply to the intersection point for branch Leg 3 in Figures 1-1 and 1-6 when $d_o/D_o > 0.5$, and to the branch centerline at the surface of the run pipe when $d_o/D_o \le 0.5$. Flexibility factors for Sketches 2.1 through 2.6 shall be applied as shown in Figures 1.1 and 1.6 for all d_o/D_o

(2) Where flanges or other rigid components are attached to one or both ends, the in-plane and out-of-plane values of k and i shall be multiplied by the factor c from Figure 1-5, entering with the computed k.

(3) When the bend angle is 90 deg and the thickness of the bend is equal to the thickness of the matching pipe, the flexibility factors k_i and k_o may be found from $1.3/k$ and adjusted by the factor c from Figure 1-5 where applicable.

(4) In large-diameter thin-wall elbows and bends, pressure can affect the magnitudes of k and i. To correct values from this table, divide k by

$$\left[1 + 6\left(\frac{P}{E}\right)\left(\frac{R}{T}\right)^{7/3}\left(\frac{R_1}{R}\right)^{1/3}\right]$$

and divide i by

$$\left[1 + 3.25\left(\frac{P}{E}\right)\left(\frac{R}{T}\right)^{5/2}\left(\frac{R_1}{R}\right)^{2/3}\right]$$

For consistency, use kPa and mm for SI and psi and in. for U.S. customary notation. Stress intensification factors shall be used with the section modulus of the matching pipe or the section modulus of the bend, whichever is smaller.

(5) Sketch 1.3 includes single miter joints.

(6) If $r_x \ge (1/8)(d_o)$ and $T_c \ge 1.5T$, the factors k and i may be divided by 1.26.

(7) The flexibility and stress intensification factors apply only if the following conditions are satisfied:

(a) The branch pipe axis is normal to within 5 deg of the surface of the run pipe unless otherwise noted.

(b) $R/T \le 50$

(c) $d/D \le 1$

(d) $r/t \le 50$

(e) The matching run pipe thickness, T, and diameter, D, are maintained for at least two run pipe diameters on each side of the branch centerline.

(f) For Sketches 2.1, 2.4, and 2.5, $t/T \le 1.2$ and $T_c/T > 1.1$.

When a Table 1-2 flexibility factor is less than or equal to 1.0, the stiffness associated with that flexibility factor shall be rigid. Flexibility factors k_{ib}, k_{ob}, and k_{tb} in Sketches 2.1 through 2.6 shall be multiplied by the factor c from Table 1-3 when flanges or other rigid components are adjacent to one or more of the run pipe ends. A flange or other rigid component is adjacent to the run pipe end when the length of any straight run pipe between the branch and the flange or rigid component is less than $0.1D^{1.4}/T^{0.4}$. Stress intensification factors i_{ib}, i_{ob}, i_{tb}, i_{ir}, i_{or}, and i_{tr} and flexibility factors k_{ib}, k_{ob}, k_{tb}, k_{ir}, k_{or}, and k_{tr} in Sketches 2.1, 2.2, 2.4, 2.5, and 2.6 shall not be greater than the corresponding stress intensification and flexibility factors for Sketch 2.3 and Figure 1-3, illustration (d), calculated using matching branch and run pipe dimensions and $r_2 = 0$. Stress intensification factors i_{ib}, i_{ob}, i_{tb}, i_{ir}, i_{or}, and i_{tr} and flexibility factors k_{ib}, k_{ob}, k_{tb}, k_{ir}, k_{or}, and k_{tr} in Sketches 2.2, 2.3, 2.4, 2.5, and 2.6 shall not be less than the corresponding stress intensification and flexibility factors for Sketch 2.1 calculated using $T_c = 1.1T$.

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

If $i_{ob} < i_{ib}$ for any of Sketches 2.1 through 2.6, then use $i_{ob} = i_{ib}$. If $i_{ir} < i_{or}$ for any of Sketches 2.1 through 2.6, then use $i_{ir} = i_{or}$. Stress intensification factors i_{ib}, i_{ob}, i_{ir}, i_{or}, and i_{tr} from this table can be used for Sketches 2.2, 2.3, 2.5, and 2.6 when the branch pipe axis is in the same plane as the run pipe axis and is normal to within 45 deg of the surface of the run pipe, provided $D/T < 50$ and $d/D \leq 0.6$; in the absence of more applicable data, i_{tb} can be taken equal to i_{ob}. The stress intensification factor i_{ob} in Sketch 2.3 shall be multiplied by the larger of $[0.75(t/T) - 0.89(t/T)^2 + 0.18](D/T)^{0.34}$ or 1.0 when $t/T \leq 0.85$, $d/D < 1$, and $D/T \geq 25$.

The stress intensification factor i_{ob} in Sketch 2.2 shall be multiplied by the larger of $[1.07(t/T) - 1.08(t/T)^2 + 0.026](D/T)^{0.34}$ or 1.0 when $t/T \leq 0.85$, $d/D < 1$, and $D/T \geq 25$.

The designer must be satisfied that the branch connection pressure rating is greater than or equal to that of the matching run pipe. Branch connection stress intensification factors shall be used with the section modulus of the matching pipe. The section modulus shall be calculated using the following equation for the run:

$$Z = \left(\frac{\pi}{32}\right)\left(\frac{D_o^4 - D_i^4}{D_o}\right)$$

and by the following equation for the branch:

$$Z_b = \left(\frac{\pi}{32}\right)\left(\frac{d_o^4 - d_i^4}{d_o}\right)$$

(8) The in-plane, out-of-plane, and torsional stress intensification factors for both the branch and the run may be multiplied by the factor 0.7 for the geometries shown in Figure 1-3 when the outer radius r_2 is provided and is not less than the smallest of $T/2$, $t/2$, $(r_p - r_i)/2$, or $(t + y)/2$. For Figure 1-3, illustrations (a), (b), and (c), the following hold:

(a) Flexibility and stress intensification factors shall be calculated by replacing the parameters t/T with t'/T and d/D with d'/D.

(b) Stress intensification factors i_{ib}, i_{ob}, and i_{tb} and flexibility factors k_{ib}, k_{ob}, and k_{tb} shall also be multiplied by $(t/t')(d/d')^2$.

(c) Calculate t' as follows

(-1) For Figure 1-3, illustrations (a) and (b)

$$\begin{aligned} t' &= t_n \text{ if } L_1 \geq 0.5(2r\ t_n)^{1/2} \\ &= t \text{ if } L_1 < 0.5(2r\ t_n)^{1/2} \end{aligned}$$

(-2) For Figure 1-3, illustration (c)

$$\begin{aligned} t' &= t + (2/3)y \text{ if } \theta_n \leq 30 \text{ deg} \\ &= t + 0.385L_1 \text{ if } \theta_n > 30 \text{ deg} \end{aligned}$$

(d) Calculate d' as follows

$$d' = d - t + t'$$

(e) Stress intensification factors i_{ib}, i_{ob}, i_{ir}, and i_{or} shall not be less than 1.5.

(9) When r_x is not provided, use $r_x = 0.05d_o$. If $r_x/r > 1$ use $r_x/r = 1$.

(10) When r/r_p is not available, a value of 0.85 may be used. If $r/r_p < 0.6$, then use $r/r_p = 0.6$. For size-on-size branch connections when $D/T < 40$, i_{ob} may be multiplied by 0.75. When the weld sizes and actual dimensions of the fitting are available, r_p can be taken as the distance along the surface of the run pipe from the branch centerline to the toe of the attachment fillet weld in the longitudinal plane. When $d/D > 0.8$, the geometry of commercially available fittings varies considerably from manufacturer to manufacturer. More applicable data from the manufacturer should be used when available. Results from tests where $D/T < 40$ should not be extrapolated to branch connections where $D/T > 40$.

(11) The flexibility and stress intensification factors apply only if the following conditions are satisfied:

(a) 5 deg $< \alpha <$ 60 deg

(b) $5 < D_2/T_2 < 80$

(c) The wall thickness is not less than T_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than T_2.

(d) $0.08 < r_2/D_2 < 0.7$

(e) $1 < T_1/T_2 < 2.12$

(f) If $L_2 < (D_2T_2)^{0.5}$, the stress intensification factors should be multiplied by $[2 - L_2/(D_2T_2)^{0.5}]$.

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)

NOTES (Cont'd):

The maximum stress intensification factor need not be greater than 2.0 but shall in no case be less than 1.0. Reducers with $D_2/T_2 \leq 55$ can be modeled as a step change in diameter and thickness from D_2, T_2 to D_1, T_1 at the middle of the reducer, or with any more applicable geometry. When $D_2/T_2 > 55$, consideration should be given to adding flexibility to the beam model to more accurately represent the stiffness of the reducer. For eccentric reducers, the dimensions shown in Sketch 3.1 are to be taken at the location on the circumference where α is the maximum. When r_2 is not given, use $r_2 = 0.1D_1$. When L_2 is not given, use $L_2 = 0.1D_2$. When α is not given, use α equal to the smaller of $60(D_1/D_2 - 1)$ or 60.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between 0.875T and 1.10T for an axial distance of $(D_oT)^{1/2}$. D_o and T are the nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) For welds to socket-welded flanges and fittings, the stress intensification factor is based on the following:

(a) the assumption that the pipe and fitting are matched in accordance with ASME B16.11 or that socket-welded pipe, flanges, and other fittings greater than NPS 2 meet the fabrication requirements of the applicable Code

(b) the weld is made as shown in Sketch 4.3

(c) the pipe wall thickness is greater than the lesser of schedule 40 or standard weight

(d) the weld size C_x is in accordance with the applicable Code. For pipe whose wall thickness is thinner than the lesser of schedule 40 or standard weight, the stress intensification factor for all directions shall be equal to 2.1 unless otherwise justified. Blending the toe of the fillet weld with no undercut smoothly into the pipe wall, as shown in Figure 1-7, illustrations (b) and (d), has been shown to improve the fatigue performance of the weld. Large-diameter socket-welded and slip-on flanges with welds smaller than those required by the applicable Code may induce stresses not considered by the stress intensification factors.

Table 1-2 Moment-Rotation Relationships for Sketches 2.1 Through 2.6 of Table 1-1

Moment (Figure 1-1)	Flexibility Factor, k	Stiffness, in.-lb/rad (N·mm/rad)	Stiffness, in.-lb/rad (N·mm/rad)
M_{i3} (Leg 3)	k_{ib}	M_{ib} / θ_{ib}	$(E)(I_b)/(k_{ib}\ d)$
M_{o3} (Leg 3)	k_{ob}	M_{ob} / θ_{ob}	$(E)(I_b)/(k_{ob}\ d)$
M_{t3} (Leg 3)	k_{tb}	M_{tb} / θ_{tb}	$(E)(I_b)/(k_{tb}\ d)$
$M_{i1,2}$ (Legs 1, 2)	k_{ir}	M_{ir} / θ_{ir}	$(E)(I_r)/(k_{ir}\ D)$
$M_{o1,2}$ (Legs 1, 2)	k_{or}	M_{or} / θ_{or}	$(E)(I_r)/(k_{or}\ D)$
$M_{t1,2}$ (Legs 1, 2)	k_{tr}	M_{tr} / θ_{tr}	$(E)(I_r)/(k_{tr}\ D)$

GENERAL NOTE: The moment-rotation relationships in this table are developed by independently applying moments to the respective run or branch leg. Simultaneous run and branch moment-rotation interaction must be accommodated by the model.

Table 1-3 Flanged End Correction Coefficients for Sketches 2.1 through 2.6 of Table 1-1

Flexibility Factor	Flexibility Factor Multiplier, c
k_{ib}	$1 - 0.032\ N_c^{1.346}\ (D/T)^{0.431}\ (d/D)^{0.903}$
k_{ob}	$1 - 0.07\ N_c^{0.61}\ (D/T)^{0.44}\ (d/D)^{0.339}$
k_{tb}	$1 - 0.003\ N_c^{3.962}\ (D/T)^{0.148}\ (d/D)^{0.693}$

Figure 1-1 Orientations for Sketches 2.1 Through 2.6 of Table 1-1

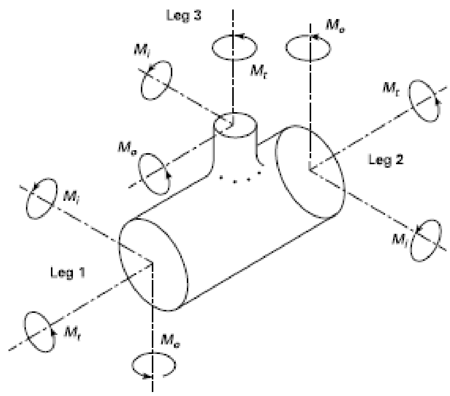


Figure 1-2 Orientations for Bends

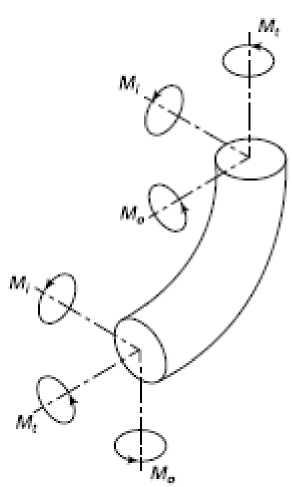


Figure 1-3 Branch Dimensions

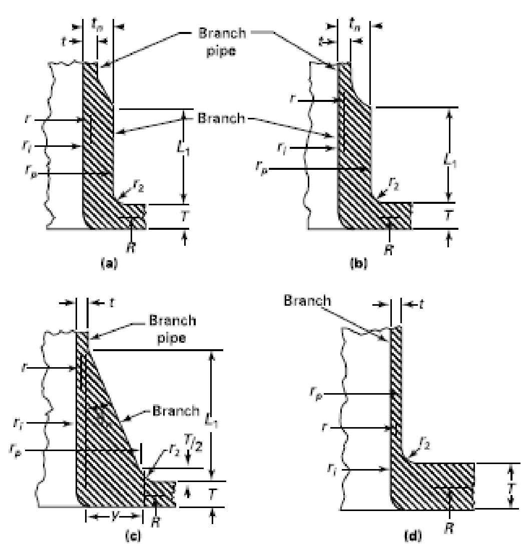


Figure 1-4 Flexibility and Stress Intensification Factors for Bends and Miters

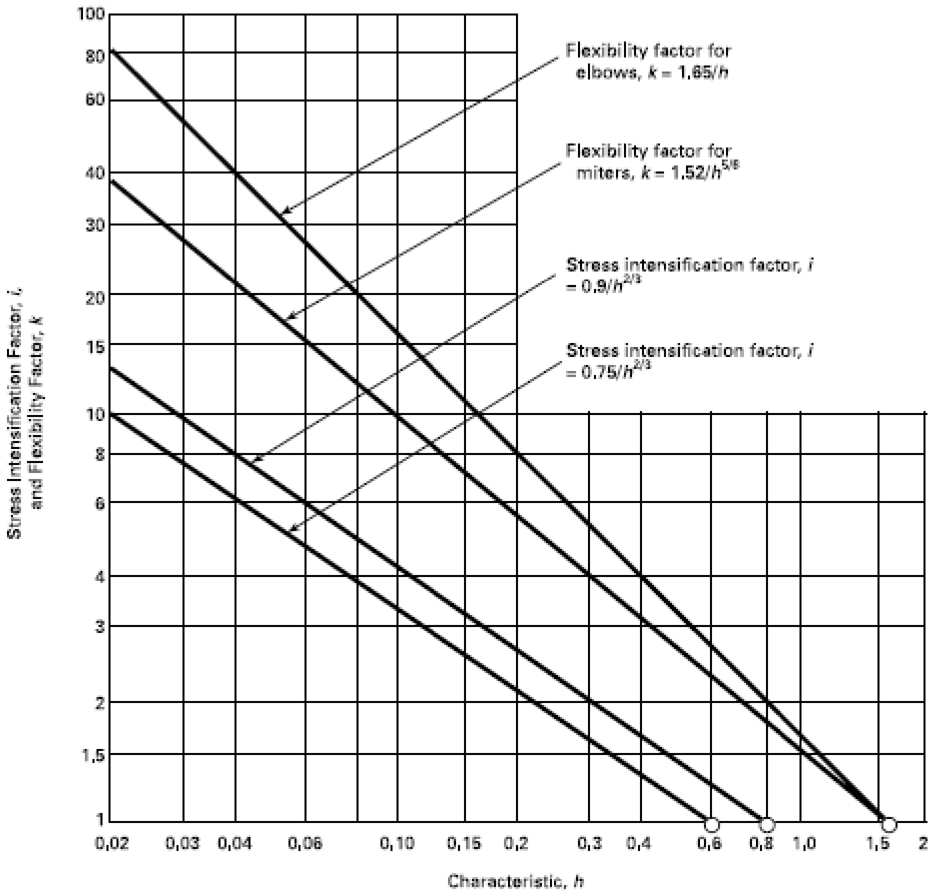


Figure 1-5 Flanged End Corrections for Bends and Miters

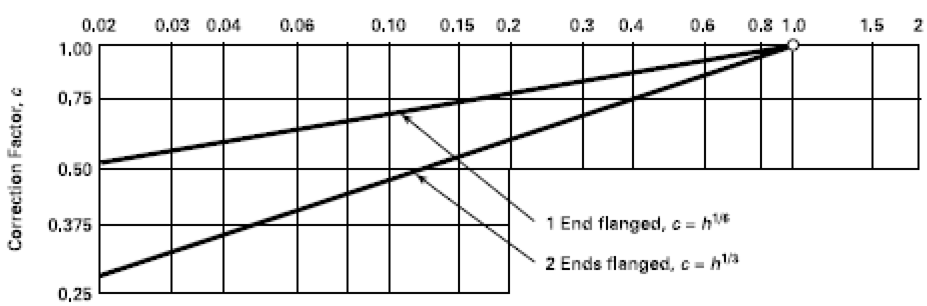
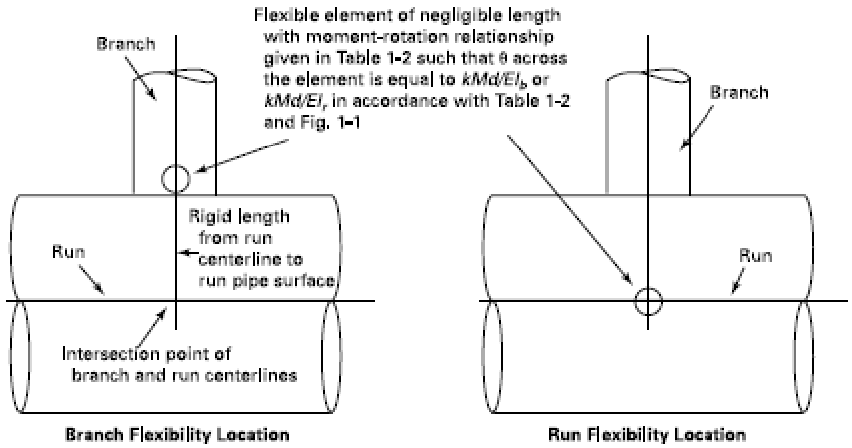
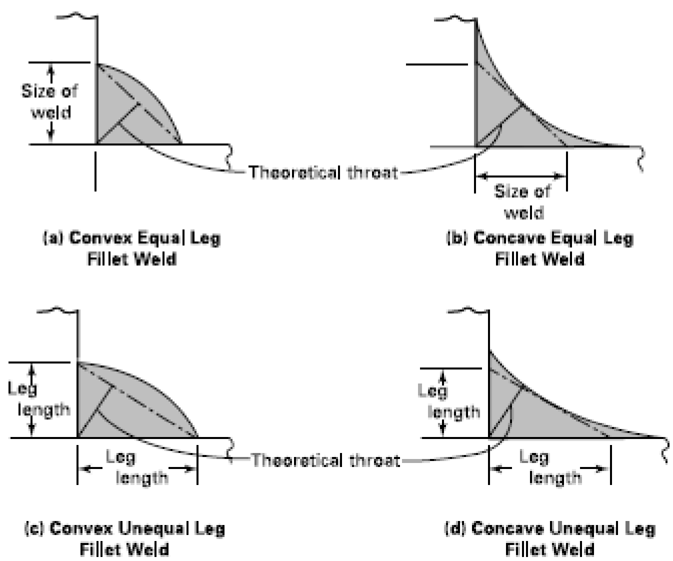


Figure 1-6 Flexibility Element Locations



GENERAL NOTE: See Figure 1-1 for flexibility orientations.

Figure 1-7 Fillet Weld Contours



Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

$$P = \frac{2SEt_m}{D - 2Yt_m}$$

where

P = allowable pressure
S = allowable stress
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowances
= $t \times$ (1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D+d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 9 of NC-3652.

$$S_L = \frac{PD}{4t} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum pressure
D = outside diameter
t = nominal wall thickness
i = stress intensification factor. The product 0.75i, shall not be less than 1.0
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus, for reduced outlets, effective section modulus
S_h = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) such as earthquake or wind from Equation 10 of NC-3652.2. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 11 of NC-3652.3.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where
M_C = resultant moment due to thermal expansion
S_A = $f(1.25S_c + 0.25S_h)$
S_c = allowable stress at cold temperature
f = stress range reduction factor from Table NC-3611.2(e)-1
The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 13 of NC-3652.2.

$$S_{TE} = S_L + S_E \leq S_h + S_A$$

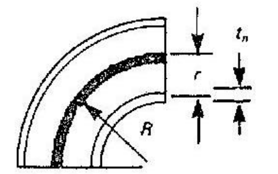
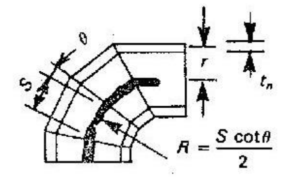
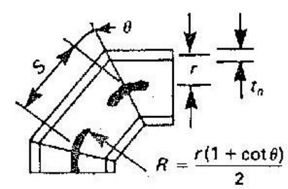
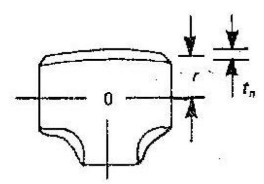
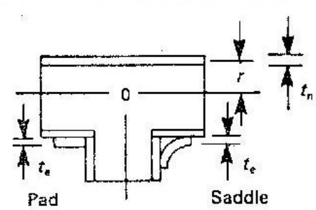
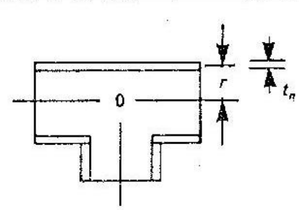
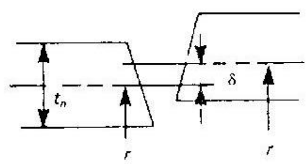
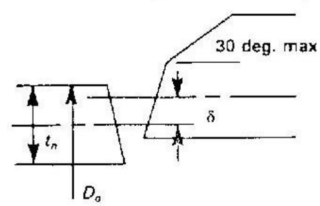
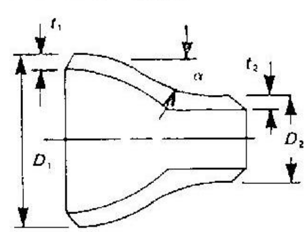
Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r\,(1 + \tan\theta)$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r\,(1 + \tan\theta)$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B16.9 [Notes (1), (2)]	$\frac{4.4\, t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (5)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Note (6)]	1	For checking branch end: $Z = \pi (r'_m)^2 T_b$; $i = 1.5 \left(\frac{R_m}{T}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T_b}{T_r}\right) \left(\frac{r_m}{r_p}\right)$ For checking run ends: $Z = \pi (R_m) r^2 T_r$; $i = 0.4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)$ but not less than 1.5	Fig. NC-3673.2(b)-2
Butt weld [Note (1)] $t_n > 3/16$ and $\frac{\delta}{t_n} \le 0.1$	1	1.0	
Butt weld [Note (1)] $t_n \le 3/16$ or $\frac{\delta}{t_n} > 0.1$	1	1.0 for flush weld 1.8 for as-welded	
Fillet welded joint, socket welded flange, or single welded slip-on flange	1	2.1	Fig. NC-3673.2(b)-3 sketches (a), (b), (c), (e), and (f)
Brazed joint	1	2.1	Fig. NC-4511-1
Full fillet weld	1	1.3	Fig. NC-3673.2(b)-3 sketch (d)
30 deg. tapered transition (ANSI B16.25) [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$	
Concentric reducer [Note (7)] (ANSI B16.9 or MSS SP48)	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2.5	

(See notes on next page)

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \le 100$) (CONT'D)

NOTES TO FIG. NC-3673.2(b)-1:

(1) The following nomenclature applies.

r = mean radius of pipe, in. (matching pipe for tees and elbows)
t_n = nominal wall thickness of pipe, in. [matching pipe for tees and elbows, see Note (9)]
R = bend radius of elbow or pipe bend, in.
θ = one-half angle between adjacent miter axes
s = miter spacing at center line, in.
t_e = reinforced thickness, in.
δ = mismatch, in.
D_o = outside diameter, in.

(2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly by entering with the characteristic h computed from the equations given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below, which can be read directly from Fig. NC-3673.2(b)-5, entering with the computed h.

(a) One end flanged, $c = h^{1/6}$
(b) Both ends flanged, $c = h^{1/3}$

(4) Also includes single miter joints.

(5) When $t_e > 1.5t_n$, $h = 4.05t_n/r$

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of NC-3643 are met.
(b) The axis of the branch pipe is normal to the surface of run pipe wall.
(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.
(d) The inside corner radius r_1 [Fig. NC-3673.2(b)-2] is between 10% and 50% of T_r.
(e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + Y)/2$ [Fig. NC-3673-2(b)-2 sketch (c)] or $T_r/2$.
(f) The outer radius r_3 is not less than the larger of
(1) $0.002\theta\, d_o$
(2) $2 (\sin \theta)^3$ times the offset for the configurations shown in Figs. NC-3673.2(b)-2 sketches (a) and (b).
(g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$.

(7) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg., and the reducer is concentric.
(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(8) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

$$P = \frac{2SEt_m}{D - 2Yt_m}$$

where

P = allowable pressure
S = allowable stress
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowance
= t ×(1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652.

$$S_L = B1\frac{PD}{2t} + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from NB-3680
P = maximum pressure
D = outside diameter
t = nominal wall thickness
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus, for reduced outlets, effective section modulus
S_h = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) such as earthquake or wind from Equation 9 of NC-3653.1. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + B2\frac{M_B}{Z} \leq 1.8S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 10 of NC-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where
i = stress intensification factor
M_C = resultant moment due to thermal expansion
S_A = $f(1.25S_c + 0.25S_h)$
S_c = allowable stress at cold temperature
f = stress range reduction factor from Table NC-3611.2(e)-1

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c).

$$S_{TE} = \frac{PD}{4t} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_h + S_A$$

0.75i shall not be less than 1.0.

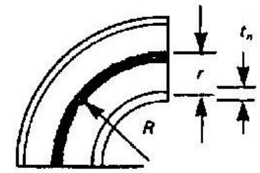
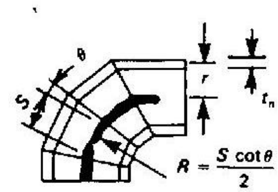
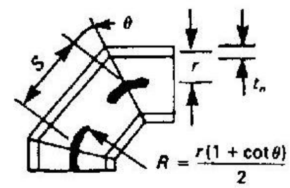
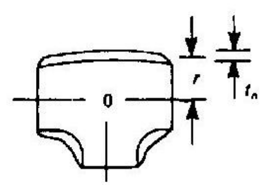
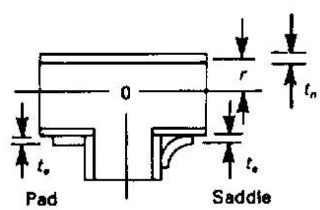
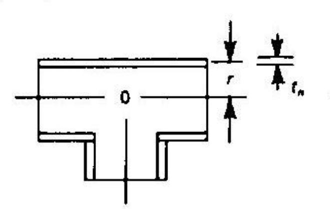
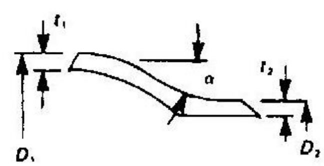
Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r\,(1 + \tan\theta)$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r\,(1 + \tan\theta)$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B16.9 [Notes (1), (2)]	$\frac{4.4\,t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (5), (10)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (10)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o / t_n \leq 100$)

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Note (6)]	1	For checking branch end $Z = \pi (r'_m)^2 T'_b$ $i = 1.5 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T'_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$ For checking run ends $Z = \pi (R_m)^2 T_r$ $i = 0.4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)$ but not less than 1.5	Fig. NC-3673.2(b)-2
Girth butt weld [Note (1)] $t_n \geq 0.237$ in.	1	1.0	
Girth butt weld [Note (1)] $t_n < 0.237$ in.	1	1.9 max. or $0.9(1 + 3\delta/t_n)$ but not less than 1.0	
Circumferential fillet welded or socket welded joints [Note (11)]	1	$2.1/(C_x/t_n)$ but not less than 1.3	Fig. NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	1	2.1	Fig. NC-4511-1
30 deg. tapered transition (ANSI B16.25) [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$	
Concentric and eccentric reducers [Note (7)] (ANSI B16.9)	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2.5	

(See notes on next page)

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) (CONT'D)

FIG. NC-3673.2(b)-1 (CONT'D):
NOTES:

(1) The following nomenclature applies:
r = mean radius of pipe, in. (matching pipe for tees and elbows)
t_n = nominal wall thickness of pipe, in. [matching pipe for tees and elbows, see Note (9)]
R = bend radius of elbow or pipe bend, in.
θ = one-half angle between adjacent miter axes, deg.
s = miter spacing at center line, in.
t_e = reinforced thickness, in.
δ = average permissible mismatch at girth butt welds as shown in Fig. NC-4233-1. A value of δ less than $\frac{1}{32}$ in. may be used provided the smaller mismatch is specified for fabrication. For "flush" welds, as defined in Fig. NB-3683.1(c)-1, δ may be taken as zero, i = 1.0, and flush welds need not be ground.
D_o = outside diameter, in.

(2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly by entering with the characteristic h computed from the equations given.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below, which can be read directly from Fig. NC-3673.2(b)-5, entering with the computed h.
(a) One end flanged, $c = h^{1/6}$
(b) Both ends flanged, $c = h^{1/3}$

(4) Also includes single miter joints.

(5) When $t_e > 1.5t_n$, $h = 4.05t_n/r$

(6) The equation applies only if the following conditions are met.
(a) The reinforcement area requirements of NC-3643 are met.
(b) The axis of the branch pipe is normal to the surface of run pipe wall.
(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
(d) The inside corner radius r_1 [Fig. NC-3673.2(b)-2] for nominal branch pipe size greater than 4 in. shall be between 10% and 50% T_r. The radius r_1 is not required for nominal branch pipe size smaller than 4 in.
(e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + Y)/2$ [Fig. NC-3673-2(b)-2 sketch (c)] or $T_r/2$.
(f) The outer radius r_3 is not less than the larger of
(1) $0.002\theta\, d_o$
(2) 2 $(\sin\theta)^3$ times the offset for the configurations shown in Fig. NC-3673.2(b)-2 sketches (a) and (b).
(g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$.
(h) The outer radius r_2 is not required provided an additional multiplier of 2.0 is included in the equations for branch end and run end stress intensification factors. In this case, the calculated value of i for the branch or run shall not be less than 2.1.

(7) The equation applies only if the following conditions are met.
(a) Cone angle α does not exceed 60 deg.
(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.
(d) For eccentric reducers, α is the maximum cone angle.

(8) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(10) The stress intensification factor i shall in no case be taken as less than 2.1.

(11) C_x is the fillet weld length. For unequal leg lengths, use the smaller leg length for C_x.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

$$P = \frac{2SEt_m}{D - 2Yt_m}$$

where

P = allowable pressure
S = allowable stress
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times$(1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D+d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from NB-3680
P = internal Design Pressure = maximum of CAEPIPE Input pressures P1 through P10
D = outside diameter
t_n = nominal wall thickness
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
S_h = material allowable stress at Design Temperature = maximum of CAEPIPE Input Temperatures T1 through T10

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 8 of NC-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as earthquake or wind) from Equation 9 of NC-3653.1 **(in case the option "Include Axial force in stress calculations" is turned OFF).**Wind and earthquake are not considered concurrently.

$$S_{LO} = 2.B1.ABS\left(\frac{f_p PD}{4t_n}\right) + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 9a as follows.

$$S_{LO} = 2.B1.ABS\left[\left(\frac{f_p PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust} + \left(\frac{F}{A}\right)_{occa}\right] + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

where

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

f_p = peak pressure factor input into CAEPIPE

P = internal Design Pressure defined above

D = outside diameter

t_n = nominal wall thickness

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

$S_{LO(\text{All})}$ = minimum ($1.80S_h$, $1.5S_y$) for Level B Service Limits as per NC-3653.1
=minimum ($2.25S_h$, $1.8S_y$) for Level C Service Limits as per NC-3654.2 (a)
= minimum ($3.0S_h$, $2.0S_y$) for Level D Service Limits as per NC-3655 (a)(2)

S_h = material allowable stress at Design Temperature defined above

S_y = material yield strength at Design Temperature

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NC-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from NB-3680

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

f = stress range reduction factor from Table NC-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c) **(in case the option "Include Axial force in stress calculations" is turned OFF).**.

$$S_{TE} = ABS\left(\frac{PD}{4t_n}\right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 11 as follows.

$$S_{TE} = ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

$0.75i$ shall not be less than 1.0.

where

P = internal Design Pressure = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

S_H = material allowable stress at Design Temperature defined above

f = stress range reduction factor from Table NC-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NC-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_C$$

where

i = stress intensification factor from Table NC-3673.2(b)-1

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

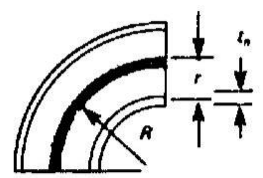
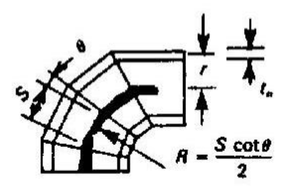
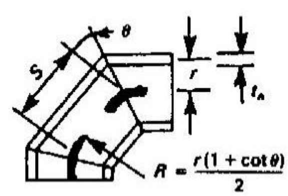
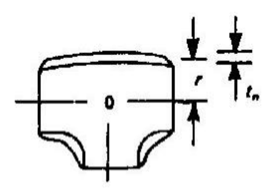
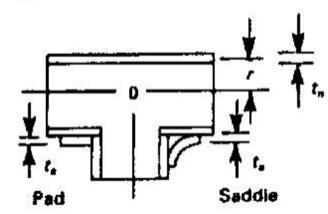
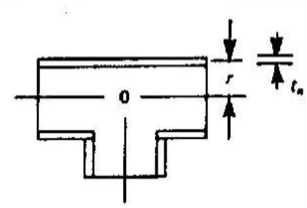
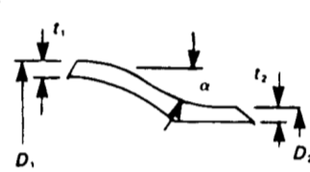
Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r\,(1 + \tan\theta)$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r\,(1 + \tan\theta)$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B16.9 [Notes (1), (2)]	$\frac{4.4\, t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (5), (10)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r\,(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (10)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Note (6)]	1	For checking branch end $Z = \pi(r'_m)^2 T'_b$ $i = 1.5 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T'_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$ For checking run ends $Z = \pi(R_m)^2 T_r$ $i = 0.4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)$ but not less than 1.5	Fig. NC-3673.2(b)-2
Girth butt weld [Note (1)] $t_n \geq 0.237$ in.	1	1.0	
Girth butt weld [Note (1)] $t_n < 0.237$ in.	1	1.9 max. or $0.9(1 + 3\delta/t_n)$ but not less than 1.0	
Circumferential fillet welded or socket welded joints [Note (11)]	1	$2.1/(C_x/t_n)$ but not less than 1.3	Fig. NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	1	2.1	Fig. NC-4511-1
30 deg. tapered transition (ANSI B16.25) [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$	
Concentric and eccentric reducers [Note (7)] (ANSI B16.9)	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2.5	

(See notes on next page)

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) (CONT'D)

NOTES:

(1) The following nomenclature applies:

r = mean radius of pipe, in. (matching pipe for tees and elbows)

t_n = nominal wall thickness of pipe, in. [matching pipe for tees and elbows, see Note (9)]

R = bend radius of elbow or pipe bend, in.

θ = one-half angle between adjacent miter axes, deg.

s = miter spacing at center line, in.

t_e = reinforced thickness, in.

D_o = outside diameter, in.

(2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.

(a) One end flanged, $c = h^{1/6}$

(b) Both ends flanged, $c = h^{1/3}$

(4) Also includes single miter joints.

(5) When $t_e > 1.6 t_n$, $h = 4.05 t_n / r$

(6) The equation applies only if the following conditions are met.

(a) The reinforcement area requirements of NC-3643 are met.

(b) The axis of the branch pipe is normal to the surface of run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.

(d) The inside corner radius r_1 [Fig. NC-3673.2(b)-2] for nominal branch pipe size greater than 4 in. shall be between 10% and 50% T_r. The radius r_1 is not required for nominal branch pipe size smaller than 4 in.

(e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_{b'} + Y)/2$ [Fig. NC-3673-2(b)-2 sketch (c)] or $T_r/2$.

(f) The outer radius r_3 is not less than the larger of

(1) $0.002 \theta d_o$

(2) $2 (\sin \theta)^3$ times the offset for the configurations shown in Fig. NC-3673.2(b)-2 sketches (a) and (b).

(g) $R_m / T_r \leq 50$ and $r'_m / R_m \leq 0.5$.

(h) The outer radius r_3 is not required provided an additional multiplier of 2.0 is included in the equtions for branch end and run end stress intensification factors. In this case, the calculated value of i for the branch or run shall not be less than 2.1.

(7) The equation applies only if the following conditions are met.

(a) Cone angle α does not exceed 60 deg.

(b) The larger of D_1 / t_1 and D_2 / t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(d) For eccentric reducers, α is the maximum cone angle.

(8) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(10) The stress intensification factor i shall in no case be taken as less than 2.1.

(11) In Fig. NC-4427-1(c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25 t_n$. In Fig. NC-4427-1 (c-3), $C_x \geq 0.75 t_n$. For unequal leg lengths use the smaller leg length for C_x.

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) (CONT'D)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

$$P_a = \frac{2SEt_m}{D - 2Yt_m}$$

where
P_a = allowable pressure
S = allowable stress for the material at the Design Temperature
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowance
= t ×(1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D+d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where
$B1, B2$ = primary stress indices from Table NC-3673.2(b)-1
P = maximum of CAEPIPE Input pressures P1 through P10
D = outside diameter
t_n = nominal wall thickness
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
S_h= material allowable stress at maximum of CAEPIPE Inputtemperatures T1 through T10

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 8 of NC-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and non-reversing dynamic loads) from Equation 9a of NC-3653.1 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_{LO} = 2.B1.ABS\left(\frac{f_p PD}{4t_n}\right) + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 9aof NC-3653.1as follows.

$$S_{LO} = 2.B1.ABS\left[\left(\frac{f_p PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust} + \left(\frac{F}{A}\right)_{occa}\right] + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

where

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and nonreversing dynamic loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

f_p = peak pressure factor input into CAEPIPE

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

$S_{LO(\mathrm{All})}$ = minimum ($1.80S_h$, $1.5S_y$) for Level B Service Limits as per NC-3653.1
=minimum ($2.25S_h$, $1.8S_y$) for Level C Service Limits as per NC-3654.2 (a)
= minimum ($3.0S_h$, $2.0S_y$) for Level D Service Limits as per NC-3655 (a)(2)

S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and nonreversing dynamic loads are to be input as "specified displacements" for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NC-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from Table NC-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

f = stress range reduction factor from Table NC-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c) **(in case the option "Include Axial force in stress calculations" is turned OFF).**.

$$S_{TE} = ABS\left(\frac{PD}{4t_n}\right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 11of NC-3653.2(c)as follows.

$$S_{TE} = ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

$0.75i$ shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)
S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table NC-3611.2(e)-1

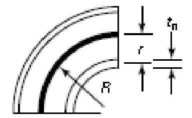
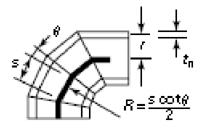
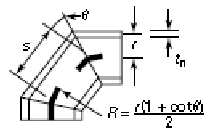
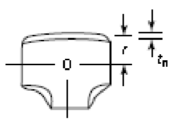
Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NC-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_C$$

where
i = stress intensification factor from Table NC-3673.2(b)-1
M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)
S_c = allowable stress at the Reference Temperature in CAEPIPE
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

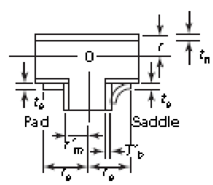
Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4h - 0.1 \le 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \ge r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4\left(\frac{r}{t_n}\right)^{2/3}$ Run end: $B_{2r} = 0.5\left(\frac{r}{t_n}\right)^{2/3}$	$\frac{4.4\,t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right)$	

Additional Note for Welding elbow or Pipe bend:

If the value of B1 = (0.4h – 0.1) < 0.0, then B1 is set to 0.0.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left[\frac{r'_m}{r}\right]^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right) \ge 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t'_e/2t_n)]^{5/3}} \ge 1.0$ [Note (8)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \ge 2.1$ For branch leg of a reduced outlet use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \ge 2.1$	

Additional Note for Reinforced fabricated tee:

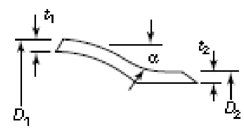
For calculating the value of rps and t'_e, the value of r_e is assumed to be equal to 2 x r'_m, where r'_m is the mean radius of the branch leg.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NC-3673.2(b)-2

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \geq 1.5$ Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \geq 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \geq 3.0$ Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \geq 2.1$	Figure NC-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75\left(\frac{t_n}{C_x}\right) \geq 0.5$	$1.5\left(\frac{t_n}{C_x}\right)$	1	For $C_x \geq 1.09 t_n$, $i = 1.3$ For $C_x < 1.09 t_n$, $i = 2.1\ (t_n/C_x) \geq 1.3$	Figure NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NC-4511-1
30 deg tapered transition [ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	(U.S. Customary Units) $1.3 + 0.0036\frac{D_o}{t_n} + 0.113/t_n \leq 1.9$ (SI Units) $1.3 + 0.0036\frac{D_o}{t_n} + 2.87/t_n \leq 1.9$	...

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
30 deg tapered transition [ASME B16.25) $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036\ D_o / t_n \leq 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg < $\alpha \leq 60$ deg	1.0	1	$0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \leq 2.0$	

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

1. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.
2. The definition of Cx as per Note 11 of Table NC-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure NC-4427-1.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:

(a) The following nomenclature applies:

d_i = nominal inside diameter of branch, in. (mm)
D_o = nominal outside diameter, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
R_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
s = miter spacing at center line, in. (mm)
t_b = thickness in reinforcement zone of branch, in. (mm)
t_e = pad or saddle thickness, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
T_r = nominal wall thickness of run pipe, in. (mm)
T'_b = nominal wall thickness of branch pipe, in. (mm)
θ = one-half angle between adjacent miter axes, deg

For Figure NC-3673.2(b)-2, sketches (a) and (b):
$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$
$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure NC-3673.2(b)-2, sketch (c):
$t_b = T'_b + (2/3)y$ if $\theta \leq 30$ deg
$= T'_b + 0.385L_1$ if $\theta > 30$ deg

For Figure NC-3673.2(b)-2, sketch (d):
$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. NC-3643.2(b)-2 and NC-3673.2(b)-2.

(b) The flexibility factors k, stress intensification factors i, and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table NC-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:
$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)
$= 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)
$= 1.0$ for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.
(a) One end flanged, $c = h^{1/6}$
(b) Both ends flanged, $c = h^{1/3}$
But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

NOTES (CONT'D):

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi (r'_m)^2 T'_b$$

For checking run leg stress:

$$Z = \pi (R_m)^2 T_r$$

(5) When $t_e > 1.5\ t_n$, $h = 4.05\ t_n/r$.

(6) The equation applies only if the following conditions are met:
(a) The reinforcement area requirements of NC-3643 are met.
(b) The axis of the branch pipe is normal to the surface of the run pipe wall.
(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
(d) The run pipe is a straight pipe.

(7) r'_m/r shall be taken as 0.5 for $r'_m/r > 0.5$.
r'_m/r_{px} shall not be taken as less than 0.5.

The definition of r_{px} is:
$r_{px} = (r'_m + r_x) / 2$ for $t_x \geq 0.8t_n$
$r_{px} = r'_m + (T'_b/2)$ for $t_x < 0.8t_n$

(8) The definition of t'_x is:
$t'_x = t_x\ [(r_x / r'_m) - 1]$ but not greater than $1.0t_n$

(9) If an r_2 radius is provided [Figure NC-3673.2(b)-2] that is not less than the larger of $T_b/2$, $(T'_b + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m/R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m/R_m \leq 0.5$.

(11) In Figure NC-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25\ t_n$. In Figure NC-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:
(a) Cone angle α does not exceed 60 deg.
(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.
(d) For eccentric reducers, α is the maximum cone angle.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

$$P_a = \frac{2SEt_m}{D - 2Yt_m}$$

where

P_a = allowable pressure
S = allowable stress for the material at the Design Temperature
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowance
= $t\times$(1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D+d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from Table NC-3673.2(b)-1
P = maximum of CAEPIPE Input pressures P1 through P10
D = outside diameter
t_n = nominal wall thickness
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 8 of NC-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and nonreversing dynamic loads) from Equation 9a of NC-3653.1 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_{LO} = 2.B1.ABS\left(\frac{f_p PD}{4t_n}\right) + B2\left(\frac{M_A + M_B}{Z}\right) \le S_{LO(All)}$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 9aof NC-3653.1as follows.

$$S_{LO} = 2.B1.ABS\left[\left(\frac{f_p PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust} + \left(\frac{F}{A}\right)_{occa}\right] + B2\left(\frac{M_A + M_B}{Z}\right) \le S_{LO(All)}$$

where

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and non-reversing dynamic loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

f_p = peak pressure factor input into CAEPIPE

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

$S_{LO(All)}$ = minimum ($1.80S_h$, $1.5S_y$) for Level B Service Limits as per NC-3653.1
=minimum ($2.25S_h$, $1.8S_y$) for Level C Service Limits as per NC-3654.2 (a)
= minimum ($3.0S_h$, $2.0S_y$) for Level D Service Limits as per NC-3655 (a)(2)

S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and nonreversing dynamic loads are to be input as "specified displacements" for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NC-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from Table NC-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress $= f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

f = stress range reduction factor from Table NC-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c) **(in case the option "Include Axial force in stress calculations" is turned OFF).**.

$$S_{TE} = ABS\left(\frac{PD}{4t_n}\right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 11of NC-3653.2(c)as follows.

$$S_{TE} = ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75*i* shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)
S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table NC-3611.2(e)-1

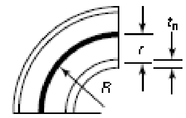
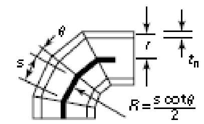
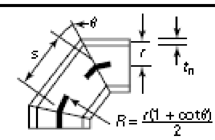
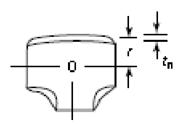
Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NC-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_C$$

where
i = stress intensification factor from Table NC-3673.2(b)-1
M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)
S_c = allowable stress at the Reference Temperature in CAEPIPE
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

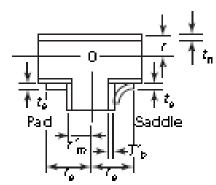
Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4h - 0.1 \le 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \ge r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4\left(\frac{r}{t_n}\right)^{2/3}$ Run end: $B_{2r} = 0.5\left(\frac{r}{t_n}\right)^{2/3}$	$\frac{4.4\,t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right)$	

Additional Note for Welding elbow or Pipe bend:

If the value of B1 = (0.4h – 0.1) < 0.0, then B1 is set to 0.0.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left[\frac{r'_m}{r}\right]^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right) \ge 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t'_e/2t_n)]^{5/3}} \ge 1.0$ [Note (8)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \ge 2.1$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \ge 2.1$	

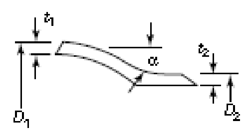
Additional Note for Reinforced fabricated tee:

For calculating the value of rps and t'_e, the value of r_e is assumed to be equal to 2 x r'_m, where r'_m is the mean radius of the branch leg.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NC-3673.2(b)-2

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \geq 1.5$ Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \geq 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \geq 3.0$ Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \geq 2.1$	Figure NC-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75\left(\frac{t_n}{C_x}\right) \geq 0.5$	$1.5\left(\frac{t_n}{C_x}\right)$	1	For $C_x \geq 1.09 t_n$, $i = 1.3$ For $C_x < 1.09 t_n$, $i = 2.1\ (t_n/C_x) \geq 1.3$	Figure NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NC-4511-1
30 deg tapered transition (ASME B16.25) t_n < 0.237 in. (6 mm)	0.5	1.0	1	(U.S. Customary Units) $1.3 + 0.0036\frac{D_o}{t_n} + 0.113 / t_n \leq 1.9$ (SI Units) $1.3 + 0.0036\frac{D_o}{t_n} + 2.87 / t_n \leq 1.9$	...
30 deg tapered transition (ASME B16.25) $t_n \geq$ 0.237 in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036\ D_o / t_n \leq 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \leq$ 30 deg 1.0 for 30 deg < $\alpha \leq$ 60 deg	1.0	1	$0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \leq 2.0$	

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

3. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.

4. The definition of Cx as per Note 11 of Table NC-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure NC-4427-1.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:

(a) The following nomenclature applies:

d_i = nominal inside diameter of branch, in. (mm)
D_o = nominal outside diameter, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
R_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
s = miter spacing at center line, in. (mm)
t_b = thickness in reinforcement zone of branch, in. (mm)
t_e = pad or saddle thickness, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
T_r = nominal wall thickness of run pipe, in. (mm)
T'_b = nominal wall thickness of branch pipe, in. (mm)
θ = one-half angle between adjacent miter axes, deg

For Figure NC-3673.2(b)-2, sketches (a) and (b):
$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$
$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure NC-3673.2(b)-2, sketch (c):
$t_b = T'_b + (2/3)y$ if $\theta \leq 30$ deg
$= T'_b + 0.385L_1$ if $\theta > 30$ deg

For Figure NC-3673.2(b)-2, sketch (d):
$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. NC-3643.2(b)-2 and NC-3673.2(b)-2.

(b) The flexibility factors k, stress intensification factors i, and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table NC-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:
$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)
$= 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)
$= 1.0$ for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.
(a) One end flanged, $c = h^{1/6}$
(b) Both ends flanged, $c = h^{1/3}$
But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Table NC-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

NOTES (CONT'D):

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi (r'_m)^2 T'_b$$

For checking run leg stress:

$$Z = \pi (R_m)^2 T_r$$

(5) When $t_e > 1.5\ t_n$, $h = 4.05\ t_n/r$.

(6) The equation applies only if the following conditions are met:
(a) The reinforcement area requirements of NC-3643 are met.
(b) The axis of the branch pipe is normal to the surface of the run pipe wall.
(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
(d) The run pipe is a straight pipe.

(7) r'_m/r shall be taken as 0.5 for $r'_m/r > 0.5$.
r'_m/r_{px} shall not be taken as less than 0.5.

The definition of r_{px} is:
$r_{px} = (r'_m + r_x) / 2$ for $t_e \geq 0.8t_n$
$r_{px} = r'_m + (T'_b/2)$ for $t_e < 0.8t_n$

(8) The definition of t'_e is:
$t'_e = t_e\ [(r_x / r'_m) - 1]$ but not greater than $1.0t_n$

(9) If an r_2 radius is provided [Figure NC-3673.2(b)-2] that is not less than the larger of $T_b/2$, $(T'_b + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m/R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m/R_m \leq 0.5$.

(11) In Figure NC-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25\ t_n$. In Figure NC-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:
(a) Cone angle α does not exceed 60 deg.
(b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.
(d) For eccentric reducers, α is the maximum cone angle.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of ND-3641.1.

$$P_a = \frac{2SEt_m}{D - 2Yt_m}$$

where

P_a = allowable pressure
S = allowable stress for the material at the Design Temperature
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowance
= $t\ \times$(1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D+d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of ND-3652 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from Table ND-3673.2(b)-1
P = maximum of CAEPIPE Input pressures P1 through P10
D = outside diameter
t_n = nominal wall thickness
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)
S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 8 of ND-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and non-reversing dynamic loads) from Equation 9a of ND-3653.1 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_{LO} = 2.B1.ABS\left(\frac{f_p PD}{4t_n}\right) + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 9aof ND-3653.1as follows.

$$S_{LO} = 2.B1.ABS\left[\left(\frac{f_p PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust} + \left(\frac{F}{A}\right)_{occa}\right] + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

where

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and non-reversing dynamic loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

f_p = peak pressure factor input into CAEPIPE

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

$S_{LO(\text{All})}$ = minimum ($1.80S_h$, $1.5S_y$) for Level B Service Limits as per ND-3653.1
=minimum ($2.25S_h$, $1.8S_y$) for Level C Service Limits as per ND-3654.2 (a)
= minimum ($3.0S_h$, $2.0S_y$) for Level D Service Limits as per ND-3655 (a)(2)

S_h= material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and non-reversing dynamic loads are to be input as "specified displacements" for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of ND-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from Table ND-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per ND-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

f = stress range reduction factor from Table ND-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of ND-3653.2(c) **(in case the option "Include Axial force in stress calculations" is turned OFF).**.

$$S_{TE} = ABS\left(\frac{PD}{4t_n}\right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 11of ND-3653.2(c)as follows.

$$S_{TE} = ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75i shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per ND-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table ND-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single non-repeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of ND-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_C$$

where

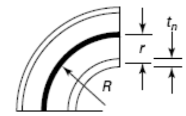
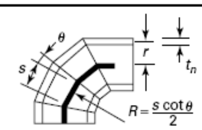
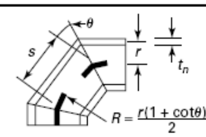
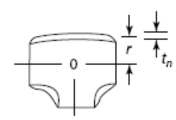
i = stress intensification factor from Table ND-3673.2(b)-1

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

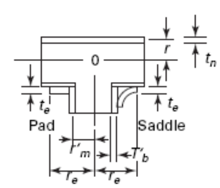
Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4\,h - 0.1 \le 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \ge r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4\left(\frac{r}{t_n}\right)^{2/3}$ Run end: $B_{2r} = 0.5\left(\frac{r}{t_n}\right)^{2/3}$	$\frac{4.4\,t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right)$	

Additional Note for Welding elbow or Pipe bend:

If the value of B1 = (0.4h – 0.1) < 0.0, then B1 is set to 0.0.

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left(\frac{r'_m}{r}\right)^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right) \ge 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t'_e/2t_n)]^{5/3}} \ge 1.0$ [Note (8)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \ge 2.1$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \ge 2.1$	

Additional Note for Reinforced fabricated tee:

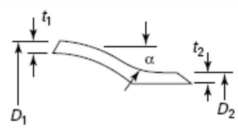
For calculating the value of rps and t'_e, the value of r_e is assumed to be equal to 2 x r'_m, where r'_m is the mean radius of the branch leg.

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure ND-3673.2(b)-2

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \ge 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 3.0$ Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure ND-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75\left(\frac{t_n}{C_x}\right) \ge 0.5$	$1.5\left(\frac{t_n}{C_x}\right)$	1	For $C_x \ge 1.09t_n$, $i = 1.3$ For $C_x < 1.09t_n$, $i = 2.1\,(t_n/C_x) \ge 1.3$	Figure ND-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure ND-4511-1
30 deg tapered transition (ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	*(U.S. Customary Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 0.113/t_n \le 1.9$ *(SI Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 2.87/t_n \le 1.9$	...

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
30 deg tapered transition (ASME B16.25) $t_n \ge 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036D_o / t_n \le 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \le 30$ deg 1.0 for 30 deg < $\alpha \le 60$ deg	1.0	1	$0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \le 2.0$	

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

5. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.

6. The definition of Cx as per Note 11 of Table ND-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure ND-4427-1.

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:

(a) The following nomenclature applies:

D_o = nominal outside diameter, in. (mm)
d_i = nominal inside diameter of branch, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
r'_m = mean radius of branch pipe, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
R_m = mean radius of run pipe, in. (mm)
θ = one-half angle between adjacent miter axes, deg
s = miter spacing at center line, in. (mm)
t_b = thickness in reinforcement zone of branch, in. (mm)
t_e = pad or saddle thickness, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
T'_b = nominal wall thickness of branch pipe, in. (mm)
T_r = nominal wall thickness of run pipe, in. (mm)

For Figure ND-3673.2(b)-2, sketches (a) and (b):
$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$
$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure ND-3673.2(b)-2, sketch (c):
$t_b = T'_b + (2/3)y$ if $\theta \leq 30$ deg
$= T'_b + 0.385L_1$ if $\theta > 30$ deg

For Figure ND-3673.2(b)-2, sketch (d):
$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. ND-3643.2(b)-2 and ND-3673.2(b)-2.

(b) The flexibility factors k, stress intensification factors i, and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table ND-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:

$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)
$Y = 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)
$Y = 1.0$ for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.
(a) One end flanged, $c = h^{1/6}$
(b) Both ends flanged, $c = h^{1/3}$
But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

NOTES (CONT'D):

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi (r'_m)^2 T'_b$$

For checking run leg stress:

$$Z = \pi (R_m)^2 T_r$$

(5) When $t_e > 1.5\ t_n$, $h = 4.05 t_n / r$.

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of ND-3643 are met.

(b) The axis of the branch pipe is normal to the surface of the run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.

(d) The run pipe is a straight pipe.

(7) r'_m / r shall be taken as 0.5 for $r'_m / r > 0.5$.
r'_m / r_{ps} shall not be taken as less than 0.5.

The definition of r_{ps} is:
$r_{ps} = (r'_m + r_e) / 2$ for $t_e \geq 0.8 t_n$
$r_{ps} = r'_m + (T'_b / 2)$ for $t_e < 0.8 t_n$

(8) The definition of t'_e is:
$t'_e = t_e\ [(r_e / r'_m) - 1]$ but not greater than $1.0 t_n$

(9) If an r_2 radius is provided [Figure ND-3673.2(b)-2] that is not less than the larger of $T_b/2$, $(T'_b + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m / R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m / R_m \leq 0.5$.

(11) In Figure ND-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25\ t_n$. In Figure ND-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:

(a) Cone angle α does not exceed 60 deg.

(b) The larger of D_1 / t_1 and D_2 / t_2 does not exceed 100.

(c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(d) For eccentric reducers, α is the maximum cone angle.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NCD-3641.1.

$$P_a = \frac{2SEt_m}{D - 2Yt_m}$$

where

P_a = allowable pressure

S = allowable stress for the material at the Design Temperature

E = joint factor (input as material property)

t_m = minimum required thickness, after deducting mechanical and corrosion allowance

= t_n ×(1 – mill tolerance/100) – corrosion allowance

t_n = nominal pipe thickness

D = nominal outside diameter

d = nominal inside diameter

Y = pressure coefficient

= 0.4 for $D/t_m \geq 6$

= $d/(D+d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NCD-3652 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from Table NCD-3673.2(b)-1

P = maximum of CAEPIPE Input pressures P1 through P10

D = nominal outside diameter

t_n = nominal wall thickness

M_A = resultant moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)

S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 8 of NCD-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F_S}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

F_S = axial force due to sustained loads
A = nominal metal area

As an option, as suggested in NCD-3651 (a), the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The occasional stress (S_{LO}) due to sustained loads (pressure, weight and other sustained mechanical loads) and stress due to occasional loads (such as thrusts from relief and safety valve loads, pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and nonreversing dynamic loads) is calculated from Equation 9a of NCD-3653.1 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_{LO} = 2.B1.ABS\left(\frac{f_pPD}{4t_n}\right) + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 9a of NCD-3653.1as follows.

$$S_{LO} = 2.B1.ABS\left[\left(\frac{f_pPD}{4t_n}\right) + \left(\frac{F_S}{A}\right)_{sust} + \left(\frac{F_O}{A}\right)_{occa}\right] + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

where

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and non-reversing dynamic loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
f_p = peak pressure factor input into CAEPIPE
P = maximum of CAEPIPE Input pressures P1 through P10
D = nominal outside diameter
t_n = nominal wall thickness
Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)
$S_{LO(All)}$ = minimum ($1.80S_h$, $1.5S_y$) for Level B Service Limits as per NCD-3653.1
= minimum ($2.25S_h$, $1.8S_y$) for Level C Service Limits as per NCD-3654.2 (a)
= minimum ($3.0S_h$, $2.0S_y$) for Level D Service Limits as per NCD-3655 (a)(2)
S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10
S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10
F_O = axial force due to occasional loads

A = nominal metal area

As an option, as suggested in NCD-3651 (a), the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and nonreversing dynamic loads are to be input as "specified displacements" for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NCD-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from Table NCD-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NCD-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

f = stress range reduction factor from Table NCD-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NCD-3653.2(c) **(in case the option "Include Axial force in stress calculations" is turned OFF).**.

$$S_{TE} = ABS\left(\frac{PD}{4t_n}\right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 11 of NCD-3653.2(c) as follows.

$$S_{TE} = ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75i shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = nominal outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NCD-3611.2(e)

S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table NCD-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NCD-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_C$$

where

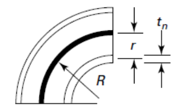
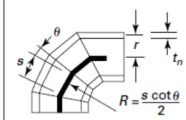
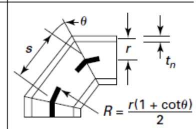
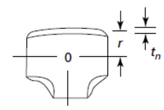
i = stress intensification factor from Table NCD-3673.2(b)-1

M_D = resultant moment due to any single non-repeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)

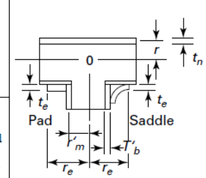
Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Note (1)], [Note (2)]	$-0.1 + 0.4h$, $0.5 \geq B_1 > 0$	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s<r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r\,(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4\left(\frac{r}{t_n}\right)^{2/3}$ Run end: $B_{2r} = 0.5\left(\frac{r}{t_n}\right)^{2/3}$	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right)$	

Additional Note for Welding elbow or Pipe bend:

If the value of B1 = (0.4h – 0.1) < 0.0, then B1 is set to 0.0.

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left(\frac{r'_m}{r}\right)^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right) \geq 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t'_e/2t_n)]^{5/3}} \geq 1.0$ [Note (8)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$ For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \geq 2.1$	

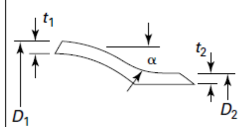
Additional Note for Reinforced fabricated tee:

For calculating the value of rps and t'_e, the value of r_e is assumed to be equal to 2 x r'_m, where r'_m is the mean radius of the branch leg.

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NCD-3673.2(b)-2
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \ge 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 3.0$ Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	Figure NCD-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index B_1	Primary Stress Index B_2	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75\left(\frac{t_n}{C_x}\right) \ge 0.5$	$1.5\left(\frac{t_n}{C_x}\right)$	1	For $C_x \ge 1.09t_n$, $i = 1.3$ For $C_x < 1.09t_n$, $i = 2.1\ (t_n/C_x) \ge 1.3$	Figure NCD-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NCD-4511-1
30 deg tapered transition (ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	*(U.S. Customary Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 0.113/t_n \le 1.9$ *(SI Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 2.87/t_n \le 1.9$	...
30 deg tapered transition (ASME B16.25) $t_n \ge 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036D_o/t_n \le 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \le 30$ deg 1.0 for 30 deg $< \alpha \le 60$ deg	1.0	1	$0.5 + 0.01\,\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \le 2.0$	
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:
(a) The following nomenclature applies:
- D_o = nominal outside diameter, in. (mm)
- d_i = nominal inside diameter of branch, in. (mm)
- r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
- r'_m = mean radius of branch pipe, in. (mm)
- R = nominal bend radius of elbow or pipe bend, in. (mm)
- R_m = mean radius of run pipe, in. (mm)
- θ = one-half angle between adjacent miter axes, deg
- s = miter spacing at center line, in. (mm)
- t_b = thickness in reinforcement zone of branch, in. (mm)
- t_e = pad or saddle thickness, in. (mm)
- t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
- T'_b = nominal wall thickness of branch pipe, in. (mm)

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

1. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.

2. The definition of Cx as per Note 11 of Table NCD-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure NCD-4427-1.

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

GENERAL NOTES: (Cont'd)

T_r = nominal wall thickness of run pipe, in. (mm)

For Figure NCD-3673.2(b)-2, sketches (a) and (b):

$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$

$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure NCD-3673.2(b)-2, sketch (c):

$t_b = T'_b + (^2/_3)y$ if $\theta_n \leq 30$ deg

$= T'_b + 0.385L_1$ if $\theta_n > 30$ deg

For Figure NCD-3673.2(b)-2, sketch (d):

$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. NCD-3643.2(b)-2 and NCD-3673.2(b)-2.

(b) The flexibility factors k, stress intensification factors i, and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table NCD-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:

$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0

$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)

$Y = 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)

$Y = 1.0$ for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.

(a) One end flanged, $c = h^{1/6}$

(b) Both ends flanged, $c = h^{1/3}$

But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi(r'_m)^2 T'_b$$

For checking run leg stress:

$$Z = \pi(R_m)^2 T_r$$

(5) When $t_e > 1.5\ t_n$, $h = 4.05t_n/r$.

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of NCD-3643 are met.

(b) The axis of the branch pipe is normal to the surface of the run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.

(d) The run pipe is a straight pipe.

(7) r'_m/r shall be taken as 0.5 for $r'_m/r > 0.5$.

r'_m/r_{ps} shall not be taken as less than 0.5.

The definition of r_{ps} is:

$r_{ps} = (r'_m + r_e)/2$ for $t_e \geq 0.8t_n$

$r_{ps} = r'_m + (T'_b/2)$ for $t_e < 0.8t_n$

(8) The definition of t'_e is:

$t'_e = t_e\ [(r_e/r'_m) - 1]$ but not greater than $1.0t_n$

(9) If an r_2 radius is provided [Figure NCD-3673.2(b)-2] that is not less than the larger of $T_b/2$, $(T'_b + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m/R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m/R_m \leq 0.5$.

(11) In Figure NCD-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{min} and $C_x \geq 1.25\ t_n$. In Figure NCD-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:

(o) Cone angle α does not exceed 60 deg.

(p) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(q) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(r) For eccentric reducers, α is the maximum cone angle.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NCD-3641.1.

$$P_a = \frac{2SEt_m}{D - 2Yt_m}$$

where

P_a = allowable pressure
S = allowable stress for the material at the Design Temperature
E = joint factor (input as material property)
t_m = minimum required thickness, after deducting mechanical and corrosion allowance
= $t_n \times(1 - \text{mill tolerance}/100)$ – corrosion allowance
t_n = nominal pipe thickness
D = nominal outside diameter
d = nominal inside diameter
Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NCD-3652 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from Table NCD-3673.2(b)-1
P = maximum of CAEPIPE Input pressures P1 through P10
D = nominal outside diameter
t_n = nominal wall thickness
M_A = resultant moment due to sustained loads $= \sqrt{M_{AX}^2 + M_{AY}^2 + M_{AZ}^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)
S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 8 of NCD-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F_S}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

F_S = axial force due to sustained loads
A = nominal metal area

As an option, as suggested in NCD-3651 (a), the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The occasional stress (S_{LO}) due to sustained loads (pressure, weight and other sustained mechanical loads) and stress due to occasional loads (such as thrusts from relief and safety valve loads, pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and nonreversing dynamic loads) is calculated from Equation 9a of NCD-3653.1 **(in case the option "Include Axial force in stress calculations" is turned OFF).**

$$S_{LO} = 2.B1.ABS\left(\frac{f_p PD}{4t_n}\right) + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 9a of NCD-3653.1as follows.

$$S_{LO} = 2.B1.ABS\left[\left(\frac{f_p PD}{4t_n}\right) + \left(\frac{F_S}{A}\right)_{sust} + \left(\frac{F_O}{A}\right)_{occa}\right] + B2\left(\frac{M_A + M_B}{Z}\right) \leq S_{LO(All)}$$

where

M_A = resultant bending moment due to sustained loads $= \sqrt{M_{AX}^2 + M_{AY}^2 + M_{AZ}^2}$
M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and non-reversing dynamic loads
$= \sqrt{M_{BX}^2 + M_{BY}^2 + M_{BZ}^2}$
f_p = peak pressure factor input into CAEPIPE

P = maximum of CAEPIPE Input pressures P1 through P10
D = nominal outside diameter
t_n = nominal wall thickness
Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)
$S_{LO(All)}$ = minimum ($1.80S_h$, $1.5S_y$) for Level B Service Limits as per NCD-3653.1
=minimum ($2.25S_h$, $1.8S_y$) for Level C Service Limits as per NCD-3654.2 (a)
= minimum ($3.0S_h$, $2.0S_y$) for Level D Service Limits as per NCD-3655 (a)(2)

S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

F_O = axial force due to occasional loads
A = nominal metal area

As an option, as suggested in NCD-3651 (a), the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and nonreversing dynamic loads are to be input as "specified displacements" for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NCD-3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where
i = stress intensification factor from Table NCD-3673.2(b)-1
M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_{CX}^2 + M_{CY}^2 + M_{CZ}^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)
S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NCD-3611.2(e)
S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

f = stress range reduction factor from Table NCD-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NCD-3653.2(c) **(in case the option "Include Axial force in stress calculations" is turned OFF).**.

$$S_{TE} = ABS\left(\frac{PD}{4t_n}\right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option "Include Axial force in stress calculations" is turned ON, then CAEPIPE evaluates Equation 11 of NCD-3653.2(c) as follows.

$$S_{TE} = ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

$0.75i$ shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10
D = nominal outside diameter
t_n = nominal wall thickness
M_A = resultant bending moment due to sustained loads $= \sqrt{M_{AX}^2 + M_{AY}^2 + M_{AZ}^2}$
M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements $= \sqrt{M_{CX}^2 + M_{CY}^2 + M_{CZ}^2}$
Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)
S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NCD-3611.2(e)
S_c = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table NCD-3611.2(e)-1

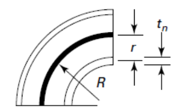
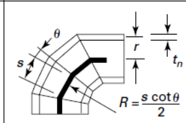
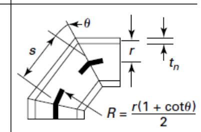
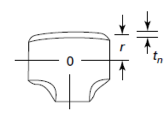
Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NCD-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_C$$

where
i = stress intensification factor from Table NCD-3673.2(b)-1
M_D = resultant moment due to any single non-repeated anchor movement (e.g., predicted building settlement) $= \sqrt{M_{DX}^2 + M_{DY}^2 + M_{DZ}^2}$
S_c = allowable stress at the Reference Temperature in CAEPIPE
Z = section modulus; for reduced outlets, effective section modulus as per NCD-3653.3(d)

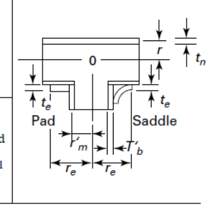
Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

Description	Primary Stress Index		Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)], [Note (2)]	$-0.1 + 0.4h$, $0.5 \geq B_1 > 0$	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s<r(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r(1 + \tan\theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4\left(\frac{r}{t_n}\right)^{2/3}$	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
		Run end: $B_{2r} = 0.5\left(\frac{r}{t_n}\right)^{2/3}$			For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right)$	

Additional Note for Welding elbow or Pipe bend:

If the value of B1 = (0.4h – 0.1) < 0.0, then B1 is set to 0.0.

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75\left(\frac{r}{t_n}\right)^{2/3}\left(\frac{r'_m}{r}\right)^{1/2}\left(\frac{T'_b}{t_n}\right)\left(\frac{r'_m}{r_{ps}}\right) \geq 1.0$ [Note (7)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$	
		Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (t'_e/2t_n)]^{5/3}} \geq 1.0$ [Note (8)]			For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}}\left(\frac{T'_b}{T_r}\right) \geq 2.1$	

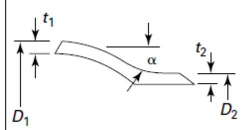
Additional Note for Reinforced fabricated tee:

For calculating the value of rps and t'_e, the value of r_e is assumed to be equal to 2 x r'_m, where r'_m is the mean radius of the branch leg.

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \le 0.9$ $B_{2b} = 0.75\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	1	Branch leg: for $(r'_m/R_m) \le 0.9$ $i_b = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{r_p}\right) \ge 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	Figure NCD-3673.2(b)-2
		Run legs: for $(r'_m/R_m) \le 0.5$ $B_{2r} = 0.75\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9\left(\frac{r'_m}{t_b}\right)^{1/4}$		Run legs: for $(r'_m/R_m) \le 0.5$ $i_r = 0.8\left(\frac{r'_m}{t_b}\right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/T_r)(t_b/d_i)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 1.5$	1	Branch leg: $i_b = 4.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \ge 3.0$	Figure NCD-3643.2(b)-2
		Run legs: $B_{2r} = 1.3\left(\frac{r'_m}{t_b}\right)^{1/4} \ge 1.5$		Run legs: $i_r = 0.8\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \ge 2.1$	
Girth butt weld	0.5	1.0	1	1.0	...

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2			
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75\left(\frac{t_n}{C_x}\right) \geq 0.5$	$1.5\left(\frac{t_n}{C_x}\right)$	1	For $C_x \geq 1.09t_n$, $i = 1.3$ For $C_x < 1.09t_n$, $i = 2.1\ (t_n/C_x) \geq 1.3$	Figure NCD-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NCD-4511-1
30 deg tapered transition (ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	*(U.S. Customary Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 0.113/t_n \leq 1.9$ *(SI Units)* $1.3 + 0.0036\frac{D_o}{t_n} + 2.87/t_n \leq 1.9$	...
30 deg tapered transition (ASME B16.25) $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036D_o/t_n \leq 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg $< \alpha \leq 60$ deg	1.0	1	$0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2} \leq 2.0$	
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:
(a) The following nomenclature applies:
D_o = nominal outside diameter, in. (mm)
d_i = nominal inside diameter of branch, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
r'_m = mean radius of branch pipe, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
R_m = mean radius of run pipe, in. (mm)
θ = one-half angle between adjacent miter axes, deg
s = miter spacing at center line, in. (mm)
t_b = thickness in reinforcement zone of branch, in. (mm)
t_e = pad or saddle thickness, in. (mm)
t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
T'_b = nominal wall thickness of branch pipe, in. (mm)

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

3. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.

4. The definition of Cx as per Note 11 of Table NCD-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure NCD-4427-1.

Table NCD-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

GENERAL NOTES: (Cont'd)

T_r = nominal wall thickness of run pipe, in. (mm)

For Figure NCD-3673.2(b)-2, sketches (a) and (b):

$t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$

$= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$

For Figure NCD-3673.2(b)-2, sketch (c):

$t_b = T'_b + (^2/_3)y$ if $\theta_n \leq 30$ deg

$= T'_b + 0.385L_1$ if $\theta_n > 30$ deg

For Figure NCD-3673.2(b)-2, sketch (d):

$t_b = T'_b = T_b$

For branch connection nomenclature, refer to Figs. NCD-3643.2(b)-2 and NCD-3673.2(b)-2.

(b) The flexibility factors k, stress intensification factors i, and stress indices B_2 apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the B_1 index in Table NCD-3673.2(b)-1 is valid. The B_2 index shall be multiplied by the factor $1/(XY)$, where:

$X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0

$Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°F)

$Y = 1.0224 - 0.000594T$ for Ferritic Material, not to exceed 1.0; T = Design temperature (°C)

$Y = 1.0$ for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.

(a) One end flanged, $c = h^{1/6}$

(b) Both ends flanged, $c = h^{1/3}$

But after such multiplication, values of k and i shall not be taken as less than 1.0.

(2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(3) Also includes single miter joints.

(4) For checking branch leg stress:

$$Z = \pi (r'_m)^2 T'_b$$

For checking run leg stress:

$$Z = \pi (R_m)^2 T_r$$

(5) When $t_e > 1.5\ t_n$, $h = 4.05 t_n/r$.

(6) The equation applies only if the following conditions are met:

(a) The reinforcement area requirements of NCD-3643 are met.

(b) The axis of the branch pipe is normal to the surface of the run pipe wall.

(c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.

(d) The run pipe is a straight pipe.

(7) r'_m/r shall be taken as 0.5 for $r'_m/r > 0.5$.

r'_m/r_{ps} shall not be taken as less than 0.5.

The definition of r_{ps} is:

$r_{ps} = (r'_m + r_e)/2$ for $t_e \geq 0.8t_n$

$r_{ps} = r'_m + (T'_b/2)$ for $t_e < 0.8t_n$

(8) The definition of t'_e is:

$t'_e = t_e\ [(r_e/r'_m) - 1]$ but not greater than $1.0t_n$

(9) If an r_2 radius is provided [Figure NCD-3673.2(b)-2] that is not less than the larger of $T_b/2$, $(T'_b + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m/R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.

(10) The equations apply only if $r'_m/R_m \leq 0.5$.

(11) In Figure NCD-4427-1 sketches (c-1) and (c-2), C_x shall be taken as $X_{\min}$ and $C_x \geq 1.25\ t_n$. In Figure NCD-4427-1 sketch (c-3), $C_x \geq 0.75\ t_n$. For unequal leg lengths, use the smaller leg length for C_x.

(12) The equation applies only if the following conditions are met:

(o) Cone angle α does not exceed 60 deg.

(p) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.

(q) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(r) For eccentric reducers, α is the maximum cone angle.

General

The Code Compliance requirements provided in this Section as per ASME NM.1 are valid for above ground installation of Thermoplastic Piping Systems.

Analysis of buried piping (i.e., restrained piping) as per Non-mandatory Appendix B of this code is not yet implemented in CAEPIPE.

Allowable Pressure

(a) Straight Pipes made of materials other than HDPE

The allowable pressure for straight pipes made of materials other than HDPE is calculated using eq. (2-3-3) in para. 2-3.2.1.1 (b).

$$P_a = \frac{2St_a}{(D_o - t_a)}$$

(b) Bends/Elbows/Miters made of materials other than HDPE

The allowable pressure for Bends/Elbows made of materials other than HDPE is calculated using eq. (2-3-5b) in para. 2-3.2.2 (b).

$$P_a = DF\,\frac{2St_a}{(D_o - t_a)}$$

(c) Straight Pipes/Bends/Elbows made of HDPE

The allowable pressure for Pipes/Bends/Elbows made of HDPE is calculated using eq. (2-3-5a) in para. 2-3.2.2 (b).

$$P_a = GSR\,\frac{2St_a}{(D_o - t_a)}$$

where

P_a = allowable pressure
S = maximum allowable stress from ASME NM.3.3 Table 1-1-1 at Design Temperature input in CAEPIPE

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

DF = Design Factor from Table 2-3.2.2-2 corresponding to Molded fittings = 0.6

GSR = Geometry Shape Rating (GSR) for HDPE Fittings from Table 2-3.2.2-1 corresponding to Molded fittings = 1.0

(d) Miter Bends made of HDPE

For miter bends, the allowable pressure is calculated in CAEPIPE as lesser of Eqs. 2-3-6 and 2-3-7 with θ <= 22.5 deg.

$$P_a = min\left[\frac{S.t_a(R-r)}{r(R-0.5r)}, \frac{S.{t_a}^2}{r(t_a + 0.622tan\theta\sqrt{r.t_a})}\right]$$

where

r = mean radius of pipe = (D - t_n)/2

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r} - 1.0\right)}\right)$

Notes:

As per para. 2-3.2.4, equation given above to compute allowable internal pressure for Miter Bend is valid only when θ <= 22.5 deg. Hence, CAEPIPE will leave the Allowable Pressure row BLANK for Miter Bend elements where θ > 22.5 degree in Code Compliance Results.

Sustained Stress

The longitudinal stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 2-3.3.1.1 and eq. (2-3-8).

$$S_L = |S_{lp}| + \frac{0.75iM_A}{Z} \leq S_h$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal design pressure that shall be not less than the maximum sustained operating pressure within the piping system, including the effects of static head (as per para. 2-1.2.2 (a)) = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from Appendix IV and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) $= \sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Notes:

1. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

   where

   F_A = axial force due to weight and other sustained mechanical loads excluding pressure

   A = nominal material area

2. Branch Section modulus "Z" as per para. 2-3.3.3(a),

   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

   where

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Occasional Stress

The longitudinal stresses S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind is calculated using eq. (2-3-9) of para. 2-3.3.1.2. Wind and earthquake are not considered to act concurrently.

$$S_{LO} = S_L + \left|S_{lpo}\right| + \frac{0.75iM_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress = $\left|\frac{(P_o - P)d^2}{D^2 - d^2}\right|$ or $\left|\frac{(P_o - P)D}{4t_n}\right|$ This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

i = stress intensification factor from Appendix IV and 0.75i shall not be less than 1.0

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. $=\sqrt{(M_{Bx})^2 + (M_{By})^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

k = 1.2 corresponding to the event duration occurring for not more than 1 h at any one time and not more than 80 h/yr

Note:

1. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lpo}\right|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

   where

   F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

   A = nominal material Area

2. Branch Section modulus "Z" as per para. 2-3.3.3(a),

   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

   where

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (2-3.-11) in para. 2-3.3.1.3 (a) and (b).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where
i = stress intensification factor from Appendix IV
M_C = resultant of bending moment range due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + (M_{Cy})^2 + (M_{Cz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

S_A = allowable stress range, SA, as given in ASME NM.3.3 based on the fatigue properties for the given material at the given temperature as per para. 2-2.3.3(b). S_A is a user input in CAEPIPE Material Properties.

Note:

1. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

   where

   F_C = axial force range due to reference displacement load range.

$A =$ nominal material area

2. Branch Section modulus "Z" as per para. 2-3.3.3(a),

   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Settlement Stress

Stress range (S_S) caused by applied noncyclic secondary axial and longitudinal loads is calculated using eq. (2-3.-12) in para. 2-3.3.1.4 (a) and (b).

$$S_S = \frac{iM_D}{Z} \leq 2.S_h$$

where

i = stress intensification factor from Appendix IV

M_C = noncyclic resultant moment loading due to settlement = $\sqrt{(M_{Dx})^2 + \left(M_{Dy}\right)^2 + (M_{Dz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note below.

S_h = allowable stress at CAEPIPE reference temperature

Note:

Branch Section modulus "Z" as per para. 2-3.3.3(a),

for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

D_{oh} = Outside Diameter of header
D_{ob} = Outside Diameter of branch
d_h = Inside Diameter of header
d_b = Inside Diameter of branch

Hydrotest Stress

The longitudinal stress S_H due to test pressure, weight and other sustained mechanical loads is calculated from para. 2-3.3.4 and eq. (2-3-8).

$$S_L = \left|S_{lp}\right| + \frac{0.75iM_T}{Z} \leq S_{LA}$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2 - d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = Test pressure input for Hydrotest load
D = nominal outside diameter
d = nominal inside diameter

i = stress intensification factor from Appendix IV and 0.75i shall not be less than 1.0
M_T = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure)

$$= \sqrt{(M_{Tx})^2 + (M_{Ty})^2 + (M_{Tz})^2}$$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

S_{LA} = 1.2 S_h where, S_h = allowable stress at CAEPIPE reference temperature

Notes:

1. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lp}|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

   where

   F_A = axial force due to weight and other sustained mechanical loads excluding pressure

   A = nominal material area

2. Branch Section modulus "Z" as per para. 2-3.3.3(a),

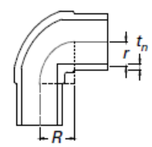
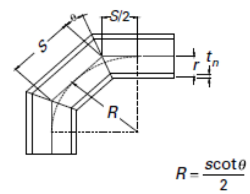
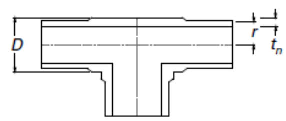
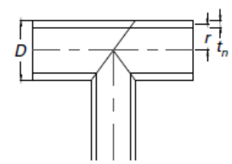
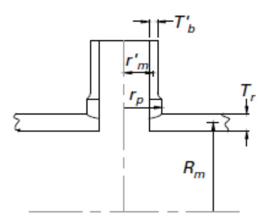
   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

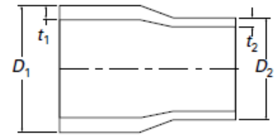
   where

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Stress Intensification Factors (SIFs) and Flexibility Factors (FFs)

Table IV-1 Stress Intensification Factors, *i*, and Flexibility Factors, *k*, for High-Density Polyethylene

Description	Flexibility Characteristic, *h*	Flexibility Factor, *k* [Note (1)]	Stress Intensification Factor, *i* [Note (1)]	Sketch
Straight pipe	N/A	1.0	1.0	N/A
Butt-fusion joint	N/A	1.0	1.0	N/A
Molded elbow	$\frac{t_n R}{r^2}$	...	$\frac{1.25}{h^{2/3}}$	
Miter elbow $s \geq r(1 + \tan\theta)$ [Note (2)]	$\frac{(1+\cot\theta)}{DR-1}$ or $\frac{t_n(1+\cot\theta)}{2r}$	In-plane loading [Note (3)] $\frac{1.1}{h^{5/6}}$	$\frac{1.7}{h^{2/3}}$	
Equal outlet molded tee [Note (4)]	$\frac{4.4t_n}{r}$	1.0	$i_b = \frac{1.73}{h^{2/3}}$ $i_r = \frac{1.17}{h^{2/3}}$	
Equal outlet mitered tee	$\frac{4.4t_n}{r}$ or $\frac{8.8}{DR-1}$	1.0	$i_b = \frac{4.45}{h^{2/3}}$ $i_r = \frac{2.21}{h^{2/3}}$	
Sidewall fusion branch connection [Note (5)]	N/A	1.0	$i_b = 1.74\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \geq 1.5$ $i_r = 1.54\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r_p}{R_m}\right) \geq 1.5$	

Concentric monolithic reducers	N/A	1.0	$0.5 + 0.32\left(\frac{D_1}{D_2}\right)\left(\frac{D_2}{t_2}\right)^{1/2} \leq 2.5$	

GENERAL NOTES:

(a) The following nomenclature applies to this Table only for use in determining stress indices, stress intensification factors, and flexibility factors:

D_1 = nominal O.D. of the larger side of a concentric fabricated reducer or the diameter of the thrust collar
D_2 = nominal O.D. of the smaller side of a concentric fabricated reducer or the nominal pipe diameter of a thrust collar
D_O = pipe O.D.
DR = pipe dimension ratio
= D_o/T_n

R = nominal bend radius of elbow or pipe bend, mm (in.)
r = mean radius of pipe, mm (in.) (matching pipe for elbows and tees)
S = miter spacing at centerline, mm (in.)
T_2 = nominal thickness of the smaller side of a concentric fabricated reducer or the nominal pipe thickness of a thrust collar
T_n = nominal wall thickness of pipe, mm (in.) (matching pipe for elbows and tees)
T_r = nominal wall thickness of run pipe, mm (in.)
θ = one-half angle between adjacent miter axes, deg

(b) All abutting piping fittings of differing DRs shall meet the requirements of Figure 2-3.2.4-1, illustration (a) or illustration (b), as applicable.

NOTES:

(1) The stress intensification factors, i, and the flexibility factors, k, shall not be taken as less than 1.0. They are applicable to moments in any plane for fittings except as noted.
(2) One-half miter angle, θ, shall be limited to ≤11.25 deg.
(3) The flexibility factor, k, is applicable only for in-plane bending moment loading.
(4) The tee thickness, t_n, shall be 1.4 times the pipe thickness, T_r ($1.4T_r$).
(5) The ratio OD_{branch}/OD_{run} shall be <0.4.
(6) The ratio OD_{branch}/OD_{run} shall be <0.6.

Notes:

1. **SIF computation for "Sidewall fusion branch connection" (Branch Connection) in CAEPIPE is valid only when Branch OD / Run OD is less than 0.4 as per Note 5 above. As the code is NOT explicit about the SIF to be used when Branch OD / Run OD >= 0.4, CAEPIPE uses the same SIF equation even for Branch Connection with Branch OD / Run OD > 0.4.**

2. **In case the user wants to input at a node a SIFs for a component which is not listed above, then user can input the desired value using the data type "User SIF" at that node. See the Section titled "User SIF" in CAEPIPE Technical Reference Manual for further details.**

General

The Code Compliance requirements provided in this Section as per ASME NM.1 are valid for above ground installation of Thermoplastic Piping Systems.

Analysis of buried piping (i.e., restrained piping) as per Non-mandatory Appendix B of this code is not yet implemented in CAEPIPE.

Allowable Pressure

(e) <u>Straight Pipes/Bends/Elbows/Miters made of materials other than HDPE</u>

The allowable pressure for Straight Pipes/Bends/Elbows/Miters made of materials other than HDPE is calculated using eq. (2-3-5b) in para. 2-3.2.2 (c).

$$P_a = DF\frac{2St_a}{(D_o - t_a)}$$

(f) <u>Straight Pipes/Bends/Elbows made of HDPE</u>

The allowable pressure for Pipes/Bends/Elbows made of HDPE is calculated using eq. (2-3-5a) in para. 2-3.2.2 (b).

$$P_a = GSR\frac{2St_a}{(D_o - t_a)}$$

where

P_a = allowable pressure
S = maximum allowable stress from ASME NM.3.3 Table 1-1-1 at Design Temperature input in CAEPIPE

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

DF = Design Factor from Table 2-3.2.2-2 for materials other than HDPE

DF = 1.0 for straight pipes and DF = 0.6 for molded fittings, solvent welded

GSR = Geometry Shape Rating (GSR) from Table 2-3.2.2-1 for HDPE materials

GSR = 1.0 for straight pipes and molded fittings

(g) Miter Bends made of HDPE

For miter bends, the allowable pressure is calculated in CAEPIPE as lesser of Eqs. 2-3-6 and 2-3-7 with θ <= 22.5 deg.

$$P_a = min\left[\frac{S.t_a(R-r)}{r(R+0.5r)}, \frac{S.{t_a}^2}{r(t_a+0.622tan\theta\sqrt{r.t_a})}\right]$$

where

r = mean radius of pipe = (D - t_n)/2

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r}-1.0\right)}\right)$

Notes:

As per para. 2-3.2.4, equation given above to compute allowable internal pressure for Miter Bend is valid only when θ <= 22.5 deg. Hence, CAEPIPE will leave the Allowable Pressure row BLANK for Miter Bend elements where θ > 22.5 degree in Code Compliance Results.

Sustained Stress

The longitudinal stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 2-3.3.1.1 and eq. (2-3-8).

$$S_L = |S_{lp}| + \frac{0.75iM_A}{Z} \leq S_h$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$ as per Eqs. 2-2-3 and 2-2-4 in para. 2-2.3.3 (a)(3). This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal pressure including the effects of static head (as per para. 2-2.3.3 (a)(3)) = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from Appendix IV and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Notes:

3. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

   where

   F_A = axial force due to weight and other sustained mechanical loads excluding pressure

   A = nominal material area

4. Branch Section modulus "Z" as per para. 2-3.3.3(a),

   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

   where

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Occasional Stress

The longitudinal stresses S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind is calculated using eq. (2-3-9) of para. 2-3.3.1.2. Wind and earthquake are not considered to act concurrently.

$$S_{LO} = S_L + \left|S_{lpo}\right| + \frac{0.75iM_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress = $\left|\frac{(P_o - P)d^2}{D^2 - d^2}\right|$ or $\left|\frac{(P_o - P)D}{4t_n}\right|$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

i = stress intensification factor from Appendix IV and 0.75i shall not be less than 1.0

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. =$\sqrt{(M_{Bx})^2 + \left(M_{By}\right)^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

k = 1.2 corresponding to the occasional event duration occurring for not more than 1 h at any one time and not more than 80 h/yr

Note:

2. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lpo}\right|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

   where

   F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

   A = nominal material Area

2. Branch Section modulus "Z" as per para. 2-3.3.3(a),

   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

   where

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (2-3-11) in para. 2-3.3.1.3 (a) and (b).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where
i = stress intensification factor from Appendix IV
M_C = resultant of bending moment range due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + \left(M_{Cy}\right)^2 + (M_{Cz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

S_A = allowable stress range, SA, as given in ASME NM.3.3 based on the fatigue properties for the given material at the given temperature as per para. 2-2.3.3(b). S_A is a user input in CAEPIPE Material Properties.

Note:

2. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

   where

   F_C = axial force range due to reference displacement load range.

$A =$ nominal material area

2. Branch Section modulus “Z” as per para. 2-3.3.3(a),

   for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

   D_{oh} = Outside Diameter of header
   D_{ob} = Outside Diameter of branch
   d_h = Inside Diameter of header
   d_b = Inside Diameter of branch

Settlement Stress

Stress range (S_S) caused by applied noncyclic secondary axial / longitudinal loads is calculated using eq. (2-3-12) in para. 2-3.3.1.4 (a) and (b).

$$S_S = \frac{iM_D}{Z} \leq 2.S_h$$

where
i = stress intensification factor from Appendix IV
M_C = noncyclic resultant moment loading due to settlement = $\sqrt{(M_{Dx})^2 + \left(M_{Dy}\right)^2 + (M_{Dz})^2}$

Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note below.

S_h = allowable stress at CAEPIPE reference temperature

Note:

Branch Section modulus “Z” as per para. 2-3.3.3(a),

for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

D_{oh} = Outside Diameter of header
D_{ob} = Outside Diameter of branch
d_h = Inside Diameter of header
d_b = Inside Diameter of branch

Hydrotest Stress

The longitudinal stress S_H due to test pressure, weight and other sustained mechanical loads is calculated from para. 2-2.3.4 and eq. (2-3-8).

$$S_{LT} = \left|S_{lp}\right| + \frac{0.75iM_T}{Z} \leq S_{LA}$$

where
S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2 - d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.
P = Test pressure input for Hydrotest load
D = nominal outside diameter
d = nominal inside diameter

i = stress intensification factor from Appendix IV and 0.75i shall not be less than 1.0
M_T = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Tx})^2 + (M_{Ty})^2 + (M_{Tz})^2}$
Z = un-corroded section modulus; for a branch, effective section modulus as per para. 2-3.3.3(a). See Note 2 below.

S_{LA} = 1.2 S_h where, S_h = allowable stress at CAEPIPE reference temperature

Notes:

3. When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lp}|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal material area

4. Branch Section modulus "Z" as per para. 2-3.3.3(a),

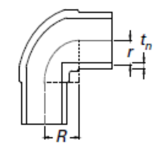
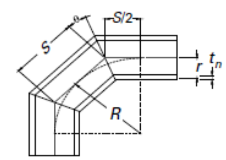
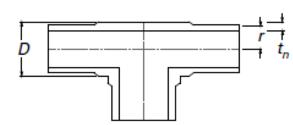
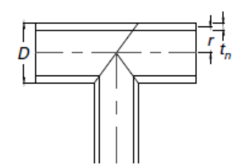
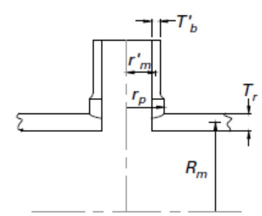
for Run pipe = $\frac{\pi(D_{oh}^4 - d_h^4)}{32D_{oh}}$ and Branch Pipe = $\frac{\pi(D_{ob}^4 - d_b^4)}{32D_{ob}}$

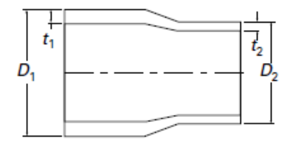
where

D_{oh} = Outside Diameter of header
D_{ob} = Outside Diameter of branch
d_h = Inside Diameter of header
d_b = Inside Diameter of branch

Stress Intensification Factors (SIFs) and Flexibility Factors (FFs)

Table IV-1 Stress Intensification Factors, *i*, and Flexibility Factors, *k*, for High-Density Polyethylene

Description	Flexibility Characteristic, h	Flexibility Factor, k [Note (1)]	Stress Intensification Factor, i [Note (1)]	Sketch
Straight pipe	N/A	1.0	1.0	N/A
Butt-fusion joint	N/A	1.0	1.0	N/A
Molded elbow	$\frac{t_n R}{r^2}$	...	$\frac{1.25}{h^{2/3}}$	
Miter elbow $s \geq r(1 + \tan\theta)$ [Note (2)]	$\frac{(1+\cot\theta)}{DR-1}$ or $\frac{t_n(1+\cot\theta)}{2r}$	In-plane loading [Note (3)] $\frac{1.1}{h^{5/6}}$	$\frac{1.7}{h^{2/3}}$	 $R = \frac{s\cot\theta}{2}$
Equal outlet molded tee [Note (4)]	$\frac{4.4t_n}{r}$	1.0	$i_b = \frac{1.73}{h^{2/3}}$ $i_r = \frac{1.17}{h^{2/3}}$	
Equal outlet mitered tee	$\frac{4.4t_n}{r}$ or $\frac{8.8}{DR-1}$	1.0	$i_b = \frac{4.45}{h^{2/3}}$ $i_r = \frac{2.21}{h^{2/3}}$	
Sidewall fusion branch connection [Note (5)]	N/A	1.0	$i_b = 1.74\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right) \geq 1.5$ $i_r = 1.54\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r_p}{R_m}\right) \geq 1.5$	

Concentric monolithic reducers	N/A	1.0	$0.5 + 0.32\left(\frac{D_1}{D_2}\right)\left(\frac{D_2}{t_2}\right)^{1/2} \le 2.5$	

GENERAL NOTES:

(a) The following nomenclature applies to this Table only for use in determining stress indices, stress intensification factors, and flexibility factors:

D_1 = nominal O.D. of the larger side of a concentric fabricated reducer or the diameter of the thrust collar
D_2 = nominal O.D. of the smaller side of a concentric fabricated reducer or the nominal pipe diameter of a thrust collar
D_O = pipe O.D.
DR = pipe dimension ratio
= D_o/T_n

R = nominal bend radius of elbow or pipe bend, mm (in.)
r = mean radius of pipe, mm (in.) (matching pipe for elbows and tees)
S = miter spacing at centerline, mm (in.)
T_2 = nominal thickness of the smaller side of a concentric fabricated reducer or the nominal pipe thickness of a thrust collar
T_n = nominal wall thickness of pipe, mm (in.) (matching pipe for elbows and tees)
T_r = nominal wall thickness of run pipe, mm (in.)
θ = one-half angle between adjacent miter axes, deg

(b) All abutting piping fittings of differing DRs shall meet the requirements of Figure 2-3.2.4-1, illustration (a) or illustration (b), as applicable.

NOTES:

(1) The stress intensification factors, i, and the flexibility factors, k, shall not be taken as less than 1.0. They are applicable to moments in any plane for fittings except as noted.
(2) One-half miter angle, θ, shall be limited to ≤11.25 deg.
(3) The flexibility factor, k, is applicable only for in-plane bending moment loading.
(4) The tee thickness, t_n, shall be 1.4 times the pipe thickness, T_r ($1.4T_r$).
(5) The ratio OD_{branch}/OD_{run} shall be <0.4.
(6) The ratio OD_{branch}/OD_{run} shall be <0.6.

Notes:

3. **SIF computation for "Sidewall fusion branch connection" (Branch Connection) in CAEPIPE is valid only when Branch OD / Run OD is less than 0.4 as per Note 5 above. As the code is NOT explicit about the SIF to be used when Branch OD / Run OD >= 0.4, CAEPIPE uses the same SIF equation even for Branch Connection with Branch OD / Run OD > 0.4.**

4. **In case the user wants to input at a node a SIFs for a component which is not listed above, then user can input the desired value using the data type "User SIF" at that node. See the Section titled "User SIF" in CAEPIPE Technical Reference Manual for further details.**

General

The Code Compliance requirements provided in this Section as per ASME NM.2 are valid for above ground installation of GRP/FRP Piping.

Section 2-6.3 of ASME NM 2 (2022) refers to AWWA Manual M45 (second edition) for Buried GRP/FRP Piping Analysis. AWWA Manual M45 is also referred by ISO 14692-3 for detailed analysis of Buried GRP/FRP Piping. Code Compliance as per ISO 14692-3 is built into CAEPIPE Version 12.00 or later. Hence, for Buried GRP/FRP Piping Analysis, ISO 14692-3 can be selected in CAEPIPE for Code Compliance checks.

Allowable Pressure

Straight Pipes and Bends

For straight pipes and bends, CAEPIPE calculates allowable pressure using Eq. (2-3-2) of para.2-3.2.2 and Eqs. (2-3-6) of para. 2-3.3.1 and Eqs. (2-3-9), (2-3-10) & (2-3-11) of para. 2-3.3.2 (a) & (b).

$$P_a = \frac{2.S_{H(2:1)}.t_a}{K_1.D.m}$$

where

P_a= allowable pressure

$S_{H(2:1)}$ = design hoop allowable stress at Design Temperature (can be obtained from applicable table in ASME NM.3.3)

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE as per para. 2-3.2.1 (a))

t_n = nominal pipe/bend thickness

D = outside diameter of pipe/bend, to be conservative

m = 1.0 for straight pipes and at the side wall on the bend / elbow centerline radius

K_1 = 1.0 for Pipe with Type I and Type II laminates

K_1 = 1.2 for Bends / Elbows with Type I and Type II laminates

Note:

Allowable pressure at the "intrados" of a bend can be manually computed by dividing the CAEPIPE computed allowable pressure for that bend by the factor "m" given by Eq. (2-3-7) in para. 2-3.3.1. Similarly, allowable pressure at the "Extrados" of a bend can be manually computed by diving the CAEPIPE computed allowable pressure for that bend by the factor "m" given by Eq. (2-3-8) in para. 2-3.3.1.

For closely spaced miter bends, the allowable pressure computed by CAEPIPE shall be the lesser of the two values calculated from Eqs. 2-3-9 and 2-3-10 with θ<= 22.5 deg.

$$P_a = min\left[\frac{S_{H(2:1)}.t_a(R-r)}{r(R-0.5r)}, \frac{S_{H(2:1)}.{t_a}^2}{r(t_a + 0.643tan\theta\sqrt{r.t_a})}\right]$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE by Eq. 2-3-9

$$P_a = \frac{S_{H(2:1)}.t_a^{\;2}}{r(t_a + 0.643 tan\theta\sqrt{r.t_a})}$$

For widely spaced miter bends and closely spaced miter bends with θ > 22.5 deg, the allowable pressure is calculated in CAEPIPE by Eq. 2-3-11

$$P_a = \frac{S_{H(2:1)}.t_a^{\;2}}{r(t_a + 1.25\, tan\theta\sqrt{r.t_a})}$$

where

r = mean radius of pipe = (D - t_n)/2

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r} - 1.0\right)}\right)$

Integrally Molded Tee fittings

For integrally molded Tee fittings, CAEPIPE calculates allowable pressure for Run and Branch of a Tee using Eq. (2-3-18) of para.2-3.4.

For Tee Run

$$P_{aR} = \frac{2.S_{H(2:1)}.t_{aR}}{D_R.m}$$

For Tee Branch

$$P_{aB} = \frac{2.S_{H(2:1)}.t_{aB}}{D_B.m}$$

where

P_{aR}= allowable pressure for Run

P_{aB}= allowable pressure for Branch

$S_{H(2:1)}$ = design hoop allowable stress (can be obtained from applicable table in ASME NM.3.3) at Design Temperature input in CAEPIPE load dialog.

m = pressure stress multiplier for integral tees = $1.4\lambda_z^{\;0.25}$

λ_z = geometry factor as given below

For equal tees (i.e., $D_B = D_R$)

$$\lambda_z = \frac{D_R}{2.t_{aR}}$$

For unequal or reducing tees (i.e., $D_B < D_R$)

$$\lambda_z = \left(\frac{D_B}{2.t_{aB}}\right)^2 \left(\frac{2t_{aR}}{D_R}\right)$$

where

t_{aR}= available Run thickness for pressure design = t_{nR} × (1 - mill tolerance/100) - corrosion allowance

t_{aB}= available Branch thickness for pressure design = t_{nB} × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE as per para. 2-3.2.1 (a))

t_{nR} = nominal thickness of Run

t_{nB} = nominal thickness of Branch

D_R = inside diameter of the main run pipe structural wall = Run OD – 2 * t_{aR}

D_B = inside diameter of the tee branch pipe structural wall = Branch OD – 2 * t_{aB}

Sustained Load

(a) The Hoop Stress (S_{HL}) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. (2-4-1) of para. 2-4.4.4 (a)(1) and compared against the limit given in para. 2-4.4.4 (b)(1).

$$S_{HL} = \sqrt{\left[\frac{mPD_m}{2T_s} + \frac{\sqrt{(i_{ih}M_i)^2 + (i_{oh}M_o)^2}}{Z}\right]^2 + \left(\frac{i_t M_t}{Z}\right)^2} \le S_{H.max}$$

(b) The Longitudinal Stress (S_{AL}) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eqs. (2-4-2a) & (2-4-2b) of para. 2-4.4.4 (a)(2) and compared against the limit given in para. 2-4.4.4 (b)(1).

$$S_{AL1} = \sqrt{\left[\frac{PD_{is}^{\ 2}}{D_o^2 - D_{is}^2} + \frac{F_A}{A_s} - \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]^2 + \left(\frac{i_t M_t}{Z}\right)^2}$$

$$S_{AL2} = \sqrt{\left[\frac{PD_{is}^{\ 2}}{D_o^2 - D_{is}^2} + \frac{F_A}{A_s} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]^2 + \left(\frac{i_t M_t}{Z}\right)^2}$$

$S_{AL.min} = minimum(S_{AL1}, S_{AL2}) \leq S_{A.max}$

$S_{AL.max} = maximum(S_{AL1}, S_{AL2}) \leq S_{A.max}$

where

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

T_S = corroded wall thickness = t_n - corrosion allowance

t_n = nominal thickness

D_{is} = inside diameter = D_o - $2T_S$

m = pressure stress multiplier from Appendix III

i_{ih} = stress intensification factor, hoop stress due to in-plane moment as per Appendix III

i_{oh} = stress intensification factor, hoop stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

i_i = stress intensification factor, axial stress due to in-plane moment as per Appendix III

i_o = stress intensification factor, axial stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

M_i, M_o, M_t = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads

F_A = axial force due to weight and other sustained mechanical loads (excluding pressure)

Z = section modulus = $\pi[D_o^4 - (D_o - 2T_s)^4]/32D_o$

A_S = area of cross-section = $\pi[D_o^2 - D_{is}^2]/4$

$S_{A.max}$ = axial allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 .. T10)]

$S_{AL.min}$ = minimum longitudinal stress due to pressure, weight and other sustained mechanical loads

$S_{AL.max}$ = maximum longitudinal stress due to pressure, weight and other sustained mechanical loads

Occasional Load (Sustained + Occasional)

(a) The Hoop stress (S_{HO}) due to sustained and occasional loads is calculated from Eq. (2-4-1) of para. 2-4.4.4 (a)(1) as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind and compared against the limit given in para. 2-4.4.4 (b)(2). Wind and earthquake are not considered to act concurrently as per para. 2-2.3.8 (a).

$$S_{HO} = S_{HL} + \sqrt{\left[\frac{m(P_{peak} - P)D_m}{2T_s} + \frac{\sqrt{(i_{ih}M_{io})^2 + (i_{oh}M_{oo})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2} \leq 1.33S_{H.max}$$

(b) The Longitudinal stress (S_{AO}) due to sustained and occasional is calculated is calculated from Eqs. (2-4-2a) and (2-4-2b) of para. 2-4.4.4 (a)(2) as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind and compared against the limit given in para. 2-4.4.4 (b)(2). Wind and earthquake are not considered to act concurrently as per para. 2-2.3.8 (a).

$$S_{AO1} = \sqrt{\left[\frac{\left(P_{peak} - P\right){D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AO}}{A_s} - \frac{\sqrt{(i_i M_{io})^2 + (i_o M_{oo})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2} \leq 1.33 S_{A.max}$$

$$S_{AO2} = \sqrt{\left[\frac{\left(P_{peak} - P\right){D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AO}}{A_s} + \frac{\sqrt{(i_i M_{io})^2 + (i_o M_{oo})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2} \leq 1.33 S_{A.max}$$

$$S_{AO.min} = S_{AL.min} + minimum(S_{AO1}, S_{AO2}) \leq 1.33\ S_{A.max}$$

$$S_{AO.max} = S_{AL.max} + maximum(S_{AO1}, S_{AO2}) \leq 1.33\ S_{A.max}$$

where

P = maximum of CAEPIPE pressures P1 through P10

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P

T_S = corroded wall thickness = t_n - corrosion allowance

t_n = nominal thickness

D_o = outside diameter of the component

D_{is} = inside diameter = D_o - $2T_S$

m = pressure stress multiplier from Appendix III

i_{ih} = stress intensification factor, hoop stress due to in-plane moment as per Appendix III

i_{oh} = stress intensification factor, hoop stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

i_i = stress intensification factor, axial stress due to in-plane moment as per Appendix III

i_o = stress intensification factor, axial stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

F_{AO} = axial force due to occasional loads such as wind or seismic, etc.

M_{io}, M_{oo}, M_{to} = in-plane, out-of-plane and torsional moment respectively due to occasional loads such as wind or seismic, etc.

Z = section modulus = $\pi[D_o^4 - (D_o - 2T_s)^4]/32D_o$

A_S = area of cross-section = $\pi[D_o^2 - D_{is}^2]/4$

$S_{H.max}$ = hoop allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 .. T10)]

$S_{A.max}$ = axial allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 .. T10)]

$S_{AO.min}$ = minimum longitudinal stress due to occasional loads such as wind or seismic, etc.

$S_{AO.max}$ = maximum longitudinal stress due to occasional loads such as wind or seismic, etc.

Operating Load (Sustained + Expansion)

(c) The Hoop Stress (S_{HE}) due to operating loads (pressure, weight, other sustained mechanical loads and thermal displacement) is calculated from Eq. (2-4-1) of para. 2-4.4.4 (a)(1) and compared against the limit given in para. 2-4.4.4 (b)(1).

$$S_{HE} = \sqrt{\left[\frac{mP_n D_m}{2T_s} + \frac{\sqrt{(i_{ih}M_{iE})^2 + (i_{oh}M_{oE})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tE}}{Z}\right)^2} \le 1.1S_{H.max}$$

(a) The Longitudinal stress (S_{AE}) due to operating loads (pressure, weight, other sustained mechanical loads and thermal displacement) is calculated from Eqs. (2-4-2a) and (2-4-2b) of para. 2-4.4.4 (a)(2) and compared against the limit given in para. 2-4.4.4 (b)(1).

$$S_{AE1} = \sqrt{\left[\frac{P_n {D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AE}}{A_s} - \frac{\sqrt{(i_i M_{iE})^2 + (i_o M_{oE})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2}$$

$$S_{AE2} = \sqrt{\left[\frac{P_n {D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AE}}{A_s} + \frac{\sqrt{(i_i M_{iE})^2 + (i_o M_{oE})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2}$$

$$S_{AE.min} = minimum(S_{AE1}, S_{AE2}) \le 1.1\, S_{A.max}$$

$$S_{AE.max} = maximum(S_{AE1}, S_{AE2}) \le 1.1\, S_{A.max}$$

where

P_n = internal operating pressure P1 through P10. For example, for Operating Load 1, P_n = P1

T_S = corroded wall thickness = t_n - corrosion allowance

t_n = nominal component thickness

D_o = outside diameter of the component

D_{is} = inside diameter = D_o - $2T_S$

m = pressure stress multiplier from Appendix III

i_{ih} = stress intensification factor, hoop stress due to in-plane moment as per Appendix III

i_{oh} = stress intensification factor, hoop stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

i_i = stress intensification factor, axial stress due to in-plane moment as per Appendix III

i_o = stress intensification factor, axial stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

F_{AE} = axial force due to operating load such as weight, other sustained mechanical loads and thermal displacement

M_{iE}, M_{oE}, M_{tE} = in-plane, out-of-plane and torsional moment respectively due to weight, other sustained mechanical loads and thermal displacement

Z = section modulus = $\pi[D_o^4 - (D_o - 2T_s)^4]/32D_o$

A_S = area of cross-section = $\pi[D_o^2 - D_{is}^2]/4$

$S_{H.max}$ = hoop allowable stress at operating temperatures T1 through T10

$S_{A.max}$ = axial allowable stress at operating temperature. For example, for Operating Load 1, Operating temperature is T1.

$S_{AE.min}$ = minimum longitudinal stress due to weight, other sustained mechanical loads and thermal displacement

$S_{AE.max}$ = maximum longitudinal stress due to weight, other sustained mechanical loads and thermal displacement

Flexibility Factors (FFs), Stress Intensification Factors (SIFs) and Pressure Stress Multipliers (PSMs)

The FFs, SIFs and PSMs as per ASME NM.2 code are given below (extracted from Appendix III of the code). How they are implemented in CAEPIPE is described below.

1. Flexibility Factors, Stress Intensification Factors and Pressure Multipliers are calculated as per Appendix III of ASME NM.2 only for Type I and Type II components in CAEPIPE at this time. Type I and Type II components can be differentiated in CAEPIPE by selecting the Material Type as "FR – Fiber/Glass Reinforced Plastics (FRP)" OR "F1 – Fiber/Glass Reinforced Plastics (FRP) Type I" and "F2 – Fiber/Glass Reinforced Plastics (FRP) Type II" respectively.
2. Flexibility factor (k) for all components except for Bends & Mitres is set as 1.0 internally in CAEPIPE.
3. Flexibility factor (k) for Bend / Mitre is 1.0 when Radius is NOT equal to long radius (i.e., k = 1.00 when Radius is <= 1.35D or >= 1.65D, where D is Outside Diameter).
4. Flexibility factor (k) for long radius Bend and Mitre is 1.0 when the Diameter / Thickness ratio is greater than 140. i.e., k = 1.00 when D/t > 140.
5. Flexibility factor (k) for long radius Bend and Mitre is 1.0 when Pipe Diameter is greater than 48".
6. Since thicknesses at intrados and extrados are not input at this time, thickness input at Bend / Mitre dialog or Thickness of section (when thickness field at Bend / Mitre dialog is left blank) (= t_n = nominal thickness) is considered in computing "t_i", "t_e", "t_{is}" and "t_{es}" in the calculation, i.e.,

   $t_{is} = t_{es} = t_n$ – mill tolerance – corrosion allowance

   $t_i = t_e = t_n$ – mill tolerance

   where,

   t_n = nominal thickness = thickness input at Bend / Mitre dialog or Thickness of section
7. Correction factor (α_2) is accounted as 1.00 in Stress Intensification Factor (SIF) calculation for the Bend / Mitre as intrados and extrados thicknesses cannot be input at this time in CAEPIPE.
8. Correction factor (α_3) is accounted as 1.00 in Pressure Stress Multiplier (m) calculation for the Bend / Mitre as intrados and extrados thicknesses cannot be input at this time in CAEPIPE.
9. Minimum value of Longitudinal Stress SIF and Shear Stress SIF for all components is 1.00.
10. Hoop SIF for all components (excepting Bend / Mitre) is 0.0. For Bend / Mitre, Minimum Hoop Stress SIF is 1.00.
11. Minimum Pressure Stress Multiplier is 1.00 for all components.
12. Pressure Stress Multiplier is 1.0 for both Type I and Type II Tees when the Diameter is greater than 24".

Flexibility Factors (FFs)

Elbows

III-2.1.1 Type I and Type II Elbows. The equations below may be used to calculate the flexibility factor, k, for Type I and Type II long-radius elbows that comply with the following criteria:

(a) The diameter-to-total-thickness ratio is not greater than 140.

(b) The pipe size does not exceed 1 200 mm (48 in.) diameter.

(c) The butt joint between the elbow and the pipe is a Type II laminate, and the connected pipe is Type II or filament-wound laminate.

For Type I elbows

$$k = 0.22\gamma\left(\frac{D}{t_e}\right)\left(\frac{t_i}{t_e}\right)^{-1.04} \qquad \text{(III-2-2)}$$

For Type II elbows

$$k = \gamma\left[0.2\left(\frac{D}{t_e}\right) - 0.7\right]\left(\frac{t_i}{t_e}\right)^{-0.98} \qquad \text{(III-2-3)}$$

where

D = inside diameter of pipe, mm (in.)

t_e = thickness of the total wall of the elbow measured at the extrados [including a corrosion-barrier thickness of at least 2.8 mm (0.11 in.)], mm (in.)

t_i = thickness of the total wall of the elbow measured at the intrados [including a corrosion barrier thickness of at least 2.8 mm (0.11 in.)], mm (in.)

γ = correction factor for reduction in flexibility due to internal pressure

$$= \left(1 + 2.53\frac{Pr}{E_h t_e} \times R_1^{0.333}\frac{r}{t_e^{1.333}}\right)^{-1}$$

E_h = hoop modulus of the elbow, MPa (psi)

P = pressure, MPa (psi)

R_1 = radius of the bend, mm (in.)

= $1.5D$

r = inside radius of the elbow, mm (in.)

NOTE: k shall not be taken as less than 1.0.

III-2.1.3 Flanged Elbows. The flexibility factor for flanged elbows shall be reduced by multiplying k by one of the following factors, c:

(a) For elbows with one flanged end

$$c = \left(\frac{t_e R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/6} \qquad \text{(III-2-4)}$$

(b) For elbows with two flanged ends

$$c = \left(\frac{t_e R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/3} \qquad \text{(III-2-5)}$$

where

D = inside diameter of pipe, mm (in.)

R_1 = radius of bend, mm (in.)

= $1.5D$

t_e = thickness of the total wall of the elbow measured at the extrados, mm (in.)

NOTE: k shall not be taken as less than 1.0.

TEES

III-3.1 Flexibility Factors for Tees

The flexibility factor, k, for tees shall be taken to be 1.0.

Reducers

III-4.1 Flexibility Factors for Concentric Reducers

The flexibility factor, k, for concentric reducers shall be taken to be 1.0.

Stress Intensification Factors (SIFs)

Elbows

Correction factor α_2 is not included in the SIF calculation for Elbows as the Bend/Elbow in CAEPIPE can only have uniform thickness around its entire circumference.

III-2.2.1 Type I and Type II Elbows

(a) The following equation shall be used to calculate i for Type I and Type II long-radius elbows for which the diameter-to-structural-thickness ratio is not greater than 140, and for which the pipe size does not exceed 1 200 mm (48 in.) diameter:

$$i = \frac{\alpha_2 \gamma}{h^{0.667}} \quad \text{(III-2-7)}$$

where

h = flexibility characteristic
$= \frac{t_{es} R_1}{r^2}$
r = inside radius of the elbow, mm (in.)
R_1 = radius of the bend, mm (in.)
= 1.5D where D is the inside diameter of the pipe
t_{es} = thickness of the structural wall of the elbow measured at the extrados, mm (in.)
α_2 = correction factor for reduction in SIF due to increased thickness at the intrados compared to the extrados; see (c) below
γ = correction factor for reduction in SIF due to internal pressure
$= \left(1 + 2.53 \frac{Pr}{E_h t_e} \times R_1^{0.333} \frac{r}{t_e^{1.333}}\right)^{-1}$
E_h = hoop modulus of the elbow, MPa (psi)
P = pressure, MPa (psi)
t_e = thickness of the total wall of the elbow measured at the extrados [including a corrosion-barrier thickness of at least 2.8 mm (0.11 in.)], mm (in.)

(b) Five SIFs are required to quantify the stresses in an elbow.

(1) longitudinal SIF due to in-plane moment, i_{ix}.
(2) longitudinal SIF due to out-of-plane moment, i_{ox}.
(3) hoop SIF due to in-plane moment, i_{ih}.
(4) hoop SIF due to out-of-plane moment, i_{oh}.
(5) shear stress SIF due to torsional moment, i_t. For Type I and Type II elbows, i_t may be taken to be 1.0.

III-2.2.3 Flanged Elbows. The SIFs for flanged elbows may be reduced by multiplying i by one of the following factors, c:

(a) For elbows with one flanged end

$$c = \left(\frac{t_{es} R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/6} \quad \text{(III-2-8)}$$

(b) For elbows with two flanged ends

$$c = \left(\frac{t_{es} R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/3} \quad \text{(III-2-9)}$$

where

D = inside diameter of pipe, mm (in.)
R_1 = radius of bend, mm (in.)
= 1.5D
t_{es} = thickness of the structural wall of the elbow measured at the extrados, mm (in.)

TEES

III-3.2.1 Type I and Type II Tees

(a) For Type I and Type II tees and reducing tees for which the diameter does not exceed 600 mm (24 in.), the SIF, i, is a function of the pipe factor, λ_t. The pipe factor, λ_t, is defined as follows:

$$\lambda_t = \frac{2t_R}{D_R} \quad \text{(III-2-12)}$$

where

D_R = inside diameter of the main run structural wall, mm (in.)
t_R = thickness of the structural layer of the main run of the tee, mm (in.)

(b) The longitudinal SIFs shall be determined by

$$i_{ix} = i_{ox} = 0.66(\lambda_t)^{-0.5} \quad \text{(III-2-13)}$$

(c) The hoop SIFs, i_{ih} and i_{oh}, may be taken to be 0.0.
(d) The torsional SIF, i_t, may be taken to be 1.5.

Reducers

III-4.2 SIFs for Concentric Reducers

In the absence of more directly applicable data, the SIFs, i, for concentric reducers may be determined as described in paras. III-4.2.1 and III-4.2.2. In no case shall i be less than 1.0 except that the hoop SIFs, i_{ih} and i_{oh}, may be taken to be 0.0.

III-4.2.1 Type I and Type II Concentric Reducers. The following values for SIFs may be used for Type I and Type II concentric reducers for which the diameter-to-structural-thickness ratio is not greater than 120, and for which the pipe size does not exceed 1 200 mm (48 in.) diameter:

	SIF	
Concentric Reducer Type	Large Diameter End	Small Diameter End
I	2.5	1.3
II	2.5	1.3

Pressure Stress Multipliers

Elbows

III-2.3.1 Type I and Type II Elbows

(a) The following equation may be used to calculate m for Type I and Type II elbows:

$$m = \alpha_3 \left(\frac{4\frac{R_1}{D} - 1}{4\frac{R_1}{D} - 2} \right) \tag{III-2-11}$$

where

D = inside diameter of elbow, mm (in.)
R_1 = bend radius of the elbow, mm (in.); $R_1 > D$
α_3 = correction factor for reduction in m due to increased thickness at the intrados compared to the extrados; see (b)

(b) FRP elbows are often manufactured such that the thickness varies uniformly around the circumference of the elbow from a minimum at the extrados to a maximum at the intrados. This additional thickness will reduce the maximum hoop pressure stress of the elbow compared to an elbow that has a uniform thickness around the entire circumference. The following values for α_3 may be used for Type I and Type II elbows:

(1) $\alpha_3 = 0.8$ if $t_{is}/t_{es} > 1.25$
(2) $\alpha_3 = [-0.8(t_{is}/t_{es}) + 1.8]$ if $1.0 < t_{is}/t_{es} < 1.25$

where

t_{es} = thickness of the structural wall measured at the extrados, mm (in.)
t_{is} = thickness of the structural wall measured at the intrados (not less than t_{es}), mm (in.)

TEES

III-3.3.1 Type I and Type II Tees

(a) For Type I and Type II tees and reducing tees for which the diameter does not exceed 600 mm (24 in.), the pressure stress multiplier, m, is a function of the pipe factor, λ_t. The pipe factor, λ_t, is defined as follows:

(1) For equal tees, $D_B = D_R$

$$\lambda_t = \frac{2t_R}{D_R} \tag{III-2-14}$$

(2) For reducing tees, $D_B < D_R$

$$\lambda_t = \left(\frac{2t_B}{D_B}\right)^2 \times \frac{D_R}{2t_R} \tag{III-2-15}$$

where

D_B = inside diameter of the branch structural wall, mm (in.)
D_R = inside diameter of the main run structural wall, mm (in.)
t_B = thickness of the structural layer of the branch of the tee, mm (in.)
t_R = thickness of the structural layer of the main run of the tee, mm (in.)

(b) The pressure stress multiplier, m, shall be determined by

$$m = 1.4(\lambda_t)^{-0.25} \tag{III-2-16}$$

Reducers

III-4.3 Pressure Stress Multipliers for Concentric Reducers

The pressure stress multiplier, m, for concentric reducers shall be taken to be 1.0.

General

The Code Compliance requirements provided in this Section as per ASME NM.2 are valid for above ground installation of GRP/FRP Piping.

Section 2-6.3 of ASME NM 2 (2020) refers to AWWA Manual M45 (second edition) for Buried GRP/FRP Piping Analysis. AWWA Manual M45 is also referred by ISO 14692-3 for detailed analysis of Buried GRP/FRP Piping. Code Compliance as per ISO 14692-3 is built into CAEPIPE Version 12.00 or later. Hence, for Buried GRP/FRP Piping Analysis, ISO 14692-3 can be selected in CAEPIPE for Code Compliance checks.

Allowable Pressure

Straight Pipes and Bends

For straight pipes and bends, CAEPIPE calculates allowable pressure using Eq. (2-3-2) of para.2-3.2.2 and Eqs. (2-3-6) of para. 2-3.3.1 and Eqs. (2-3-9), (2-3-10) & (2-3-11) of para. 2-3.3.2 (a) & (b).

$$P_a = \frac{2.S.t_a}{K_1.D.m}$$

where

P_a= allowable pressure

S = design hoop allowable stress at Design Temperature (can be obtained from applicable table in ASME NM.3.3)

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE as per para. 2-3.2.1 (a))

t_n = nominal pipe/bend thickness

D = outside diameter of pipe/bend, to be conservative

m = 1.0 for straight pipes and at the side wall on the bend / elbow centerline radius

K_1 = 1.0 for Pipe with Type I and Type II laminates

K_1 = 1.2 for Bends / Elbows with Type I and Type II laminates

Note:

Allowable pressure at the "intrados" of a bend can be manually computed by dividing the CAEPIPE computed allowable pressure for that bend by the factor "m" given by Eq. (2-3-7) in para. 2-3.3.1. Similarly, allowable pressure at the "Extrados" of a bend can be manually computed by diving the CAEPIPE computed allowable pressure for that bend by the factor "m" given by Eq. (2-3-8) in para. 2-3.3.1.

For closely spaced miter bends, the allowable pressure computed by CAEPIPE shall be the lesser of the two values calculated from Eqs. 2-3-9 and 2-3-10 with θ <= 22.5 deg.

$$P_a = min\left[\frac{S.t_a(R-r)}{r(R-0.5r)}, \frac{S.{t_a}^2}{r(t_a+0.643tan\theta\sqrt{r.t_a})}\right]$$

For widely spaced miter bends with θ <= 22.5 deg, the allowable pressure is calculated in CAEPIPE by Eq. 2-3-9

$$P_a = \frac{S.{t_a}^2}{r(t_a+0.643tan\theta\sqrt{r.t_a})}$$

For widely spaced miter bends and closely spaced miter bends with θ > 22.5 deg, the allowable pressure is calculated in CAEPIPE by Eq. 2-3-11

$$P_a = \frac{S.{t_a}^2}{r(t_a+1.25\ tan\theta\sqrt{r.t_a})}$$

where

r = mean radius of pipe = $(D - t_n)/2$

R = equivalent bend radius of the miter (an input in CAEPIPE for Miter)

θ = miter half angle = $\tan^{-1}\left(\frac{1.0}{\left(\frac{2R}{r}-1.0\right)}\right)$

Integrally Molded Tee fittings

For integrally molded Tee fittings, CAEPIPE calculates allowable pressure for Run and Branch of a Tee using Eq. (2-3-18) of para.2-3.4.

For Tee Run

$$P_{aR} = \frac{2.S.t_{aR}}{D_R.m}$$

For Tee Branch

$$P_{aB} = \frac{2.S.t_{aB}}{D_B.m}$$

where

P_{aR}= allowable pressure for Run

P_{aB}= allowable pressure for Branch

S = design hoop allowable stress (can be obtained from applicable table in ASME NM.3.3) at Design Temperature input in CAEPIPE load dialog.

m = pressure stress multiplier for integral tees = $1.4{\lambda_z}^{0.25}$

λ_z = geometry factor as given below

For equal tees (i.e., $D_B = D_R$)

$$\lambda_z = \frac{D_R}{2.t_{aR}}$$

For unequal or reducing tees (i.e., $D_B < D_R$)

$$\lambda_z = \left(\frac{D_B}{2.t_{aB}}\right)^2 \left(\frac{2t_{aR}}{D_R}\right)$$

where

t_{aR}= available Run thickness for pressure design = t_{nR} × (1 - mill tolerance/100) - corrosion allowance

t_{aB}= available Branch thickness for pressure design = t_{nB} × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE as per para. 2-3.2.1 (a))

t_{nR} = nominal thickness of Run

t_{nB} = nominal thickness of Branch

D_R = inside diameter of the main run pipe structural wall = Run OD – 2 * t_{aR}

D_B = inside diameter of the tee branch pipe structural wall = Branch OD – 2 * t_{aB}

Sustained Load

(d) The Hoop Stress (S_{HL}) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. (2-4-1) of para. 2-4.4.4 (a) and compared against the limit given in para. 2-4.4.4 (c).

$$S_{HL} = \sqrt{\left[\frac{mPD_m}{2T_s} + \frac{\sqrt{(i_{ih}M_i)^2 + (i_{oh}M_o)^2}}{Z}\right]^2 + \left(\frac{i_t M_t}{Z}\right)^2} \leq S_{H.max}$$

(e) The Longitudinal Stress (S_{AL}) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eqs. (2-4-2a) & (2-4-2b) of para. 2-4.4.4 (b) and compared against the limit given in para. 2-4.4.4 (c).

$$S_{AL1} = \sqrt{\left[\frac{P{D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_A}{A_s} - \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]^2 + \left(\frac{i_t M_t}{Z}\right)^2}$$

$$S_{AL2} = \sqrt{\left[\frac{P{D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_A}{A_s} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}\right]^2 + \left(\frac{i_t M_t}{Z}\right)^2}$$

$S_{AL.min} = minimum(S_{AL1}, S_{AL2}) \leq S_{A.max}$

$S_{AL.max} = maximum(S_{AL1}, S_{AL2}) \leq S_{A.max}$

where

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

T_S = corroded wall thickness = t_n - corrosion allowance

t_n = nominal thickness

D_{is} = inside diameter = D_o - $2T_S$

m = pressure stress multiplier from Appendix III

i_{ih} = stress intensification factor, hoop stress due to in-plane moment as per Appendix III

i_{oh} = stress intensification factor, hoop stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

i_i = stress intensification factor, axial stress due to in-plane moment as per Appendix III

i_o = stress intensification factor, axial stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

M_i, M_o, M_t = in-plane, out-of-plane and torsional moment respectively due to weight and other sustained mechanical loads

F_A = axial force due to weight and other sustained mechanical loads (excluding pressure)

Z = section modulus = $\pi[D_o^4 - (D_o - 2T_S)^4]/32D_o$

A_S = area of cross-section = $\pi[D_o^2 - D_{is}^2]/4$

$S_{A.max}$ = axial allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 .. T10)]

$S_{AL.min}$ = minimum longitudinal stress due to pressure, weight and other sustained mechanical loads

$S_{AL.max}$ = maximum longitudinal stress due to pressure, weight and other sustained mechanical loads

Occasional Load (Sustained + Occasional)

(c) The Hoop stress (S_{HO}) due to sustained and occasional loads is calculated from Eq. (2-4-1) of para. 2-4.4.4 (a) as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind and compared against the limit given in para. 2-4.4.4 (d). Wind and earthquake are not considered to act concurrently as per para. 2-2.3.8 (a).

$$S_{HO} = S_{HL} + \sqrt{\left[\frac{m(P_{peak} - P)D_m}{2T_s} + \frac{\sqrt{(i_{ih}M_{io})^2 + (i_{oh}M_{oo})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2} \le k.S_{H.max}$$

(d) The Longitudinal stress (S_{AO}) due to sustained and occasional is calculated is calculated from Eqs. (2-4-2a) and (2-4-2b) of para. 2-4.4.4 (b) as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind and compared against the limit given in para. 2-4.4.4 (d). Wind and earthquake are not considered to act concurrently as per para. 2-2.3.8 (a).

$$S_{AO1} = \sqrt{\left[\frac{(P_{peak} - P){D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AO}}{A_s} - \frac{\sqrt{(i_i M_{io})^2 + (i_o M_{oo})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2} \le k.S_{A.max}$$

$$S_{AO2} = \sqrt{\left[\frac{(P_{peak} - P){D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AO}}{A_s} + \frac{\sqrt{(i_i M_{io})^2 + (i_o M_{oo})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2} \le k.S_{A.max}$$

$$S_{AO.min} = S_{AL.min} + minimum(S_{AO1}, S_{AO2}) \le 1.33\ S_{A.max}$$

$$S_{AO.max} = S_{AL.max} + maximum(S_{AO1}, S_{AO2}) \le 1.33\ S_{A.max}$$

where

P = maximum of CAEPIPE pressures P1 through P10

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE) x P

T_S = corroded wall thickness = t_n - corrosion allowance

t_n = nominal thickness

D_o = outside diameter of the component

D_{is} = inside diameter = D_o - $2T_S$

m = pressure stress multiplier from Appendix III

i_{ih} = stress intensification factor, hoop stress due to in-plane moment as per Appendix III

i_{oh} = stress intensification factor, hoop stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

i_i = stress intensification factor, axial stress due to in-plane moment as per Appendix III

i_o = stress intensification factor, axial stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

F_{AO} = axial force due to occasional loads such as wind or seismic, etc.

M_{io}, M_{oo}, M_{to} = in-plane, out-of-plane and torsional moment respectively due to occasional loads such as wind or seismic, etc.

Z = section modulus = $\pi[D_o^4 - (D_o - 2T_s)^4]/32D_o$

A_S = area of cross-section = $\pi[D_o^2 - D_{is}^2]/4$

k = 1.33 corresponding to the occasional event duration occurring for not more than 1 hr at any one time and not more than 80 hr/yr

$S_{H.max}$ = hoop allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 .. T10)]

$S_{A.max}$ = axial allowable stress at maximum CAEPIPE temperature [i.e., at max (Tref, T1 .. T10)]

$S_{AO.min}$ = minimum longitudinal stress due to occasional loads such as wind or seismic, etc.

$S_{AO.max}$ = maximum longitudinal stress due to occasional loads such as wind or seismic, etc.

Operating Load (Sustained + Expansion)

(f) The Hoop Stress (S_{HE}) due to operating loads (pressure, weight, other sustained mechanical loads and thermal displacement) is calculated from Eq. (2-4-1) of para. 2-4.4.4 (a) and compared against the limit given in para. 2-4.4.4 (c).

$$S_{HE} = \sqrt{\left[\frac{mP_n D_m}{2T_s} + \frac{\sqrt{(i_{ih}M_{iE})^2 + (i_{oh}M_{oE})^2}}{Z}\right]^2 + \left(\frac{i_t M_{tE}}{Z}\right)^2} \leq 1.1 S_{H.max}$$

(b) The Longitudinal stress (S_{AE}) due to operating loads (pressure, weight, other sustained mechanical loads and thermal displacement) is calculated from Eqs. (2-4-2a) and (2-4-2b) of para. 2-4.4.4 (b) and compared against the limit given in para. 2-4.4.4 (c).

$$S_{AE1} = \sqrt{\left[\frac{P_n {D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AE}}{A_s} - \frac{\sqrt{(i_i M_{iE})^2 + (i_o M_{oE})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2}$$

$$S_{AE2} = \sqrt{\left[\frac{P_n {D_{is}}^2}{D_o^2 - D_{is}^2} + \frac{F_{AE}}{A_s} + \frac{\sqrt{(i_i M_{iE})^2 + (i_o M_{oE})^2}}{Z}\right]^2 + \left(\frac{i_t M_{to}}{Z}\right)^2}$$

$$S_{AE.min} = minimum(S_{AE1}, S_{AE2}) \leq 1.1\ S_{A.max}$$

$$S_{AE.max} = maximum(S_{AE1}, S_{AE2}) \leq 1.1\ S_{A.max}$$

where

P_n = internal operating pressure P1 through P10. For example, for Operating Load 1, P_n = P1

T_S = corroded wall thickness = t_n - corrosion allowance

t_n = nominal component thickness

D_o = outside diameter of the component

D_{is} = inside diameter = D_o - $2T_S$

m = pressure stress multiplier from Appendix III

i_{ih} = stress intensification factor, hoop stress due to in-plane moment as per Appendix III

i_{oh} = stress intensification factor, hoop stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

i_i = stress intensification factor, axial stress due to in-plane moment as per Appendix III

i_o = stress intensification factor, axial stress due to out-of-plane moment as per Appendix III

i_t = torsional stress intensification factor as per Appendix III

F_{AE} = axial force due to operating load such as weight, other sustained mechanical loads and thermal displacement

M_{iE}, M_{oE}, M_{tE} = in-plane, out-of-plane and torsional moment respectively due to weight, other sustained mechanical loads and thermal displacement

Z = section modulus = $\pi[D_o^4 - (D_o - 2T_s)^4]/32D_o$

A_S = area of cross-section = $\pi[D_o^2 - D_{is}^2]/4$

$S_{H.max}$ = hoop allowable stress at operating temperatures T1 through T10

$S_{A.max}$ = axial allowable stress at operating temperature. For example, for Operating Load 1, Operating temperature is T1.

$S_{AE.min}$ = minimum longitudinal stress due to weight, other sustained mechanical loads and thermal displacement

$S_{AE.max}$ = maximum longitudinal stress due to weight, other sustained mechanical loads and thermal displacement

Flexibility Factors (FFs), Stress Intensification Factors (SIFs) and Pressure Stress Multipliers (PSMs)

The FFs, SIFs and PSMs as per ASME NM.2 code are given below (extracted from Appendix III of the code). How they are implemented in CAEPIPE is described below.

1. Flexibility Factors, Stress Intensification Factors and Pressure Multipliers are calculated as per Appendix III of ASME NM.2 only for Type I and Type II components in CAEPIPE at this time. Type I and Type II components can be differentiated in CAEPIPE by selecting the Material Type as "FR – Fiber/Glass Reinforced Plastics (FRP)" OR "F1 – Fiber/Glass Reinforced Plastics (FRP) Type I" and "F2 – Fiber/Glass Reinforced Plastics (FRP) Type II" respectively.

2. Flexibility factor (k) for all components except for Bends & Mitres is set as 1.0 internally in CAEPIPE.

3. Flexibility factor (k) for Bend / Mitre is 1.0 when Radius is NOT equal to long radius (i.e., k = 1.00 when Radius is <= 1.35D or >= 1.65D, where D is Outside Diameter).

4. Flexibility factor (k) for long radius Bend and Mitre is 1.0 when the Diameter / Thickness ratio is greater than 140. i.e., k = 1.00 when D/t > 140.

5. Flexibility factor (k) for long radius Bend and Mitre is 1.0 when Pipe Diameter is greater than 48".

6. Since thicknesses at intrados and extrados are not input at this time, thickness input at Bend / Mitre dialog or Thickness of section (when thickness field at Bend / Mitre dialog is left blank) (= t_n = nominal thickness) is considered in computing "t_i", "t_e", "t_{is}" and "t_{es}" in the calculation, i.e.,

   $t_{is} = t_{es} = t_n$ – mill tolerance – corrosion allowance
   $t_i = t_e = t_n$ – mill tolerance
   where,
   t_n = nominal thickness = thickness input at Bend / Mitre dialog or Thickness of section

7. Correction factor (α_2) is accounted as 1.00 in Stress Intensification Factor (SIF) calculation for the Bend / Mitre as intrados and extrados thicknesses cannot be input at this time in CAEPIPE.

8. Correction factor (α_3) is accounted as 1.00 in Pressure Stress Multiplier (m) calculation for the Bend / Mitre as intrados and extrados thicknesses cannot be input at this time in CAEPIPE.

9. Minimum value of Longitudinal Stress SIF and Shear Stress SIF for all components is 1.00.

10. Hoop SIF for all components (excepting Bend / Mitre) is 0.0. For Bend / Mitre, Minimum Hoop Stress SIF is 1.00.

11. Minimum Pressure Stress Multiplier is 1.00 for all components.

12. Pressure Stress Multiplier is 1.0 for both Type I and Type II Tees when the Diameter is greater than 24".

Flexibility Factors (FFs)

Elbows

III-2.1.1 Type I and Type II Elbows. The equations below may be used to calculate the flexibility factor, k, for Type I and Type II long-radius elbows that comply with the following criteria:

(a) The diameter-to-total-thickness ratio is not greater than 140.

(b) The pipe size does not exceed 1 200 mm (48 in.) diameter.

(c) The butt joint between the elbow and the pipe is a Type II laminate, and the connected pipe is Type II or filament-wound laminate.

For Type I elbows

$$k = 0.22\gamma\left(\frac{D}{t_e}\right)\left(\frac{t_i}{t_e}\right)^{-1.04} \quad \text{(III-2-2)}$$

For Type II elbows

$$k = \gamma\left[0.2\left(\frac{D}{t_e}\right) - 0.7\right]\left(\frac{t_i}{t_e}\right)^{-0.98} \quad \text{(III-2-3)}$$

where

D = inside diameter of pipe, mm (in.)

t_e = thickness of the total wall of the elbow measured at the extrados [including a corrosion-barrier thickness of at least 2.8 mm (0.11 in.)], mm (in.)

t_i = thickness of the total wall of the elbow measured at the intrados [including a corrosion barrier thickness of at least 2.8 mm (0.11 in.)], mm (in.)

γ = correction factor for reduction in flexibility due to internal pressure

$= \left(1 + 2.53\frac{Pr}{E_h t_e} \times R_1^{0.333}\frac{r}{t_e^{1.333}}\right)^{-1}$

E_h = hoop modulus of the elbow, MPa (psi)

P = pressure, MPa (psi)

R_1 = radius of the bend, mm (in.)

= $1.5D$

r = inside radius of the elbow, mm (in.)

NOTE: k shall not be taken as less than 1.0.

III-2.1.3 Flanged Elbows. The flexibility factor for flanged elbows shall be reduced by multiplying k by one of the following factors, c:

(a) For elbows with one flanged end

$$c = \left(\frac{t_e R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/6} \quad \text{(III-2-4)}$$

(b) For elbows with two flanged ends

$$c = \left(\frac{t_e R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/3} \quad \text{(III-2-5)}$$

where

D = inside diameter of pipe, mm (in.)

R_1 = radius of bend, mm (in.)

= $1.5D$

t_e = thickness of the total wall of the elbow measured at the extrados, mm (in.)

NOTE: k shall not be taken as less than 1.0.

TEES

III-3.1 Flexibility Factors for Tees

The flexibility factor, k, for tees shall be taken to be 1.0.

Reducers

III-4.1 Flexibility Factors for Concentric Reducers

The flexibility factor, k, for concentric reducers shall be taken to be 1.0.

Stress Intensification Factors (SIFs)

Elbows

Correction factor α_2 is not included in the SIF calculation for Elbows as the Bend/Elbow in CAEPIPE can only have uniform thickness around its entire circumference.

III-2.2.1 Type I and Type II Elbows

(a) The following equation shall be used to calculate i for Type I and Type II long-radius elbows for which the diameter-to-structural-thickness ratio is not greater than 140, and for which the pipe size does not exceed 1 200 mm (48 in.) diameter:

$$i = \frac{\alpha_2 \gamma}{h^{0.667}} \qquad \text{(III-2-7)}$$

where

h = flexibility characteristic

$= \frac{t_{es} R_1}{r^2}$

r = inside radius of the elbow, mm (in.)

R_1 = radius of the bend, mm (in.)

= $1.5D$ where D is the inside diameter of the pipe

t_{es} = thickness of the structural wall of the elbow measured at the extrados, mm (in.)

α_2 = correction factor for reduction in SIF due to increased thickness at the intrados compared to the extrados; see (c) below

γ = correction factor for reduction in SIF due to internal pressure

$$= \left(1 + 2.53\frac{Pr}{E_h t_e} \times R_1^{0.333} \frac{r}{t_e^{1.333}}\right)^{-1}$$

E_h = hoop modulus of the elbow, MPa (psi)

P = pressure, MPa (psi)

t_e = thickness of the total wall of the elbow measured at the extrados [including a corrosion-barrier thickness of at least 2.8 mm (0.11 in.)], mm (in.)

(b) Five SIFs are required to quantify the stresses in an elbow.

(1) longitudinal SIF due to in-plane moment, i_{ix}.
(2) longitudinal SIF due to out-of-plane moment, i_{ox}.
(3) hoop SIF due to in-plane moment, i_{ih}.
(4) hoop SIF due to out-of-plane moment, i_{oh}.
(5) shear stress SIF due to torsional moment, i_t. For Type I and Type II elbows, i_t may be taken to be 1.0.

III-2.2.3 Flanged Elbows. The SIFs for flanged elbows may be reduced by multiplying i by one of the following factors, c:

(a) For elbows with one flanged end

$$c = \left(\frac{t_{es} R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/6} \qquad \text{(III-2-8)}$$

(b) For elbows with two flanged ends

$$c = \left(\frac{t_{es} R_1}{\left(\frac{D}{2}\right)^2}\right)^{1/3} \qquad \text{(III-2-9)}$$

where

D = inside diameter of pipe, mm (in.)

R_1 = radius of bend, mm (in.)

= $1.5D$

t_{es} = thickness of the structural wall of the elbow measured at the extrados, mm (in.)

TEES

III-3.2.1 Type I and Type II Tees

(a) For Type I and Type II tees and reducing tees for which the diameter does not exceed 600 mm (24 in.), the SIF, i, is a function of the pipe factor, λ_t. The pipe factor, λ_t, is defined as follows:

$$\lambda_t = \frac{2t_R}{D_R} \qquad \text{(III-2-12)}$$

where

D_R = inside diameter of the main run structural wall, mm (in.)

t_R = thickness of the structural layer of the main run of the tee, mm (in.)

(b) The longitudinal SIFs shall be determined by

$$i_{ix} = i_{ox} = 0.66(\lambda_t)^{-0.5} \qquad \text{(III-2-13)}$$

(c) The hoop SIFs, i_{ih} and i_{oh}, may be taken to be 0.0.
(d) The torsional SIF, i_t, may be taken to be 1.5.

Reducers

III-4.2 SIFs for Concentric Reducers

In the absence of more directly applicable data, the SIFs, i, for concentric reducers may be determined as described in paras. III-4.2.1 and III-4.2.2. In no case shall i be less than 1.0 except that the hoop SIFs, i_{ih} and i_{oh}, may be taken to be 0.0.

III-4.2.1 Type I and Type II Concentric Reducers. The following values for SIFs may be used for Type I and Type II concentric reducers for which the diameter-to-structural-thickness ratio is not greater than 120, and for which the pipe size does not exceed 1 200 mm (48 in.) diameter:

Concentric Reducer Type	SIF Large Diameter End	SIF Small Diameter End
I	2.5	1.3
II	2.5	1.3

Pressure Stress Multipliers

Elbows

III-2.3.1 Type I and Type II Elbows

(a) The following equation may be used to calculate m for Type I and Type II elbows:

$$m = \alpha_3 \left(\frac{4\frac{R_1}{D} - 1}{4\frac{R_1}{D} - 2} \right) \quad \text{(III-2-11)}$$

where

D = inside diameter of elbow, mm (in.)
R_1 = bend radius of the elbow, mm (in.); $R_1 > D$
α_3 = correction factor for reduction in m due to increased thickness at the intrados compared to the extrados; see (b)

(b) FRP elbows are often manufactured such that the thickness varies uniformly around the circumference of the elbow from a minimum at the extrados to a maximum at the intrados. This additional thickness will reduce the maximum hoop pressure stress of the elbow compared to an elbow that has a uniform thickness around the entire circumference. The following values for α_3 may be used for Type I and Type II elbows:

(1) α_3 = 0.8 if $t_{is}/t_{es} > 1.25$
(2) $\alpha_3 = [-0.8(t_{is}/t_{es}) + 1.8]$ if $1.0 < t_{is}/t_{es} < 1.25$

where

t_{es} = thickness of the structural wall measured at the extrados, mm (in.)
t_{is} = thickness of the structural wall measured at the intrados (not less than t_{es}), mm (in.)

TEES

III-3.3.1 Type I and Type II Tees

(a) For Type I and Type II tees and reducing tees for which the diameter does not exceed 600 mm (24 in.), the pressure stress multiplier, m, is a function of the pipe factor, λ_t. The pipe factor, λ_t, is defined as follows:

(1) For equal tees, $D_B = D_R$

$$\lambda_t = \frac{2t_R}{D_R} \quad \text{(III-2-14)}$$

(2) For reducing tees, $D_B < D_R$

$$\lambda_t = \left(\frac{2t_B}{D_B} \right)^2 \times \frac{D_R}{2t_R} \quad \text{(III-2-15)}$$

where

D_B = inside diameter of the branch structural wall, mm (in.)
D_R = inside diameter of the main run structural wall, mm (in.)
t_B = thickness of the structural layer of the branch of the tee, mm (in.)
t_R = thickness of the structural layer of the main run of the tee, mm (in.)

(b) The pressure stress multiplier, m, shall be determined by

$$m = 1.4(\lambda_t)^{-0.25} \quad \text{(III-2-16)}$$

Reducers

III-4.3 Pressure Stress Multipliers for Concentric Reducers

The pressure stress multiplier, m, for concentric reducers shall be taken to be 1.0.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from 4.2(4).

$$P = \frac{2fet_f}{D - 2t_f}$$

where

P = allowable pressure

f = allowable stress

e = joint factor (input as material property)

t_f = minimum required thickness, including mechanical and corrosion allowances

= nominal pipe thickness × (1 – mill tolerance/100) – corrosion allowance

D = outside diameter

$$P = \frac{fe}{X\left(1 + 0.6427\, tan\, \alpha\sqrt{X}\right)}$$

where

α = miter angle

X = $\left(D - 2t_f\right)/2t_f$

Stresses

Stresses are calculated according to 4.11.

Sustained stresses are due to pressure, weight and other sustained mechanical loads. Maximum value is 0.8 × proof stress value or rupture stress value in hot condition.

Expansion stresses are due to thermal (including specified displacements) and pressure loadings. Maximum value is lower of

1) 0.9 × proof stress at room temperature plus 0.9 × proof stress at design temperature.

2) 0.9 × proof stress at room temperature plus rupture stress at design temperature.

Hot stresses are due to pressure, deadweight, other sustained mechanical loads, thermal and cold pull loadings. Maximum value is the rupture stress at design temperature.

Occasional stresses (which are due to seismic, dynamic or wind loadings) are not calculated. If these are to be evaluated, ASME B31.1 code should be used according to Inquiry Case 806/2 : November 1986 to BS 806 : 1986.

Stresses on Straight Pipes and Bends (4.11.4)

The combined stress fc on straight pipes and bends including miter bends is calculated from (28).

$$F_C = F^2 + 4f_S^2$$

where

F = greater of f_T or f_L
f_T = transverse stress (4.11.4.2)
 = transverse pressure stress + transverse bending stress
f_L = longitudinal stress (4.11.4.3)
 = longitudinal pressure stress + longitudinal bending stress
f_S = torsional stress (4.11.4.4)

Transverse Stress f_T (4.11.4.2)

The transverse pressure stress on both straight pipes and bends excluding miter bends is calculated from (29).

$$\frac{pd}{2t} + 0.5p$$

The transverse pressure stress on miter bends is calculated from (30)

$$\left(\frac{pd}{2t} + 0.5p\right)\left(1 + 0.6427\, tan\, \alpha \sqrt{\frac{d+t}{2t}}\right)$$

The transverse bending stress on straight pipe is zero.

The transverse bending stress on bends including miter bends is calculated from (31)

$$\frac{r}{I}(M_i F_{Ti})^2 + (M_o F_{To})^2$$

where

d = inside diameter
t = thickness
p = pressure
M_i = in-plane bending moment
M_o = out-of-plane bending moment
F_{Ti} = in-plane transverse stress intensification factor
F_{To} = out-of-plane transverse stress intensification factor
r = mean radius of pipe
I = moment of inertia
D = outside diameter
α = miter angle

Longitudinal Stress f_L (4.11.4.3)

The longitudinal pressure stress on both straight pipes and bends including miter bends is calculated form (32)

$$\frac{pd^2}{4t(d+t)}$$

The longitudinal bending stress on straight pipe is calculated from (33).

$$\frac{d+2t}{2I}\sqrt{M_i^2+M_o^2}$$

The longitudinal bending stress on bends including miter bends is calculated from (34).

$$\frac{r}{I}\sqrt{(M_iF_{Li})^2+(M_oF_{Lo})^2}$$

where
F_{Li} = in-plane longitudinal stress intensification factor
F_{Lo} = out-of-plane longitudinal stress intensification factor

Torsional Stressf_S (4.11.4.4)

The torsional stress for both straight pipes and bends including miter bends is calculated from (35).

$$f_S = M_t\frac{d+2t}{4I}$$

where
M_t = torsional moment

Stress at Branch Junction (4.11.5)

The combined stress at a branch junction is calculated from (36)

$$f_{CB} = f_B^2 + 4f_{SB}^2$$

where
f_B = transverse pressure stress at the junction plus nondirectional bending stress
f_{SB} = torsional stress at the junction

Transverse Pressure Stress at Branch Junction (4.11.5.2)

The transverse pressure stress at branch junction is calculated from (37)

$$pm\left(\frac{d_1 + t_a}{2t_a}\right)$$

where
d_1 = mean radius of main pipe
t_a = minimum thickness of main pipe
p = design pressure
m = stress multiplier, or equal to:
(a) for branch junctions where both r2/r1 and t2/t1 are less than or equal to 0.3
$m = 1.8 + \frac{2.8r_2}{r_1}\sqrt{\frac{r_1}{t_1}}$
(b) for branch junctions where either r2/r1 and t2/t1 are greater than 0.3
m = $2.5Z_1^{0.2042}$ for $d_2/d_1 \leq 0.7$
m = $2.5Z_1^{0.2415}$ for $d_2/d_1 > 0.7$
Z_1 = $(r_2/t_2)^2 t_1/r_1$
r_1 = mean radius of main pipe
r_2 = mean radius of branch pipe
t_1 = thickness of main pipe
t_2 = thickness of branch pipe

Non-directional Bending Stress at Branch Junction (4.11.5.3)

For the main pipe, the bending stress is calculated from (40)

$$\frac{r_1}{I}\sqrt{(M_iB_i)^2 + (M_oB_o)^2}$$

where
r_1 = mean radius of pipe
I = moment of inertia of main pipe
M_i = in-plane bending moment
M_o = out-of-plane bending moment
B_i = in-plane branch stress intensification factor (Fig.4.11.1(6))
B_o = out-of-plane branch stress intensification factor (Fig.4.11.1(6))
For the branch pipe, the bending stress is calculated from

$$\frac{r_2}{I}\sqrt{(M_iB_i)^2 + (M_oB_o)^2}$$

where
r_2 = mean radius of branch pipe
I = calculated from $\pi r_2^3 B_o t_2$ or $\pi r_2^3 t_1$ whichever gives the lower value

Sustained Stress

The Allowable Stress Design (ASD) provisions as given in Section 5.6.2.2 of DNV-ST-F101 (2021) code are implemented in CAEPIPE as detailed below.

(a) The hoop stress is defined by the following formula as per Section 5.6.2.2

$$\sigma_{h(s)} = \frac{PD_{r,min}}{2.t_2}$$

(b) The longitudinal / axial stresses are defined by the following formulae as per Section 5.6.2.2

$$\sigma_{a(s)} = \frac{F_{a(s)}}{A_r} + \frac{PD_{r,min}}{4.t_2} = \frac{F_{a(s)}}{\frac{\pi}{4}(OD_{r,min}{}^2 - ID_r{}^2)} + \frac{PD_{r,min}}{4.t_2}$$

$$\sigma_{b(s)} = \frac{\sqrt{\left(SIF_{ai}.M_{i(s)}\right)^2 + \left(SIF_{ao}.M_{o(s)}\right)^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32}\frac{(OD_{r,min}{}^4 - ID_r{}^4)}{OD_{r,min}}$$

(c) Torsional stress is defined by the following formula as per Section 5.6.2.2

Torsional Stress = $\sigma_{t(s)} = \frac{M_{t(s)}}{2Z_r}$

where

P = maximum of CAEPIPE input pressures P1 through P10, where the maximum operating pressure Pi (with i between 1 & 10) = the difference between the corresponding internal pressure Pi and external pressure Pe = $(P_i - P_e)$

t_2 = minimum pipe wall thickness

= nominal thickness x (1 – mill tolerance/100) – corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

$OD_{r,min}$= minimum outside diameter of the pipe wall = Outer Diameter in CAEPIPE

$D_{r,min}$ = mean diameter of the pipe wall = $OD_{r,min} - t_2$

ID_r= inside diameter of the pipe wall = $OD_{r,min} - 2.t_2$

A_r= inside metallic area of the pipe

SIF_{ai}, SIF_{ao} = in-plane and out-of-plane stress longitudinal/axial intensification factors as per Appendix D of ASME B31.8 (2020).

$M_{i(s)}, M_{o(s)}, M_{t(s)}$ = in-plane, out-of-plane bending moment and torsional moment respectively due to weight and other sustained mechanical loads (excluding pressure)

Z_r= minimum pipe wall section modulus.

$F_{a(s)}$= axial force due to weight and other sustained mechanical loads (excluding pressure).

(d) Equivalent stress, Von Mises, is computed as given below.

Equivalent Stress, Von Mises at One Extreme Surface of Pipe

In CAEPIPE, Equivalent Stress, Von Mises, at One Extreme Surface of Pipe is computed as given below.

$$T1_{(s)} = \frac{\sigma_{h(s)} - \sigma_{a(s)} - \sigma_{b(s)}}{2}$$

$$U1_{(s)} = \sqrt{\mathrm{T1}^2_{(s)} + \left(\sigma_{t(s)}\right)^2}$$

Sigma 1 = $\sigma_{1(s)} = \frac{\sigma_{h(s)} + \sigma_{a(s)} + \sigma_{b(s)}}{2} + U1_{(s)}$

Sigma 2 = $\sigma_{2(s)} = \frac{\sigma_{h(s)} + \sigma_{a(s)} + \sigma_{b(s)}}{2} - U1_{(s)}$

$$VonMises\_t_{(s)} = \sqrt{\left(\boldsymbol{\sigma_{1(s)}}\right)^2 - \boldsymbol{\sigma_{1(s)}}\boldsymbol{\sigma_{2(s)}} + \left(\boldsymbol{\sigma_{2(s)}}\right)^2}$$

$Max\_t_{(s)} = \boldsymbol{\sigma_{1(s)}}$; $Min\_t_{(s)} = \boldsymbol{\sigma_{2(s)}}$

Equivalent Stress, Von Mises at Other Extreme Surface of Pipe

In CAEPIPE, Equivalent Stress, Von Mises, at Other Extreme Surface of Pipe is computed as given below.

$$T2_{(s)} = \frac{\sigma_{h(s)} - \sigma_{a(s)} + \sigma_{b(s)}}{2}$$

$$U2_{(s)} = \sqrt{\mathrm{T2}^2_{(s)} + \left(\sigma_{t(s)}\right)^2}$$

Sigma 1 = $\sigma_{1(s)} = \frac{\sigma_{h(s)} + \sigma_{a(s)} - \sigma_{b(s)}}{2} + U2_{(s)}$

Sigma 2 = $\sigma_{2(s)} = \frac{\sigma_{h(s)} + \sigma_{a(s)} - \sigma_{b(s)}}{2} - U2_{(s)}$

$$VonMises\_b_{(s)} = \sqrt{\left(\boldsymbol{\sigma_{1(s)}}\right)^2 - \boldsymbol{\sigma_{1(s)}}\boldsymbol{\sigma_{2(s)}} + \left(\boldsymbol{\sigma_{2(s)}}\right)^2}$$

$Max\_b_{(s)} = \boldsymbol{\sigma_{1(s)}}$; $Min\_b_{(s)} = \boldsymbol{\sigma_{2(s)}}$

Based on the above (d), for the entire Pipe Cross-section at a Node

$$\mathbf{Equivalent\ Stress, VonMises}_{(s)} = \boldsymbol{Max}\left[\boldsymbol{VonMises\_t}_{(s)}, \boldsymbol{VonMises\_b}_{(s)}\right] \leq \boldsymbol{\eta}.\boldsymbol{f_y} \ldots \boldsymbol{Eq}.(\mathbf{5.51})$$

$$\mathbf{Max.Principal\ Stress}_{(s)} = \boldsymbol{Max}\left[\boldsymbol{Max\_t}_{(s)}, \boldsymbol{Max\_b}_{(s)}\right] \leq \boldsymbol{\eta}.\boldsymbol{f_y} \ldots \boldsymbol{Eq}.(\mathbf{5.52})$$

$$\mathbf{Min.Principal\ Stress}_{(s)} = \boldsymbol{Min}\left[\boldsymbol{Min\_t}_{(s)}, \boldsymbol{Min\_b}_{(s)}\right] \leq \boldsymbol{\eta}.\boldsymbol{f_y} \ldots \boldsymbol{Eq}.(\mathbf{5.52})$$

where

η = design factor for equivalent stress check as per Table 5-15 of DNV-ST-F101 code. This can be selected in CAEPIPE through Layout Window > Options > Analysis > Design factor.

f_y = Yield strength at room temperature.

Operating Stress

(a) The hoop stress is defined by the following formula as per Section 5.6.2.2

$$\sigma_{h(op)} = \frac{PD_{r,min}}{2.t_2}$$

(b) The longitudinal / axial stresses are defined by the following formulae as per Section 5.6.2.2

$$\sigma_{a(op)} = \frac{F_{a(op)}}{A_r} + \frac{PD_{r,min}}{4.t_2} = \frac{F_{a(op)}}{\frac{\pi}{4}(OD_{r,min}{}^2 - ID_r{}^2)} + \frac{PD_{r,min}}{4.t_2}$$

$$\sigma_{b(op)} = \frac{\sqrt{\left(SIF_{ai}.M_{i(op)}\right)^2 + \left(SIF_{ao}.M_{o(op)}\right)^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32}\frac{(OD_{r,min}{}^4 - ID_r{}^4)}{OD_{r,min}}$$

(c) Torsional stress is defined by the following formula as per Section 5.6.2.2

Torsional Stress = $\sigma_{t(s)} = \frac{M_{t(op)}}{2Z_r}$

where

P = CAEPIPE input pressures P1 through P10 (= P1 for Operating 1, P2 for Operating 2, …, P10 for Operating 10, where the Operating pressure Pi with I between 1 & 10) = the difference between the corresponding internal pressure Pi and external pressure Pe = $(P_i - P_e)$.

t_2 = minimum pipe wall thickness

= nominal thickness x (1 – mill tolerance/100) – corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

$OD_{r,min}$= minimum outside diameter of the pipe wall = Outer Diameter in CAEPIPE

$D_{r,min}$ = mean diameter of the pipe wall = $OD_{r,min} - t_2$

ID_r= inside diameter of the pipe wall = $OD_{r,min} - 2.t_2$

A_r= inside metallic area of the pipe

SIF_{ai}, SIF_{ao} = in-plane and out-of-plane stress longitudinal/axial intensification factors as per Appendix D of ASME B31.8 (2020).

$M_{i(op)}, M_{o(op)}, M_{t(op)}$ = in-plane, out-of-plane bending moment and torsional moment respectively due to weight, other sustained mechanical loads (excluding pressure) and thermal expansion including thermal movements at supports.

Z_r= minimum pipe wall section modulus.

$F_{a(op)}$= axial force due to weight, other sustained mechanical loads and thermal displacement (excluding pressure).

(d) Equivalent stress, Von Mises, is computed as given below.

Equivalent Stress, Von Mises at One Extreme Surface of Pipe

In CAEPIPE, Equivalent Stress, Von Mises, at One Extreme Surface of Pipe is computed as given below.

$$T1_{(op)} = \frac{\sigma_{h(op)} - \sigma_{a(op)} - \sigma_{b(op)}}{2}$$

$$U1_{(op)} = \sqrt{\mathrm{T1}^2_{(op)} + \left(\sigma_{t(op)}\right)^2}$$

$$\text{Sigma 1} = \sigma_{1(op)} = \frac{\sigma_{h(op)} + \sigma_{a(op)} + \sigma_{b(op)}}{2} + U1_{(op)}$$

$$\text{Sigma 2} = \sigma_{2(op)} = \frac{\sigma_{h(op)} + \sigma_{a(op)} + \sigma_{b(op)}}{2} - U1_{(op)}$$

$$VonMises\_t_{(op)} = \sqrt{\left(\boldsymbol{\sigma_{1(op)}}\right)^2 - \boldsymbol{\sigma_{1(op)}\sigma_{2(op)}} + \left(\boldsymbol{\sigma_{2(op)}}\right)^2}$$

$$Max\_t_{(op)} = \boldsymbol{\sigma_{1(op)}};\ Min\_t_{(op)} = \boldsymbol{\sigma_{2(op)}}$$

Equivalent Stress, Von Mises at Other Extreme Surface of Pipe

In CAEPIPE, Equivalent Stress, Von Mises, at Other Extreme Surface of Pipe is computed as given below.

$$T2_{(op)} = \frac{\sigma_{h(op)} - \sigma_{a(op)} + \sigma_{b(op)}}{2}$$

$$U2_{(op)} = \sqrt{\mathrm{T2}^2_{(op)} + \left(\sigma_{t(op)}\right)^2}$$

$$\text{Sigma 1} = \sigma_{1(op)} = \frac{\sigma_{h(op)} + \sigma_{a(op)} - \sigma_{b(op)}}{2} + U2_{(op)}$$

$$\text{Sigma 2} = \sigma_{2(op)} = \frac{\sigma_{h(op)} + \sigma_{a(op)} - \sigma_{b(op)}}{2} - U2_{(op)}$$

$$VonMises\_b_{(op)} = \sqrt{\left(\boldsymbol{\sigma_{1(op)}}\right)^2 - \boldsymbol{\sigma_{1(op)}\sigma_{2(op)}} + \left(\boldsymbol{\sigma_{2(op)}}\right)^2}$$

$$Max\_b_{(op)} = \boldsymbol{\sigma_{1(op)}};\ Min\_b_{(op)} = \boldsymbol{\sigma_{2(op)}}$$

Based on the above (d), for the entire Pipe Cross-section at a Node

$$\textbf{Equivalent Stress, VonMises}_{(op)} = \boldsymbol{Max}\left[\boldsymbol{VonMises\_t_{(op)}}, \boldsymbol{VonMises\_b_{(op)}}\right] \le \boldsymbol{\eta . f_y} \ldots \boldsymbol{Eq.}\,(\mathbf{5.51})$$

$$\textbf{Max. Principal Stress}_{(op)} = \boldsymbol{Max}\left[\boldsymbol{Max\_t_{(op)}}, \boldsymbol{Max\_b_{(op)}}\right] \le \boldsymbol{\eta . f_y} \ldots \boldsymbol{Eq.}\,(\mathbf{5.52})$$

$$\textbf{Min. Principal Stress}_{(op)} = \boldsymbol{Min}\left[\boldsymbol{Min\_t_{(op)}}, \boldsymbol{Min\_b_{(op)}}\right] \le \boldsymbol{\eta . f_y} \ldots \boldsymbol{Eq.}\,(\mathbf{5.52})$$

where

η = design factor for equivalent stress check as per Table 5-15 of DNV-ST-F101 code. This can be selected in CAEPIPE through Layout Window > Options > Analysis > Design factor.

f_y = Yield strength at room temperature**.**

Sustained + Occasional Stress

(a) The hoop stress is defined by the following formula as per Section 5.6.2.2

$$\sigma_{h(o)} = \frac{(P_{peak} - P)D_{r,min}}{2.t_2}$$

(b) The longitudinal / axial stresses are defined by the following formulae as per Section 5.6.2.2

$$\sigma_{a(o)} = \frac{F_{a(o)}}{A_r} + \frac{PD_{r,min}}{4.t_2} = \frac{F_{a(o)}}{\frac{\pi}{4}(OD_{r,min}{}^2 - ID_r{}^2)} + \frac{PD_{r,min}}{4.t_2}$$

$$\sigma_{b(o)} = \frac{\sqrt{\left(SIF_{ai}.M_{i(o)}\right)^2 + \left(SIF_{ao}.M_{o(o)}\right)^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32}\frac{(OD_{r,min}{}^4 - ID_r{}^4)}{OD_{r,min}}$$

(c) Torsional stress is defined by the following formulae as per Section 5.6.2.2

Torsional Stress = $\sigma_{t(o)} = \frac{M_{t(o)}}{2Z_r}$

where

P = maximum of CAEPIPE input pressures P1 through P10, where the maximum operating pressure Pi (with i between 1 & 10) = the difference between the corresponding internal pressure Pi and external pressure Pe = $(P_i - P_e)$

P_{peak} = peak pressure = peak pressure factor x P

t_2 = minimum pipe wall thickness

= nominal thickness x (1 – mill tolerance/100) – corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

$OD_{r,min}$= minimum outside diameter of the pipe wall = Outer Diameter in CAEPIPE

$D_{r,min}$ = mean diameter of the pipe wall = $OD_{r,min} - t_2$

ID_r= inside diameter of the pipe wall = $OD_{r,min} - 2.t_2$

A_r= inside metallic area of the pipe

SIF_{ai}, SIF_{ao} = in-plane and out-of-plane stress longitudinal/axial intensification factors as per Appendix D of ASME B31.8 (2020).

$M_{i(o)}, M_{o(o)}, M_{t(o)}$ = in-plane, out-of-plane bending moment and torsional moment respectively due to occasional loads such as flow transients, earthquake, wind, etc.

Z_r= minimum reinforced pipe wall section modulus.

$F_{a(o)}$= axial force due to occasional loads such as flow transients, earthquake, wind, etc.

(d) Equivalent stress, Von Mises, is computed as given below.

Equivalent Stress, Von Mises at One Extreme Surface of Pipe

In CAEPIPE, Equivalent Stress, Von Mises, at One Extreme Surface of Pipe is computed as given below.

$T1_{(o)} = \frac{\sigma_{h(o)} - \sigma_{a(o)} - \sigma_{b(o)}}{2}$

$U1_{(o)} = \sqrt{\mathrm{T1}^2_{(o)} + (\sigma_{t(o)})^2}$

Sigma 1 = $\sigma_{1(o)} = \frac{\sigma_{h(o)} + \sigma_{a(o)} + \sigma_{b(o)}}{2} + U1_{(o)}$

Sigma 2 = $\sigma_{2(o)} = \frac{\sigma_{h(o)} + \sigma_{a(o)} + \sigma_{b(o)}}{2} - U1_{(o)}$

$VonMises\_t_{(o)} = \sqrt{(\boldsymbol{\sigma}_{1(o)})^2 - \boldsymbol{\sigma}_{1(o)}\boldsymbol{\sigma}_{2(o)} + (\boldsymbol{\sigma}_{2(o)})^2}$

$Max\_t_{(o)} = \boldsymbol{\sigma}_{1(o)}$; $Min\_t_{(o)} = \boldsymbol{\sigma}_{2(o)}$

Equivalent Stress, Von Mises at Other Extreme Surface of Pipe

In CAEPIPE, Equivalent Stress, Von Mises, at Other Extreme Surface of Pipe is computed as given below.

$T2_{(o)} = \frac{\sigma_{h(o)} - \sigma_{a(o)} + \sigma_{b(o)}}{2}$

$U2_{(o)} = \sqrt{\mathrm{T2}^2_{(o)} + (\sigma_{t(o)})^2}$

Sigma 1 = $\sigma_{1(o)} = \frac{\sigma_{h(o)} + \sigma_{a(o)} - \sigma_{b(o)}}{2} + U2_{(o)}$

Sigma 2 = $\sigma_{2(o)} = \frac{\sigma_{h(o)} + \sigma_{a(o)} - \sigma_{b(o)}}{2} - U2_{(o)}$

$VonMises\_b_{(o)} = \sqrt{(\boldsymbol{\sigma}_{1(o)})^2 - \boldsymbol{\sigma}_{1(o)}\boldsymbol{\sigma}_{2(o)} + (\boldsymbol{\sigma}_{2(o)})^2}$

$Max\_b_{(o)} = \boldsymbol{\sigma}_{1(o)}$; $Min\_b_{(o)} = \boldsymbol{\sigma}_{2(o)}$

Based on the above (d), for the entire Pipe Cross-section at a Node

$\textbf{Equivalent Stress, VonMises}_{(o)} = \boldsymbol{Max}\left[\boldsymbol{VonMises\_t}_{(o)}, \boldsymbol{VonMises\_b}_{(o)}\right]$

$\textbf{Max. Principal Stress}_{(o)} = \boldsymbol{Max}\left[\boldsymbol{Max\_t}_{(o)}, \boldsymbol{Max\_b}_{(o)}\right]$

$\textbf{Min. Principal Stress}_{(o)} = \boldsymbol{Min}\left[\boldsymbol{Min\_t}_{(o)}, \boldsymbol{Min\_b}_{(o)}\right]$

Sustained + Occasional Stress at a Node

$\textbf{Equivalent Stress, VonMises}_{(so)} = \textbf{VonMises}_{(s)} + \textbf{VonMises}_{(o)} \leq \boldsymbol{\eta}.\boldsymbol{f_y} \ldots \boldsymbol{Eq.}(\mathbf{5.51})$

$\textbf{Max. Principal Stress}_{(o)} = \textbf{Max. Principal Stress}_{(s)} + \textbf{Max. Principal Stress}_{(o)}$
$\leq \boldsymbol{\eta}.\boldsymbol{f_y} \ldots \boldsymbol{Eq.}(\mathbf{5.52})$

$\textbf{Min. Principal Stress}_{(o)} = \textbf{Min. Principal Stress}_{(s)} + \textbf{Min. Principal Stress}_{(o)}$
$\leq \boldsymbol{\eta}.\boldsymbol{f_y} \ldots \boldsymbol{Eq.}(\mathbf{5.52})$

where

η = design factor for equivalent stress check as per Table 5-15 of DNV-ST-F101 code. This can be selected in CAEPIPE through Layout Window > Options > Analysis > Design factor.

f_y = Yield strength at room temperature.

Stress Intensification Factors (SIFs) and Flexibility Factors (FFs)

For structural design of components and bends, Table 5-14 of DNV-ST-F101 refers to ASME B31.4 or ASME B31.8. Hence, Stress Intensification Factors (SIFs) for DNV-ST-F101 code are computed as per SIF equations provided in Appendix D of ASME B31.8 (2020) as given below.

In addition, Section 5.6.2.2 of DNV-ST-F101 states the following "*The moment and axial loads are calculated based on pipe type finite elements, not including the benefit of reduced stiffness in bends*". In view of the above, flexibility factors for Bends and Miter Bends are set as 1.0 internally in CAEPIPE for this code. Also, the analysis options "Include Bourdon Effect" and "Use Pressure Correction for Bends" are not available for DNV-ST-F101 Code.

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i*

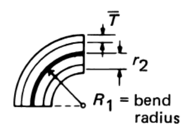
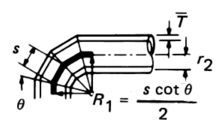
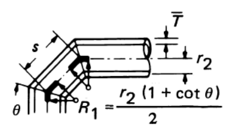
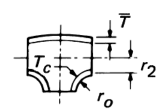
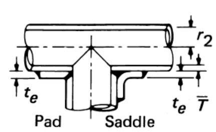
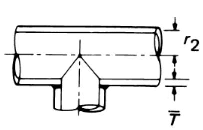
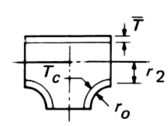
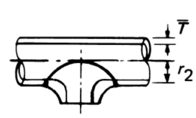
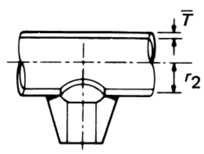
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)] Out-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Illustration
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^{\,2}}$	
Closely spaced miter bend $s < r_2 (1 + \tan\theta)$ [Notes (1), (2), (3), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\frac{\bar{T}s}{r_2^{\,2}}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan\theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\frac{\bar{T}}{r_2}$	
Welding tee per ASME B16.9 with $r_o \geq d/8$ $T_c \geq 1.5\bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$^3/_4\, i_o + {}^1/_4$	$4.4\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)]	1	$\frac{0.9}{h^{2/3}}$	$^3/_4\, i_o + {}^1/_4$	$\frac{\left(\bar{T} + {}^1/_2 t_e\right)^{5/2}}{\bar{T}^{3/2} r_2}$	
Unreinforced fabricated tee [Notes (1), (2), and (9)]	1	$\frac{0.9}{h^{2/3}}$	$^3/_4\, i_o + {}^1/_4$	$\frac{\bar{T}}{r_2}$	
Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5\,\bar{T}$ [Notes (1), (2), and (6)]	1	$\frac{0.9}{h^{2/3}}$	$^3/_4 i_o + {}^1/_4$	$\left(1 + \frac{r_0}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert $r_o \geq d/8$ $T_c \geq 1.5\bar{T}$ [Notes (1), (2), and (10)]	1	$\frac{0.9}{h^{2/3}}$	$^3/_4\, i_o + {}^1/_4$	$4.4\frac{\bar{T}}{r_2}$	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)] Out-Plane, i_o	Stress Intensification Factor, i [Notes (1) and (2)] In-Plane, i_i	Flexibility Characteristic, h	Illustration
Branch welded-on fitting (integrally reinforced) in accordance with MSS SP-97 [Notes (1), (2), (9), and (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\bar{T}}{r_2}$	

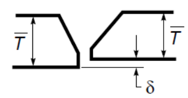
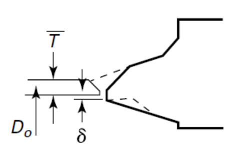
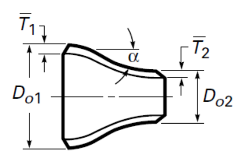
Description	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Butt weld [Notes (1) and (12)]			
$\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
$\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq 1/8$ in. (3.18 mm), and $\delta_{avg}/\bar{T}$ = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\bar{T})]$, but not less than 1.0	
$\bar{T} \leq 0.237$ in. (6.02 mm), $\delta_{max} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$			
Tapered transition per ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{\bar{T}} + 3.6\frac{\delta}{\bar{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max. or $2.1\,\bar{T}/C_x$ but not less than 1.3	
Lap joint flange (with vASME B16.9 lap joint stub) [Note (14)]	1	1.6	
Threaded pipe joint or threaded flange [Note (14)]	1	2.3	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]	5	2.5	

Table E-1 Flexibility Factor, *k*, and Stress Intensification Factor, *i* (Cont'd)

NOTES: (Cont'd)

D_0 = outside diameter, in. (mm)
d = outside diameter of branch, in. (mm)
R_1 = bend radius of welding elbow or pipe bend, in. (mm)
r_0 = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
r_2 = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
$\bar{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
T_c = the crotch thickness of tees, in. (mm)
t_e = pad or saddle thickness, in. (mm)
α = reducer cone angle, deg
δ = mismatch, in. (mm)
θ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, *k*, applies to bending in any plane. The flexibility factors, *k*, and stress intensification factors, *i*, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends and to the intersection point for tees. The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of *k* and *i* shall be corrected by the factors, C_u, which can be read directly from Chart B, entering with the computed *h*.

(4) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of *k* and *i*. To correct values from the table, divide *k* by

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide *i* by

$$\left[1 + 3.25\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}\right]$$

where
E_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(7) When $t_e > 1\frac{1}{2}\bar{T}$, use $h = 4.05\bar{T}/r_2$.

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875\bar{T}$ and $1.10\bar{T}$ for an axial distance of $\sqrt{D_0\bar{T}}$. D_0 and $\bar{T}$ are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) The equation applies only if the following conditions are met:
(a) Cone angle α does not exceed 60 deg, and the reducer is concentric.
(b) The larger of $D_{o1}/\bar{T}$ and $D_{o2}/\bar{T}$ does not exceed 100.
(c) The wall thickness is not less than $\bar{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\bar{T}_2$.

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4)\left(S_b A_b - P A_p\right)$$

where
A_b = total area of flange bolts, in.^{2} (mm^3)
A_p = area to outside of gasket contact, in.^{2} (mm^2)
C = bolt circle, in. (mm)
M_L = moment to produce flange leakage, in.-lb (mm·N)
P = internal pressure, psi (MPa)
S_b = bolt stress, psi (MPa)

(15) C_x is the fillet weld length. For unequal lengths, use the smaller leg for C_x.

(16) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using the equation provided in para. 5.2.1 for straight pipes and bends.

$$P_a = \frac{2fS_{yt}t_a}{DX}$$

where

P_a= allowable pressure

S_{yt} = specified minimum yield strength

t_a= available thickness for pressure design

= t_n × (1 - mill tolerance/100) - corrosion allowance "c" (as per para. 8.3.3)

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D = outside diameter

f = design factor from Table 2.

Stress from Normal Sustained Loads

The von Mises equivalent stress (S_L) due to Normal Sustained Loads (pressure, weight and other sustained loads inclusive of snow/ice loading) is calculated as per para. 6.3, para. 8.5.2 and Appendix 3 for all components in CAEPIPE and compared with the acceptance limit given in para. 8.5.3, as given below.

$$S_L = \sqrt{(S_h - S_a)^2 + (S_h S_a) + 3{S_q}^2} \leq S_s$$

where

For Bends, Miter Bends and Welding Elbows

$$S_a = i_t\left[\frac{PD_o}{4t_s} + \frac{4F}{\pi[{D_o}^2 - {D_i}^2]}\right] \pm \frac{i_t 32 M_b D_0}{\pi[{D_o}^4 - {D_i}^4]}$$

$$S_h = i_p\left[\frac{PD_o}{2t_s}\right] \pm \frac{i_b 32 M_b D_0}{\pi[{D_o}^4 - {D_i}^4]}$$

$$S_q = i_q\left[\frac{16 D_o M_q}{\pi[{D_o}^4 - {D_i}^4]}\right] + i_s \frac{4V_T}{\pi[{D_o}^2 - {D_i}^2]}$$

For Other components such as Straight Pipes, Reducers, Branch Pipes, Header Pipes, etc.

$$S_a = i_t \left[\frac{PD_o}{4t_s} + \frac{4F}{\pi[D_o{}^2 - D_i{}^2]}\right] \pm \frac{i_b 32 M_b D_0}{\pi[D_o{}^4 - D_i{}^4]}$$

$$S_h = i_p \left[\frac{PD_o}{2t_s}\right]$$

$$S_q = i_q \left[\frac{16 D_o M_q}{\pi[D_o{}^4 - D_i{}^4]}\right] + i_s \frac{4V_T}{\pi[D_o{}^2 - D_i{}^2]}$$

P = maximum of CAEPIPE input pressures P1 through P10 (inclusive of any overpressure as per para. 5.2.3)
D_o = outside diameter
D_i = inside diameter
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 8.3.3
i_p, i_b, i_t, i_q, i_s = sustained stress concentration factor (SCF) for pressure, bending, thrust, torsion and shear computed as per Appendix 4.
S_h = sustained hoop stress
S_a = sustained axial stress
S_q = sustained shear stress
F = axial force due to sustained loads
M_b = bending moment due to sustained loads = $\sqrt{M_i{}^2 + M_o{}^2}$
M_q = torsional moment due to sustained loads
V_T = shear force due to sustained loads = $\sqrt{V_i{}^2 + V_o{}^2}$
M_i = in-plane bending moment due to sustained loads
M_o = out-of-plane bending moment due to sustained loads
V_i = in-plane shear force (local fy from CAEPIPE) due to sustained loads
V_o = out-of-plane shear force (local fz from CAEPIPE) due to sustained loads
S_s = allowable equivalent stress for Normal condition from Table 3 (given below).

Note:

In CAEPIPE, any wind load input is always considered as an "Abnormal" sustained load (and NOT as a Normal sustained load).

In addition, CAEPIPE always considers snow/ice loading as a "Normal" sustained load (and NOT as an Abnormal sustained load).

In CAEPIPE, the effect of cold-pull/cold spring is included only in support loads and not included in stress calculations as many piping codes do not allow credit for any reduction in stresses due to cold spring since the displacement range is unaffected.On the other hand, piping codes allow reduction in support loads due to cold spring (which can be helpful at the equipment).

Stress from Abnormal Sustained Loads

The von Mises equivalent stress (S_{Lo}) due to Abnormal Sustained Loads is calculated as per para. 6.4, para. 8.5.2 and Appendix 3 for all components as the Sum of stress (S_L) due to Normal Sustained Loads (pressure, weight and other sustained loads) and stress (S_o) due to Abnormal Sustained Loads (i.e., occasional loads) such as earthquake or wind. Wind and earthquake are not considered as acting concurrently. The resulting stress S_{Lo} is compared with the acceptance limit given in para. 8.5.3.

$$S_{Lo} \leq S_{sab}$$

where

$S_{LO} = S_L + S_O$, where S_L is computed as above.

$$S_o = \sqrt{(S_{ho} - S_{ao})^2 + (S_{ho}S_{ao}) + 3{S_{qo}}^2}$$

For Bends, Miter Bends and Welding Elbows

$$S_{a0} = i_t\left[\frac{P_{peak}D_o}{4t_s} + \frac{4F_o}{\pi[{D_o}^2 - {D_i}^2]}\right] \pm \frac{i_t 32 M_{b0} D_0}{\pi[{D_o}^4 - {D_i}^4]}$$

$$S_{ho} = i_p\left[\frac{P_{peak}D_o}{2t_s}\right] \pm \frac{i_b 32 M_{b0} D_0}{\pi[{D_o}^4 - {D_i}^4]}$$

$$S_{qo} = i_q\left[\frac{16 D_o M_{qo}}{\pi[{D_o}^4 - {D_i}^4]}\right] + i_s\frac{4V_{To}}{\pi[{D_o}^2 - {D_i}^2]}$$

For Other components such as Straight Pipes, Reducers, Branch Pipes, Header Pipes, etc.,

$$S_{a0} = i_t\left[\frac{P_{peak}D_o}{4t_s} + \frac{4F_o}{\pi[{D_o}^2 - {D_i}^2]}\right] \pm \frac{i_b 32 M_{b0} D_0}{\pi[{D_o}^4 - {D_i}^4]}$$

$$S_{ho} = i_p\left[\frac{P_{peak}D_o}{2t_s}\right]$$

$$S_{qo} = i_q\left[\frac{16 D_o M_{qo}}{\pi[{D_o}^4 - {D_i}^4]}\right] + i_s\frac{4V_{To}}{\pi[{D_o}^2 - {D_i}^2]}$$

P_{peak}= peak pressure = (peak pressure factor in CAEPIPE – 1.0) x P

P = maximum of CAEPIPE input pressures P1 through P10
D_o = outside diameter
D_i = inside diameter
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 8.3.3

i_p, i_b, i_t, i_q, i_s= sustained stress concentration factor (SCF) for pressure, bending, thrust, torsion and shear computed as per Appendix 4.
S_{ho} = occasional hoop stress
S_{ao} = occasional axial stress
S_{qo} = occasional shear stress
F_o = axial force due to occasional loads
M_{bo} = bending moment due to occasional loads = $\sqrt{{M_{io}}^2 + {M_{oo}}^2}$
M_{qo} = torsional moment due to occasional loads
V_{To} = shear force due to occasional loads = $\sqrt{{V_{io}}^2 + {V_{oo}}^2}$
M_{io} = in-plane bending moment due to occasional loads
M_{oo} = out-of-plane bending moment due to occasional loads
V_{io} = in-plane shear force (local fy from CAEPIPE) due to occasional loads
V_{oo} = out-of-plane shear force (local fz from CAEPIPE) due to occasional loads
S_{sab} = allowable equivalent stress for Abnormal condition from Table 3 (given below).

Note:

In CAEPIPE, any ground settlement input is considered in computing "Shakedown Stress" (which is covered next) and NOT as an Abnormal sustained load.

Table 3: Allowable Stress for Normal and Abnormal Sustained Loads

f	NORMAL (S_s)		ABNORMAL ($S_{sab1}, S_{sab2}, ..., S_{sabi}$)	
	$\frac{SMYS}{UTS} \leq 0.74$	$\frac{SMYS}{UTS} > 0.74$	$\frac{SMYS}{UTS} \leq 0.74$	$\frac{SMYS}{UTS} > 0.74$
0.67	0.80 SMYS	0.34 (SMYS +UTS)	0.90 SMYS	0.38 (SMYS +UTS)
0.50	0.60 SMYS	0.25 (SMYS +UTS)	0.67 SMYS	0.28 (SMYS +UTS)
0.30	0.36 SMYS	0.15 (SMYS +UTS)	0.40 SMYS	0.17 (SMYS +UTS)

Expansion Stress (Shakedown Stress)

The von Mises equivalent stress (S_E) range due to thermal expansion is calculated as per para. 8.5.4 and Appendix 3 for all components in CAEPIPE and compared with the acceptance limit given in para. 8.5.5, as given below.

$$S_E \leq 0.5K_{SD}(S_y + S_{YT})$$

where

$$S_E = \sqrt{(S_{he} - S_{ae})^2 + (S_{he}S_{ae}) + 3{S_{qe}}^2}$$

For Bends, Miter Bends and Welding Elbows

$$S_{ae} = i_t \left[\frac{PD_o}{4t_s} + \frac{4F_e}{\pi[D_o{}^2 - D_i{}^2]} \right] \pm \frac{i_t 32 M_{be} D_0}{\pi[D_o{}^4 - D_i{}^4]}$$

$$S_{he} = i_p \left[\frac{PD_o}{2t_s} \right] \pm \frac{i_b 32 M_{be} D_0}{\pi[D_o{}^4 - D_i{}^4]}$$

$$S_{qe} = i_q \left[\frac{16 D_o M_{qe}}{\pi[D_o{}^4 - D_i{}^4]} \right] + i_s \frac{4V_{Te}}{\pi[D_o{}^2 - D_i{}^2]}$$

For Other components such as Straight Pipes, Reducers, Branch Pipes, Header Pipes, etc.,

$$S_{ae} = i_t \left[\frac{PD_o}{4t_s} + \frac{4F_e}{\pi[D_o{}^2 - D_i{}^2]} \right] \pm \frac{i_b 32 M_{be} D_0}{\pi[D_o{}^4 - D_i{}^4]}$$

$$S_{he} = i_p \left[\frac{PD_o}{2t_s} \right]$$

$$S_{qe} = i_q \left[\frac{16 D_o M_{qe}}{\pi[D_o{}^4 - D_i{}^4]} \right] + i_s \frac{4V_{Te}}{\pi[D_o{}^2 - D_i{}^2]}$$

P = operating pressure corresponding to the temperature considered for displacement cycle under analysis. For example, P = P1 from CAEPIPE for Expansion T1.
D_o = outside diameter
D_i = inside diameter
t_S = nominal thickness – corrosion allowance in CAEPIPE, as per para. 8.3.3
i_p, i_b, i_t, i_q, i_s = cyclic stress concentration factor (SCF) for pressure, bending, thrust, torsion and shear computed as per Appendix 4.
S_{he} = thermal expansion hoop stress
S_{ae} = thermal expansion axial stress
S_{qe} = thermal expansion shear stress
F_e = axial force due to thermal expansion
M_{be} = bending moment due to thermal expansion = $\sqrt{M_{ie}{}^2 + M_{oe}{}^2}$
M_{qe} = torsional moment due to thermal expansion
V_{Te} = shear force due to thermal expansion = $\sqrt{V_{ie}{}^2 + V_{oe}{}^2}$
M_{ie} = in-plane bending moment due to thermal expansion
M_{oe} = out-of-plane bending moment due to thermal expansion
V_{ie} = in-plane shear force (local fy from CAEPIPE) due to thermal expansion
V_{oe} = out-of-plane shear force (local fz from CAEPIPE) due to thermal expansion
K_{SD} = shakedown factor for the material from Table 4.

K_{SD} = 1.8 for Carbon Steel (CS) and 2.0 for Austenitic Steel (AS). For other materials, it is assumed to be 1.8.

S_y = yield stress of material at room temperature (reference temperature in CAEPIPE).

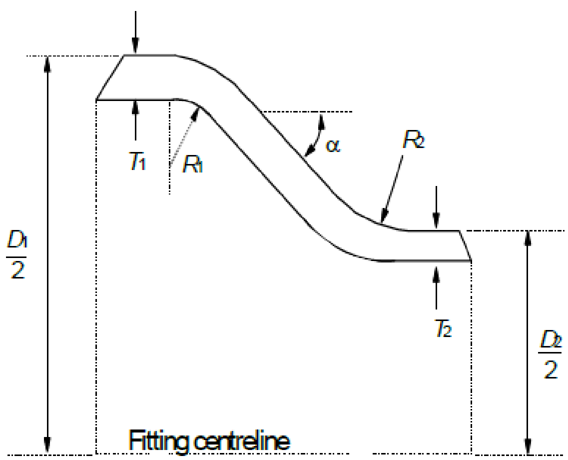
S_{YT} = yield stress of material at maximum of CAEPIPE input temperatures T1 through T10.

Fatigue Analysis

Fatigue compliance checks as described in para. 6.7, para. 8.5.6, para. 8.5.7 and Appendix 5 are not included in CAEPIPE analysis.

Stress Concentration Factors (SCF)

CONCENTRIC AND ECCENTRIC REDUCERS

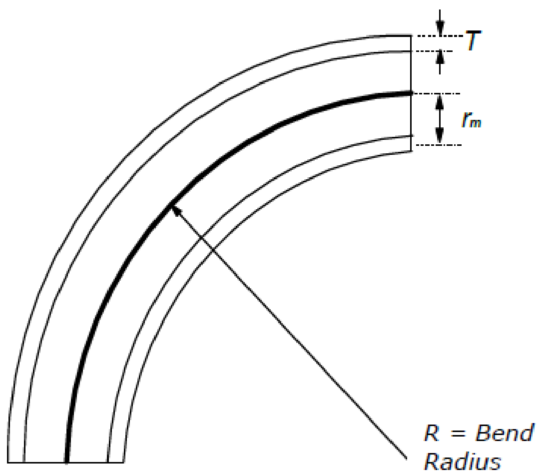
Sketch	Validity limits	k
	Cone angle α < 60° Wall thickness throughout the body of the reducer is not less than the minimum thicknesses required to resist the design pressure.	1.0

For reducers meeting the validity limits, take the sustained SCF for all loadings as 1.0 for cone angles < 30°, and 2.0 for cone angles from 30° to 60°.

Take the cyclic SCF for the pressure, bending, thrust, torsion and shear loadings as those given in Table 8.

TYPE	CYCLIC SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
Reducer with R_1 and R_2 ≥0.1 D_1	$1.0+0.0058\alpha\sqrt{\frac{D_n}{T_n}}$	$1.0+0.36\alpha^{0.4}(\frac{D_n}{T_n})^{0.4(\frac{D_2}{D_1}-0.5)}$	1.0	1.0	2.0

BEND & WELDING ELBOWS

Sketch	h	k *Never less than 1.0*
	$\frac{TR}{r_m^2}$	$\frac{1.65}{h}$

TYPE	SUSTAINED SCF					CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 1.0*	i_t Thrust	i_q Torsion	i_s Shear	i_p Pressure	i_b Bending *Never less than 1.5*	i_t Thrust	i_q Torsion	i_s Shear
Seam welded	1.0	$\frac{1.3}{h^{2/3}}$	1.0	1.0	1.0	2.0	$\frac{1.95}{h^{2/3}}$	1.3	1.0	2.0

Notes:

1. *For large diameter, thin walled elbows and bends pressure stiffening effects can significantly affect the magnitudes of k and i_b. For the application of this effect, satisfy the following criteria;*

a. *No flanges at either end*

b. *$R/r_m < 1.7$*

c. *$R\alpha > 2r_m$, where α is the arc angle of the bend in radians.*

Where the above criteria are satisfied, to correct values from the above tables,

Divide k by $\left[1 + 6\left(\frac{P}{E}\right)\left(\frac{r_m}{T}\right)^{7/3}\left(\frac{R}{r_m}\right)^{1/3}\right]$ *and divide i_b by*

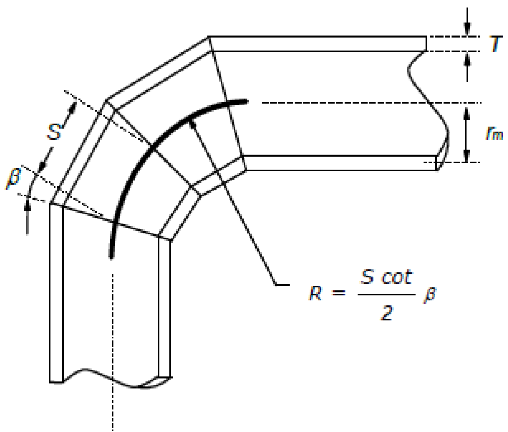
$$\left[1 + 3.25\left(\frac{P}{E}\right)\left(\frac{r_m}{T}\right)^{5/2}\left(\frac{R}{r_m}\right)^{2/3}\right]$$

2. *Where flanges are attached to one or both ends, multiply the values of k and i_b in by the factor C.*

a. *For one end flanged, $C = h^{1/6}$*

b. *For both ends flanged, $C = h^{1/3}$.*

CLOSELY SPACED MITRE BEND

Sketch	Validity limits	h	k *Never less than 1.0*
	$S < r_m(1+\tan\beta)$	$\frac{TR}{r_m^2}$	$\frac{1.52}{h^{5/6}}$

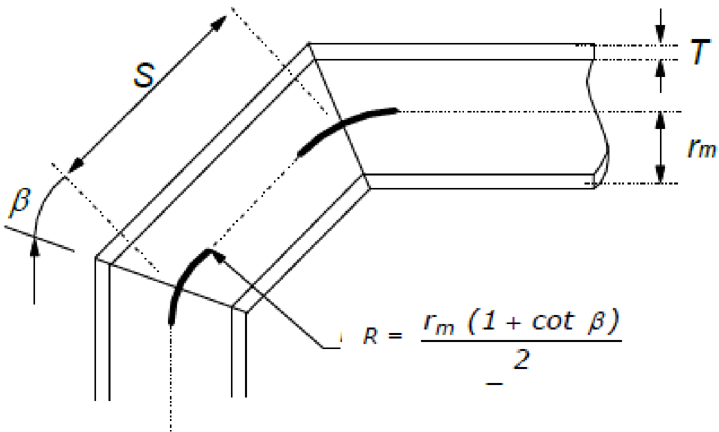
TYPE	SUSTAINED SCF					CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 1.0*	i_t Thrust	i_q Torsion	i_s Shear	i_p Pressure	i_b Bending *Never less than 1.5*	i_t Thrust	i_q Torsion	i_s Shear
Seam welded	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0	2.0	$\frac{1.8}{h^{2/3}}$	1.3	1.0	2.0

Note: *Where flanges are attached to one or both ends, multiply the values of k and i_b by the factor C.*

a. *For one end flanged, $C = h^{1/6}$*

b. *For both ends flanged, $C = h^{1/3}$.*

SINGLE OR WIDELY SPACED MITRE BEND

Sketch	Validity limits	h	k *Never less than 1.0*
	$S \geq r_m (1+\tan\beta)$	$\frac{TR}{r_m^2}$	$\frac{1.52}{h^{5/6}}$

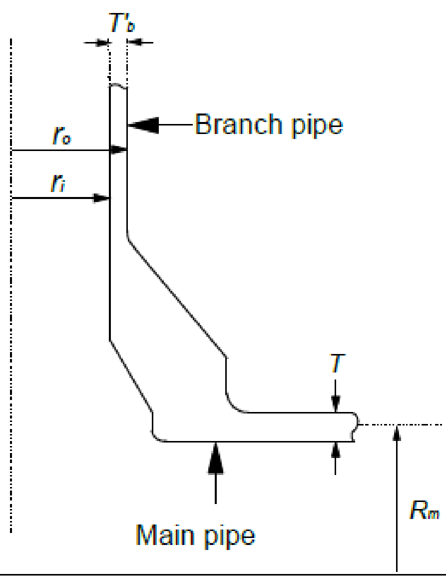
TYPE	SUSTAINED SCF					CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 1.0*	i_t Thrust	i_q Torsion	i_s Shear	i_p Pressure	i_b Bending *Never less than 1.5*	i_t Thrust	i_q Torsion	i_s Shear
Seam welded	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0	2.0	$\frac{1.8}{h^{2/3}}$	1.3	1.0	2.0

Notes: *Where flanges are attached to one or both ends, multiply the values of k and i_b in by the factor C.*

a. *For one end flanged,* $C = h^{1/6}$

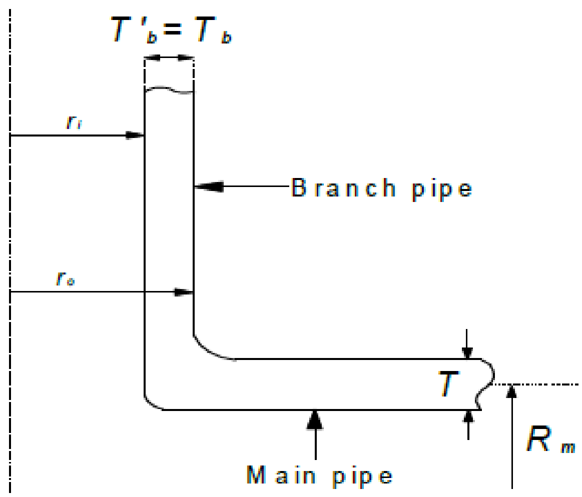
b. *For both ends flanged,* $C = h^{1/3}$.

WELDOLET

	h	k
	$3.3\frac{T}{R_m}$	1.0

TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending *Never less than 1.0 (See Notes)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 1.5 (See Notes)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29\left[\frac{d_o T'_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89\left[\frac{d_o T'_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

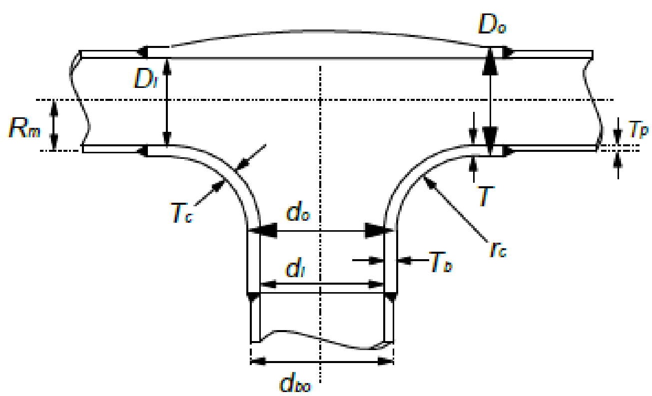
FABRICATED TEE



	h	k
	$\frac{T}{R_m}$	1.0

TYPE	SUSTAINED SCF				
	i_p **Pressure**	i_b **Bending** *Never less than 1.0 (See Note 1)*	i_t **Thrust**	i_q **Torsion**	i_s **Shear**
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p **Pressure**	i_b **Bending** *Never less than 1.5 (See Note 1)*	i_t **Thrust**	i_q **Torsion**	i_s **Shear**
Main pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29\left[\frac{d_o T'_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89\left[\frac{d_o T'_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

Welding TEE

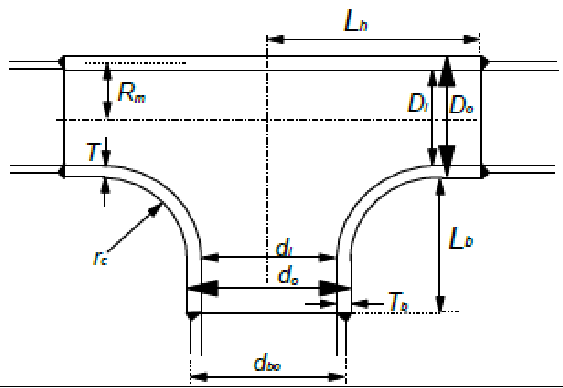
Sketch	Validity limits	k
	$r_c \geq 0.125\ d_{bo}$ $T_c \geq 1.5T_p$ *(See Note 1)*	1.0

TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending *Never less than 1.0 (See Note 2)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	1.0	$0.5\left(\frac{R_m}{T_p}\right)^{2/3}$	1.0	1.0	1.0
Branch pipe	1.0	$0.4\left(\frac{R_m}{T_p}\right)^{2/3}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 2.0 (See Note 2)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	For $d_i/D_i \leq 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.241}$	$0.67\left(\frac{R_m}{T_p}\right)^{2/3}$	$1.29\left[\frac{d_o T_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.241}$	$0.67\left(\frac{R_m}{T_p}\right)^{2/3}$	$0.89\left[\frac{d_o T_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

Notes:

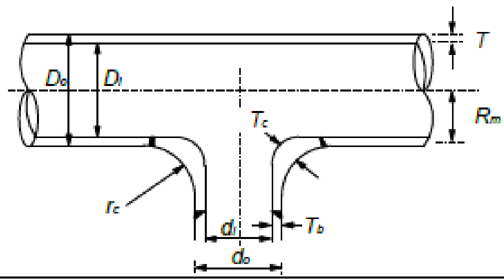
1. T_p *is the pipe wall thickness not the tee thickness.*
2. *The product* $i_b.w$ *(see Appendix 3) is never less than 1.0 for sustained or 2.0 for cyclic assessments.*

Extruded TEE

	Validity limits	h	k
	$0.05d_{bo} \leq r_c \leq (0.1d_{bo} + 12.5)$ $L_b \geq 0.7\sqrt{d_o T_b}$ $L_h \geq d_i$	$\frac{T}{R_m}(1 + \frac{T_b}{R_m}$	1.0

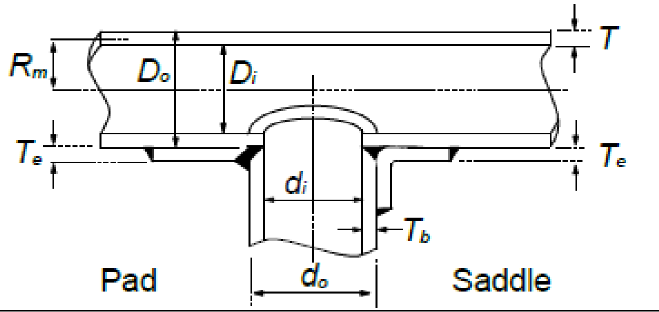
TYPE	SUSTAINED SCF				
	i_p **Pressure**	i_b **Bending** *Never less than 1.0 (See Note)*	i_t **Thrust**	i_q **Torsion**	i_s **Shear**
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p **Pressure**	i_b **Bending** *Never less than 1.5 (See Note)*	i_t **Thrust**	i_q **Torsion**	i_s **Shear**
Main pipe	For $d_i/D_i \leq 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29\left[\frac{d_o T_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89\left[\frac{d_o T_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

SWEEPOLET & WELDED-IN CONTOUR INSERT

	Validity limits	h	k
	$r_c \geq 0.125\ d_o$ $T_c \geq 1.5T$	$4.4\dfrac{T}{R_m}$	1.0

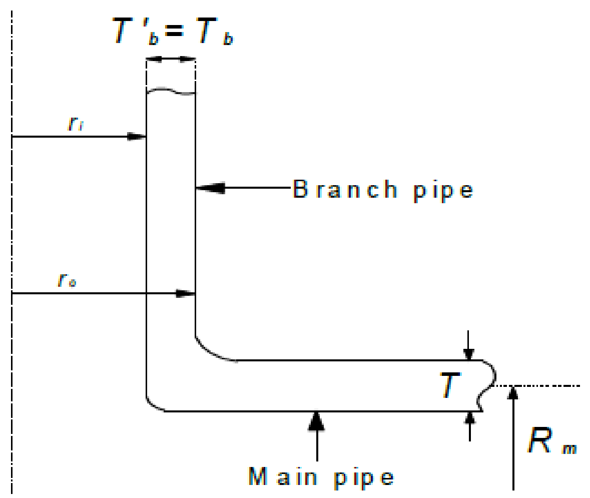
TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending *Never less than 1.0 (See Notes)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	1.0	$\dfrac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\dfrac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 1.5 (See Notes)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	For $d_i/D_i \leq 0.7$ $2.5\left[\dfrac{2T}{D_o}\left[\dfrac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\dfrac{2T}{D_o}\left[\dfrac{d_o}{2T_b}\right]^2\right]^{0.241}$	$\dfrac{1.8}{h^{2/3}}$	$1.29\left[\dfrac{d_o T_b}{D_o T}\left(\dfrac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5\left[\dfrac{2T}{D_o}\left[\dfrac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\dfrac{2T}{D_o}\left[\dfrac{d_o}{2T_b}\right]^2\right]^{0.241}$	$\dfrac{1.8}{h^{2/3}}$	$0.89\left[\dfrac{d_o T_b}{D_o T}\left(\dfrac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

Reinforced Fabricated TEE

	h	k
	$\dfrac{(T+0.5T_e)^{5/2}}{R_m(T)^{3/2}}$	1.0

TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending *Never less than 1.0 (See Note 1)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	1.0	$\dfrac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\dfrac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p Pressure	i_b Bending *Never less than 1.5 (See Note 1)*	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.241}$	$\dfrac{1.8}{h^{2/3}}$	$1.29\left[\frac{d_oT_b}{D_oT}\left(\frac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T_b}\right]^2\right]^{0.241}$	$\dfrac{1.8}{h^{2/3}}$	$0.89\left[\frac{d_oT_b}{D_oT}\left(\frac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

Unreinforced Fabricated TEE

	h	k
	$\frac{T}{R_m}$	1.0

TYPE	SUSTAINED SCF				
	i_p **Pressure**	i_b **Bending** *Never less than 1.0 (See Note 1)*	i_t **Thrust**	i_q **Torsion**	i_s **Shear**
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p **Pressure**	i_b **Bending** *Never less than 1.5 (See Note 1)*	i_t **Thrust**	i_q **Torsion**	i_s **Shear**
Main pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29\left[\frac{d_o T'_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \le 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5\left[\frac{2T}{D_o}\left[\frac{d_o}{2T'_b}\right]^2\right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89\left[\frac{d_o T'_b}{D_o T}\left(\frac{D_o}{T}\right)^2\right]^{0.3437}$	1.0	2.0

Sustained and Cyclic SCF for Welds and Threaded Joints in CAEPIPE

Type	Ip Pressure	Ib Bending	It Thrust	Iq Torsion	Is Shear
			Sustained SCF		
Buttweld	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	2.00	1.30	1.30	1.00	2.00
			Sustained SCF		
Tapered Transition	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	1.80	2.10	2.00	1.00	2.00
			Sustained SCF		
Filletweld	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	2.00	1.30	1.30	1.00	2.00
			Sustained SCF		
Concave Filletweld	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	2.00	1.30	1.30	1.00	2.00
			Sustained SCF		
Threaded Joint	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	1.00	2.30	2.30	1.00	1.00

Sustained and Cyclic SCF for Flanges in CAEPIPE

Type	Ip Pressure	Ib Bending	It Thrust	Iq Torsion	Is Shear
			Sustained SCF		
Weldneck	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	1.00	1.00	1.00	1.00	1.00
			Sustained SCF		
Double Welded	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	1.00	1.20	1.20	1.00	1.00
			Sustained SCF		
Single, Fillet & Socket Welded	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	2.00	1.30	1.30	1.00	1.00
			Sustained SCF		
Lap Joint	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	2.00	1.60	1.60	1.00	1.00
			Sustained SCF		
Threaded	1.00	1.00	1.00	1.00	1.00
			Cyclic SCF		
	2.00	2.30	2.30	1.00	1.00

Vertical deflection in Buried Piping Systems

The predicted vertical pipe deflection, Δy as a fraction of $D_{r,min}$ shall be less than 5% as per para. 7.7.2. This predicted vertical deflection as a fraction of $D_{r,min}$ shall be calculated as per Formula (9) of para. 7.7.2. The same Formula in English units is given below , which is Eq. (5-8) as per Section 5.7.3 of AWWA Manual M45 (second edition).

$$\frac{\Delta y}{D_{r,min}} = \frac{(D_L W_C + W_L)K_x}{0.149PS + 0.061M_s}$$

where

D_L = deflection lag factor to compensate for the time-consolidation rate of the soil as per Section. 5.7.3 and Section. 5.7.3.3 of AWWA Manual M45 (second edition) = 1.05 (assumed)

W_C = vertical soil load on pipe = $\frac{\gamma_s H}{144}$

W_L = live load on the pipe from surface traffic = $\frac{M_P P I_f}{L_1 L_2}$

K_X = bedding coefficient, dimensionless as per Section. 5.7.3.4 of AWWA Manual M45 (second edition) = 0.083 (for uniform-shaped bottom support)

γ_s = unit weight of overburden, lb/ft^3

H = burial depth to top of pipe, ft

I_f = Impact factor = 1 + 0.33 [(96 – *h*)/96] ≥ 1.0

In order to be conservative, formulae for calculations of L_1 and L_2 given below are for Single Axle Truck travelling perpendicular to the pipe on an unpaved surface or a road with flexible pavement, as per Section 5.7.3.6 of AWWA Manual M45 (second edition).

L_1 = load width parallel to direction of travel (in) = $t_l + LLDF\ (h)$

h = depth of cover (in)

h_{int} = depth at which load from wheels interact (in) = $(72 - t_w)/LLDF$

$LLDF$ = factor to account for live load distribution with depth of fill . See Section 5.7.3.6 of AWWA Manual M45 (second edition)] = 1.15 for backfill SC1 and SC2 or 1.0 for other backfills

t_l = length of tire foot print = 10 inch as per Section 5.7.3.6 of AWWA Manual M45 (second edition)

t_w = width of tire foot print = 20 inch as per Section 5.7.3.6 of AWWA Manual M45 (second edition)

When $h \leq h_{int}$, then

L_2 = load width perpendicular to direction of travel (in) = $t_w + LLDF\ (h)$

When $h > h_{int}$, then

L_2 = load width perpendicular to direction of travel (in) = $[t_w + 72 + LLDF\ (h)]/2$

P = wheel load magnitude = 20,000 lb for AASHTO HS-25 truck or 16000 lb for AASHTO HS-20 truck as per Section 5.7.3.6 of AWWA Manual M45 (second edition)

M_P = multiple presence factor = 1.2

PS = pipe stiffness (psi). Determined by conducting parallel-plate loading tests in accordance with ASTM D2412 with a vertical diameter reduction of 5% = $EI/(0.149r^3)$ as per Chapter 4, AWWA Manual M23 (second edition)

where

E = ring flexural (i.e., bending) modulus, psi

I = moment of inertia of unit length (in^3) = (1/12) t^3

r = mean pipe radius = (OD – t)/2, where t = thickness of buried pipe

M_s = composite constrained soil modulus = $S_c.M_{sb}$ as per Section 5.7.3.8 of AWWA Manual M45 (second edition). Values of S_c and M_{sb} are provided in Tables 5.5 and 5.4 of AWWA Manual M45 (second edition).

Sustained Load

(a) The sum of the hoop stresses is defined by the following formulae as per para. 7.8 of ISO 14692-3 code.

$$\sigma_{hps} = \frac{PD_{r,min}}{2t_{r,min}}$$

$\sigma_{hus} = r_c.D_f.E_{hb}.\frac{\Delta y}{D_{r,min}}.\frac{t_{r,min}}{D_{r,min}}$ (applicable only when the piping is buried and the value of σ_{hus} is Tensile)

$\boldsymbol{\sigma_{hs,sum} = (\sigma_{hps} + \sigma_{hus}) \leq f_2.A_0.A_2.A_3.\sigma_{h,LT}}$ **as per para. 6.4**

(b) The sum of the axial stresses is defined by the following formulae as per para. 7.8 of ISO 14692-3 code.

$\sigma_{as,sum} = (\sigma_{aps} \pm \sigma_{abs} + \sigma_{afs}) \leq f_2.A_0.A_2.A_3.\sigma_{a,LT}$ as per para. 6.4

$\sigma_{aps} = \frac{PD_{r,min}}{4t_{r,min}}$ for Unrestrained piping (i.e., for all above ground piping in CAEPIPE)

$\sigma_{aps} = \nu \frac{PD_{r,min}}{2t_{r,min}}$ for Restrained piping (i.e., only for buried piping in CAEPIPE)

$$\sigma_{abs} = axial\ stress = \frac{\sqrt{(SIF_{ai}.M_{is})^2 + (SIF_{ao}.M_{os})^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32}\frac{(OD_{r,min}{}^4 - ID_r{}^4)}{OD_{r,min}}$$

$$\sigma_{afs} = \frac{F_{as}}{A_r} = \frac{F_{as}}{\frac{\pi}{4}(OD_{r,min}{}^2 - ID_r{}^2)}$$

$\boldsymbol{\sigma_{as,sum}}$**(min)** $\boldsymbol{= (\sigma_{aps} - \sigma_{abs} + \sigma_{afs}) \leq f_2.A_0.A_2.A_3.\sigma_{a,LT}}$ **as per para. 6.4**

$\boldsymbol{\sigma_{as,sum}}$**(max)** $\boldsymbol{= (\sigma_{aps} + \sigma_{abs} + \sigma_{afs}) \leq f_2.A_0.A_2.A_3.\sigma_{a,LT}}$ **as per para. 6.4**

where

P = maximum of CAEPIPE pressures P1 through P10

$t_{r,min}$ = minimum reinforced pipe wall thickness (in)

$D_{r,min}$ = mean diameter of the minimum reinforced pipe wall (in)

r_c = rerounding coefficient

r_c = 0 when P > 3 MPa (145 psi) and

r_c = 1 – P/3 when P <= 3 MPa (145 psi)

D_f = shape factor from Table 5.1 of AWWA Manual M45 (second edition)

$\frac{\Delta y}{D_{r,min}}$ = predicted vertical pipe deflection as given above

E_{hb} = hoop bending (flexural) modulus (psi)

ID_r= inside diameter of the reinforced pipe wall

$OD_{r,min}$= minimum outside diameter of the reinforced pipe wall

SIF_{ai}= axial in-plane stress intensification factor

SIF_{ao}= axial out-of-plane stress intensification factor

M_{is}, M_{os} = in-plane and out-of-plane bending moment respectively due to weight and other sustained mechanical loads (excluding pressure)

Z_r= minimum reinforced pipe wall section modulus

F_{as}= axial force due to weight and other sustained mechanical loads (excluding pressure)

A_r= minimum reinforced pipe wall cross section

f_2 = part factor for loading

f_2 = 0.67 for Sustained load case from para. 6.2 and Table 1 of ISO 14692-3 code

A_0 = partial factor for design life = 1.00 (default) (see Note below)

A_2 = partial factor for chemical resistance = 1.00 (default) (see Note below)

A_3 = partial factor for cyclic service = 1.00 (default) (see Note below)

$\sigma_{h,LT}$ = long term envelope hoop allowable stress

$\sigma_{a,LT}$ = long term envelope axial allowable stress

Note:

Values of A_0, A_2 & A_3 can be input into CAEPIPE through Layout Window > Options > Analysis.

Operating Load (Sustained + Expansion)

(a) The sum of the hoop stresses is defined by the following formulae as per para. 7.8 of ISO 14692-3 code.

$$\sigma_{hpo} = \frac{P_i D_{r,min}}{2t_{r,min}}$$

$\sigma_{huo} = r_c . D_f . E_{hb} . \frac{\Delta y}{D_{r,min}} . \frac{t_{r,min}}{D_{r,min}}$ (applicable only when the piping is buried and the value of σ_{huo} is Tensile)

$\boldsymbol{\sigma_{ho,sum} = (\sigma_{hpo} + \sigma_{huo}) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{h,LT}}$ **as per para. 6.4**

(b) The sum of the axial stresses is defined by the following formulae as per para. 7.8 of ISO 14692-3 code.

$\sigma_{ao,sum} = (\sigma_{apo} \pm \sigma_{abo} + \sigma_{afo}) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{a,LT}$ as per para. 6.4

$\sigma_{apo} = \frac{P_i D_{r,min}}{4t_{r,min}}$ for Unrestrained piping (i.e., for all above ground piping in CAEPIPE)

$\sigma_{apo} = \nu \frac{P_i D_{r,min}}{2t_{r,min}}$ for Restrained piping (i.e., only for buried piping in CAEPIPE)

$$\sigma_{abo} = axial\ stress = \frac{\sqrt{(SIF_{ai} . M_{io})^2 + (SIF_{ao} . M_{oo})^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32} \frac{(OD_{r,min}{}^4 - ID_r{}^4)}{OD_{r,min}}$$

$$\sigma_{afo} = \frac{F_{ao}}{A_r} = \frac{F_{ao}}{\frac{\pi}{4}(OD_{r,min}{}^2 - ID_r{}^2)}$$

$\boldsymbol{\sigma_{ao,sum(\mathrm{min})} = \left(\sigma_{apo} - \sigma_{abo} + \sigma_{afo}\right) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{a,LT}}$ **as per para. 6.4**

$\boldsymbol{\sigma_{ao,sum(\mathrm{max})} = \left(\sigma_{apo} + \sigma_{abo} + \sigma_{afo}\right) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{a,LT}}$ **as per para. 6.4**

where

P_i = internal design pressure P1 through P10. For example, for operating load case 1, $P_i = P1$

M_{io}, M_{oo} = in-plane and out-of-plane moment respectively due to weight, other sustained mechanical loads (excluding pressure) and self-limiting displacements (Thermal load T1 through T10).

F_{ao}= axial force due to weight, other sustained mechanical loads (excluding pressure) and self-limiting displacement load

f_2 = part factor for loading

f_2 = 0.83 for Operating load case from para. 6.2 and Table 1 of ISO 14692-3 code

All other parameters are defined under Sustained Load.

Occasional Load (Sustained + Occasional)

(a) The sum of the hoop stresses is defined by the following formulae as per para. 7.8 of ISO 14692-3 code.

$$\sigma_{hpc} = \frac{P_o D_{r,min}}{2t_{r,min}}$$

$\sigma_{huc} = r_c . D_f . E_{hb} . \frac{\Delta y}{D_{r,min}} . \frac{t_{r,min}}{D_{r,min}}$ (applicable only when the piping is buried and the value of σ_{huc} is Tensile)

$\boldsymbol{\sigma_{hc,sum} = (\sigma_{hpc} + \sigma_{huc}) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{h,LT}}$ **as per para. 6.4**

(b) The sum of the axial stresses is defined by the following formulae as per para. 7.8 of ISO 14692-3 code.

$\sigma_{ac,sum} = (\sigma_{apc} \pm \sigma_{abc} + \sigma_{afc}) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{a,LT}$ as per para. 6.4

$\sigma_{apc} = \frac{P_o D_{r,min}}{4t_{r,min}}$ for Unrestrained piping (i.e., for all above ground piping in CAEPIPE)

$\sigma_{apc} = \nu \frac{P_o D_{r,min}}{2t_{r,min}}$ for Restrained piping (i.e., only for buried piping in CAEPIPE)

$$\sigma_{abc} = axial\ stress = \sigma_{abs} + \frac{\sqrt{(SIF_{ai} . M_{ic})^2 + (SIF_{ao} . M_{oc})^2}}{Z_r}$$

$$Z_r = \frac{\pi}{32} \frac{(OD_{r,min}{}^4 - ID_r{}^4)}{OD_{r,min}}$$

$$\sigma_{afc} = \frac{F_{ac}}{A_r} = \sigma_{afs} + \frac{F_{ac}}{\frac{\pi}{4}(OD_{r,min}{}^2 - ID_r{}^2)}$$

$\boldsymbol{\sigma_{a,sum(\min)} = \left(\sigma_{apc} - \sigma_{abc} + \sigma_{afc}\right) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{a,LT}}$ **as per para. 6.4**

$\boldsymbol{\sigma_{a,sum(\max)} = \left(\sigma_{apc} + \sigma_{abc} + \sigma_{afc}\right) \leq f_2 . A_0 . A_2 . A_3 . \sigma_{a,LT}}$ **as per para. 6.4**

where

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = maximum of CAEPIPE pressures P1 through P10

M_{ic}, M_{oc} = in-plane and out-of-plane moment respectively due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

F_{ac}= axial force due to weight, other sustained mechanical loads (excluding pressure), and occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake, wind, etc.

f_2 = part factor for loading

f_2 = 0.89 for Occasional load case from para. 6.2 and Table 1 of ISO 14692-3 code

Flexibility Factors and Stress Intensification Factors [Refer to Annex B of ISO 14692-3 (2017)]

Flexibility Factor for Bend and Miter Bend

The flexibility factor, κ_b, for GRP bends is based on the pipe factor, λ_b, and the axial pressure correction factor, δ_a, due to the effect of internal pressure.

λ_b is given by Formula (B.1):

$$\lambda_b = \frac{4t_b R_b}{D_i^2} \quad \text{(B.1)}$$

where

t_b is the average wall thickness of the reference laminate of the bend, in mm;

D_i is the internal diameter of the reinforced body of the bend, in mm;

R_b is the mean pipe bend radius, in mm.

The "axial pressure correction factor δa" is given by formula (B.3):

$$\delta_a = \frac{1}{\left[1 + \left(2{,}53p / (E_{h,bend}) \cdot (R_b / t_b)^{1/3} \cdot (D_i / 2t_b)^2\right)\right]} \quad \text{(B.3)}$$

where

p is the applied pressure, in MPa;

$E_{h,bend}$ is the hoop modulus of the bend, in MPa.

The flexibility factor for smooth bends is given as a function of λ_b:

$$\kappa_b = \delta_a \cdot \frac{0{,}7}{\lambda_b} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b} \quad \text{(B.4)}$$

The flexibility factor for mitred bends is given as a function of λ_b:

$$\kappa_b = \delta_a \cdot \frac{0{,}64}{(\lambda_b)^{0{,}83}} \cdot \frac{E_{a,pipe} \cdot t_{pipe}}{E_{a,bend} \cdot t_b} \quad \text{(B.5)}$$

where

$E_{a,pipe}$ is the axial modulus of the attached pipe, in MPa;

$E_{a,bend}$ is the axial modulus of the bend, in MPa.

Note:

If thickness field is input in the Bend / Miter dialog then that thickness will be used as "t_b" in the above calculation. On the other hand, if the thickness field is left blank then CAEPIPE will use the pipe thickness as "t_b" in the above calculation.

Flexibility Factor for TEE

Flexibility factor for TEE is 1.0

Stress Intensification Factors (SIF)

Bends and Miters (in line with Section B.3 of Annex B of ISO 14692-3)

Sl. No.	Designation	In-plane Stress intensification factor (SIF_{ai})	Out-of-plane Stress intensification factor (SIF_{ao})
1	Bends	2.3	2.3
2	Miters – Closely Spaced	2.3	2.3
3	Miters – Widely Spaced	2.3	2.3

TEEs (in line with Section B.3 of Annex B of ISO 14692-3)

Sl. No.	Designation	In-plane Stress intensification factor (SIF_{ai})	Out-of-plane Stress intensification factor (SIF_{ao})
1	Integral TEE	2.3	2.3

Reducers

ISO 14692-3 does not provide SIFs for Reducers. Hence, in CAEPIPE, SIFs for the Reducer Types will be assigned internally as listed below when used in the Stress model.

Sl. No.	Designation	In-plane Stress intensification factor (SIF_{ai})	Out-of-plane Stress intensification factor (SIF_{ao})
1	Concentric Reducer	1.0	1.0
2	Eccentric Reducer	1.0	1.0

Threaded Joint

ISO 14692-3 does not provide SIFs for Threaded Joint. Hence, in CAEPIPE, SIF for the Threaded Joint be assigned internally as listed below when used in the Stress model.

Sl. No.	Designation	In-plane Stress intensification factor (SIF_{ai})	Out-of-plane Stress intensification factor (SIF_{ao})
1	Threaded Joints	2.3	2.3

Flanges

ISO 14692-3 does not provide SIFs for Flanges. Hence, in CAEPIPE, SIFs for the Flange Types will be assigned internally as listed below when used in the Stress model.

Sl. No.	Designation	In-plane Stress intensification factor (SIF_{ai})	Out-of-plane Stress intensification factor (SIF_{ao})
1	Weld Neck Flange	1.0	1.0
2	Double Welded Slip on Flange	1.0	1.0
3	Single Welded Slip on Flange	1.0	1.0
4	Fillet Welded Flange	1.0	1.0
5	Socket Welded Flange	1.0	1.0
6	Lap Joint Flange	1.0	1.0
7	Threaded Flange	1.0	1.0
8	Threaded Joint	1.0	1.0

In case the user wants to input at a node a different value for any of the SIFs listed above, the user can input the desired value using the data type “User SIF” at that node. Any value input in the “User SIF” field will always replace any internally calculated or internally set value.

Allowable Pressure

A.2.1 Straight pipes: For straight pipes, the allowable internal pressure is calculated from Equations (A.1) and (A.2):

$$P_a = \frac{2\sigma_d z t_{min}}{\gamma_a d_o} \quad (A.1)$$

where,

P_a= allowable pressure

d_o= outside diameter of the pipe

z = joint efficiency factor

$$t_{min} = t_n - (c_1 + c_2) \quad (A.2)$$

t_n= nominal wall thickness of the pipe

c_1 = mill/fabrication tolerance (input as a % of thickness)

c_2= corrosion allowance

σ_d = allowable stress (i.e., design stress) = $R_e(T)/\gamma_m$, where $R_e(T)$ is the specified minimum yield strength at design temperature (sec 5.2.3.1), where design temperature is a CAEPIPE input, and γ_m = 1.1, the partial safety factor for strength of material per sec. 7.2.2.1

γ_a = 1.25 = partial load factor for LC2 and LC3 cases from Table 9 in sec.6.4.2.

A.2.2 Bends: The allowable internal pressure for bends is calculated as

$$P_a = \frac{2\sigma_d z\, t_{min}}{\gamma_a d_o I}$$

$$I = \frac{R - 0.25 d_i}{R - 0.5 d_m} \quad (A.3)$$

d_i= inside diameter of the pipe

d_m= mean diameter of the pipe

R = bend radius

A.4 Reducers and extensions: shall withstand the same internal pressure as the connecting pipes where the half angle α, at the apex of the component does not exceed 30 degrees,

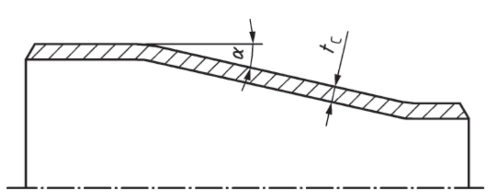


Figure A.2 — Reducer

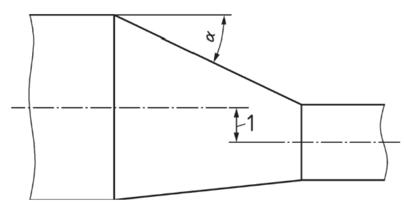


Figure A.3 — Offset reducer

The allowable internal pressure is calculated from

$$P_a = min\left\{\frac{2\sigma_d z\ \cos\alpha\ t_{n1,min}}{\gamma_a . d_{o1}}, \frac{2\sigma_d z\ \cos\alpha\ \ t_{n2,min}}{\gamma_a . d_{o2}}\right\}$$

where:

$$t_{n1,min} = t_{n1} - (c_1 + c_2)$$

$t_{n2,min} = t_{n2} - (c_1 + c_2)$
$t_{n1}, and\ t_{n2}$ is nominal wall thickness of pipe at inlet and outlet of reducer.
$d_{o1}, and\ d_{o2}$ is nominal outer diameter at inlet and outlet of reducer.

Note 1: CAEPIPE permits to model the reducers with $\alpha \leq 30^o$. Reducers with $\alpha > 30^o$ cannot be modeled, because the stress concetration factors are not explcitly given in C.3.5 for reducers with $\alpha > 30^o$.

Note 2: The above allowable pressures calculated by CAEPIPE are valid only for pipes and components delivered with the required certificate as per sec. 5.2.2.

For pipes and components delivered without the required certificate as per sec. 5.2.2, the allowable pressures P_a computed by CAEPIPE as given above should be manually divided by an extra safety coefficient $\gamma_{m,yield}$ = 1.2 (sec. 5.2.3.1) to arrive at lower allowable pressures for such uncertified pipes and components.

Evaluation of Stresses

Stress components and internal forces as per sec. 6.6.2 of the code are defined as:

Axial stress

$$(\Delta\sigma_a)_+ = i_{a1}\frac{\Delta N_x}{A} + i_{a2}\frac{\sqrt{\Delta M_y{}^2+\Delta M_z{}^2}}{W}$$

and

$$(\Delta\sigma_a)_- = i_{a1}\frac{\Delta N_x}{A} - i_{a2}\frac{\sqrt{\Delta M_y{}^2+\Delta M_z{}^2}}{W}$$

Shear Stress

$$(\Delta\tau)_+ = i_{a3}\frac{\Delta M_x}{2W} + i_{a4}\frac{2\sqrt{\Delta V_y{}^2+\Delta V_z{}^2}}{A}$$ and

$$(\Delta\tau)_- = i_{a3}\frac{\Delta M_x}{2W} - i_{a4}\frac{2\sqrt{\Delta V_y{}^2+\Delta V_z{}^2}}{A}$$

Membrane Tangential Stress

$$(\Delta\sigma_t)_m = i_{ap}\frac{p \cdot d_i}{2t_{min}}$$

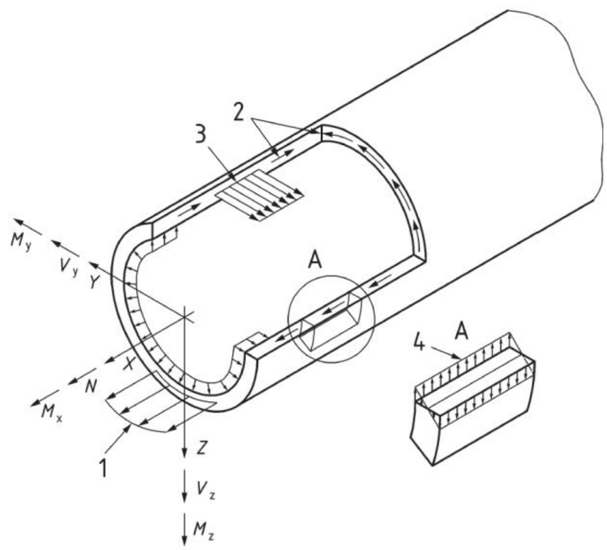


Figure 21 — Stress components and internal forces

(Membrane + Bending) Tangential Stress

$$(\Delta\sigma_t)_{mb} = i_{ap}\frac{p \cdot d_i}{2t_{min}} + i_{a5}\frac{\sqrt{\Delta M_y{}^2+\Delta M_z{}^2}}{W} + \sigma_q$$

The equivalent stress as per sec. 6.6.3 is calculated from the axial and tangential stress components (calculated with sign) by von Mises for either membrane stress or membrane + bending stress ($\boldsymbol{m|mb}$)

$$\boldsymbol{S_{m|mb}} = \boldsymbol{max}\{S1_{m|mb}, S2_{m|mb}, S3_{m|mb}, S4_{m|mb}, |(\Delta\sigma_a)_+|, |(\Delta\sigma_a)_-|\}$$

where,

$$S1_{m|mb} = \sqrt{(\Delta\sigma_a)_+^2 - (\Delta\sigma_a)_+ \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_+^2}$$

$$S2_{m|mb} = \sqrt{(\Delta\sigma_a)_-^2 - (\Delta\sigma_a)_- \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_+^2}$$

$$S3_{m|mb} = \sqrt{(\Delta\sigma_a)_+^2 - (\Delta\sigma_a)_+ \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_-^2}$$

$$S4_{m|mb} = \sqrt{(\Delta\sigma_a)_-^2 - (\Delta\sigma_a)_- \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_-^2}$$

N_x = Axial force (positive for tension), (pressure, temperature and soil reaction)
M_x = Torsional moment
M_y and M_z = Bending moment
A = Metal area of pipe
W = Section modulus
V_y and V_z = Shear force
p = Internal pressure
d_i = Inside diameter of the steel service pipe.
t_{min} = Minimum pipe wall thickness = $t_n - (c_1 + c_2)$
i_{a1} = Stress concentration factor for axial stresses from normal force
i_{a2} = Stress concentration factor for axial stresses from bending moments
i_{a3} = Stress concentration factor for shear stresses from torsion
i_{a4} = Stress concentration factor for shear stresses from shear forces
i_{ap} = Stress concentration factor for hoop stresses from pressure

Area and section modulus are calculated, as per 6.6.2, as follows:

$$A = \pi \times (d_o - t_n) \times t_n \quad (45)$$

$$W = \frac{\pi}{32 \times d_o}[d_o^4 - (d_o - 2t_n)^4] \quad (46)$$

d_o = Outer diameter of the steel service pipe
t_n = nominal pipe wall thickness
c_1 = Correction to wall thickness for fabrication tolerance
c_2 = Correction to wall thickness for corrosion allowance

S_m = Membrane stress
S_{mb} = Resulting stress of membrane stress and bending stress

σ_a = Axial (normal) stress
σ_t = Tangential stress
τ = Shear stress
σ_p = Hoop stress from internal pressure
σ_q = Ovalisation stress from soil pressure, traffic, lateral soil reactions, etc. (see sec. 6.6.4) to be manually computed by the user and input into soil model dialog of CAEPIPE at this time.

Forced Control Action LC2 (sec. 7.2.2.2)

In CAEPIPE, the LC2 case (both S_m and S_{res}) is evaluated for sustained loads (W+P) which include weight (of pipe, fluid, and insulation) ***at maximum operating pressure***. The displacements specified as settlement at anchor and nozzle locations are also included in force-controlled action.

1) **S_m = Membrane stress A1:**

$$S_m \leq S_{ma} \; (= R_e(T)/\gamma_m)$$

S_m = is the equilibrium membrane stress
S_{ma} = is the allowable membrane stress ($= R_e(T)/\gamma_m$)
$R_e(T)$ = Specified minimum yield strength ***at maximum operating temperature***
$\gamma_m = 1.1$ is the partial safety factor for the base material, as per sec. 7.2.2.2.

2) **S_{res} = Membrane + Bending stress A1:**

$$S_{res} (= S_{mb}) \; \leq S_{resa}$$

S_{res} ($= S_{mb}$) is the resulting stress of equilibrium membrane stress and equilibrium bending stress
S_{resa} = is the allowable resulting stress (including membrane + bending)

$$S_{resa} = \begin{cases} 1.5 \dfrac{R_e(T)}{\gamma_m} & \text{for} \quad S_m \leq 0.67 \dfrac{R_e(T)}{\gamma_m} \\ 2.5 \dfrac{R_e(T)}{\gamma_m} - 1.5\, S_m & \text{for} \quad 0.67 \dfrac{R_e(T)}{\gamma_m} < S_m \leq \dfrac{R_e(T)}{\gamma_m} \end{cases}$$

Note: The above stresses calculated by CAEPIPE is valid only for pipes and components delivered with the required certificate as per sec. 5.2.2, where $\gamma_m = 1.1$ as per sec. 7.2.2.2.

For pipes and components delivered without the required certificate as per sec. 5.2.2, the allowable stresses S_{ma} and S_{resa} computed by CAEPIPE as given above should be manually divided by an extra safety coefficient $\gamma_{m,yield}$ = 1.2 (sec. 5.2.3.1) to arrive at the corresponding lower allowable stresses for such uncertified pipes and components.

Stepwise plastic deformation LC3 (sec. 7.2.2.3)

In CAEPIPE, the LC3 case is evaluated for each operating load case (Weight of pipe, fluid & insulation + Pressure + Temperature) and ***at each set of operating pressure and temperature***.

S_{pd} = Force + Deformation stress A2

Limit state A2 concerns incremental collapse and stress ratcheting. The limit state for stress ratcheting for fully restrained sections is obtained from:

$$S_{pd} \leq S_{pda}$$

S_{pd} is the maximum of axial stress due to plastic deformation.

$$S_{pd} = \boldsymbol{max}\{(\Delta\sigma_a)_+, (\Delta\sigma_a)_-\}$$

The allowable/limit state for stress ratcheting for fully restrained sections is obtained from:

$$S_{pda} = R_e(T)\left[\sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2} + \sqrt{\gamma^2 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2}\right] \qquad (79)$$

$R_e(T)$ = Specific minimum yield strength ***at operating temperature***

σ_p $(= Pd_o/2zt_{min})$ = hoop stress ***at operating pressure***. (78)

γ = 0.7, is a safety factor

Note: EN13941-1:2019 does not specify stress concentration factors for calculating S_{pd}. In CAEPIPE, the stress concentration factors for S_{pd} calculations are considered the same as those for resulting stresses for each component given in Tables C1, C3, C4, and C6.

TEES

- In CAEPIPE, σ and τ are calculated separately for run pipe and branch pipe with sectional forces chosen as follows:

  For stresses in the run pipe, the forces and moments determined in the run at the intersection between the centerlines of the pipes are used.

  For stresses in the branch pipe, the forces and moments determined in the branch at a distance of $0.5\ d_{ro}$ from the centreline of the run pipe are used.

  Note: CAEPIPE automatically refines the elements connected to the node point with a defined tee. Two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Pipe OD and one (1) node on Branch Pipe at a distance equal to Run pipe OD/2 from the Branch SIF node are internally added with appropriate node numbers.

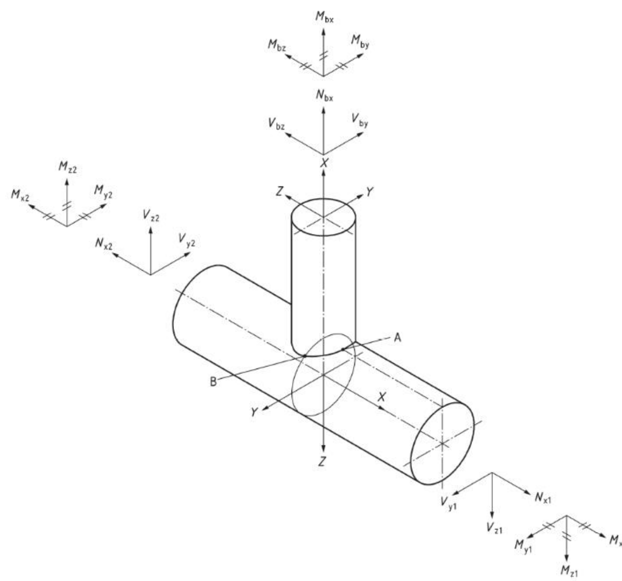


Figure 24 — Symbols for T-pieces

- As per sec. 6.6.7, the stresses at the intersection of run pipe are calculated after combining the axial and shear stresses from the run pipe and branch element as follows.

$$(\Delta\sigma_a)_{\pm}(run\ intersection) = (\Delta\sigma_a)_{\pm}\ (run) + \Delta\sigma_a\ (branch) \qquad (63)$$

$$(\Delta\tau)_{\pm}(run\ intersection) = (\Delta\tau)_{\pm}\ (run) + \Delta\tau\ (branch) \qquad (64)$$

In CAEPIPE,

$$\Delta\sigma_a\ (branch) = \begin{cases}(\Delta\sigma_a)_+\ (branch) & if \quad |(\Delta\sigma_a)_+| > |(\Delta\sigma_a)_-| \\ (\Delta\sigma_a)_-\ (branch) & if \quad |(\Delta\sigma_a)_-| \geq |(\Delta\sigma_a)_+|\end{cases}$$

$$\Delta\tau\ (branch) = \begin{cases}(\Delta\tau)_+\ (branch) & if \quad |(\Delta\tau)_+| > |(\Delta\tau)_-| \\ (\Delta\tau)_-\ (branch) & if \quad |(\Delta\tau)_-| \geq |(\Delta\tau)_+|\end{cases}$$

Modeling buried pipe bilinear restraints

Longitudinal/Axial soil stiffness (sec. 6.5.3.1)

Cohesionless Soil	Cohesive Soil
For sandy soils, the ultimate axial load per unit length $F_u = \mu\left(\frac{1+K_o}{2}\pi D_c \sigma_v + G - \gamma_s \cdot \pi\left(\frac{D_c}{2}\right)^2\right)$ (8) where, K_o = coefficient of horizontal soil pressure at rest $K_o = 1 - \sin\varphi'$ φ' - the effective angle of Internal friction of soil σ_v - Effective (normal) intergranular soil stress at pipe center level. $\mu = \tan\delta$ (12) is the friction coefficient, sec.6.5.3.2 δ = Angle of interface friction between soil and (casing) pipe.	The ultimate axial/longitudinal load per unit length $F_u = \pi\, D_c C_f \cdot C_s$ where F_u - Ultimate axial soil load C_s – Cohesion strength. C_f - Cohesion factor

For granular soils

$$\sigma_v = \gamma_s H_w + \gamma_{sw}(Z - H_w) \text{ for } H_w < Z \qquad (9)$$

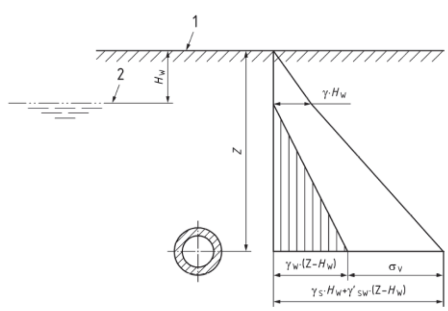
$$\sigma_v = \gamma_s Z \text{ for } H_w \geq Z \qquad (10)$$

$$\gamma_{sw} = \gamma'_{sw} - \gamma_w \qquad (11)$$

D_c = Outer diameter of the casing
G = Effective self-weight of the factory-made pipe assembly (including pipe fill) per meter of pipe length
γ_s= Effective weight of soil above ground water table
γ_{sw} = Effective weight of soil below ground water table $= \gamma'_{sw} - \gamma_w$
γ'_{sw} = Effective weight of saturated soil below ground water table
γ_w = Effective weight of water
Z = Depth of buried pipe (measured to pipe centerline)
H_w = Depth of ground water table below grade

For sandy soils, the relative displacement u_u between the pipe and surrounding soil required to reach the maximum friction resistance *f*u is approx. u_u = 3 mm = 0.003m.

Axial soil stiffness = F_u/u_u



Key
1 grade
2 groundwater table

Figure 8 — Calculation of effective soil stress

Horizontal/Lateral soil stiffness (sec. 6.5.4.1)

The coefficient of horizontal/lateral soil reaction or horizontal/lateral bedding constant is defined as the ratio between horizontal/lateral soil pressure and horizontal/lateral movement of the pipe system.

The ultimate horizontal/lateral soil resistance P_u is assessed using the equivalent equation for side support:

Cohesionless Soil	Cohesive Soil
For sandy soils, the ultimate horizontal/lateral load per unit length $P_u = \gamma \cdot Z \cdot K_q \cdot D_c$ (16) γ = Soil density Z = depth of buried pipe (measured to pipe centerline) K_q = soil pressure coefficient for sand (Fig 10)	The ultimate horizontal/lateral load per unit length $P_u = \left(K_q \cdot \gamma \cdot Z + 0.7\,\alpha \cdot K_c \cdot c'\right) \cdot D_c$ (17) α = 0.6, in case of open excavation; and α =1.0, in case of jacking methods; $c' = C_f \cdot C_s$ Effective cohesion of the soil K_c = soil pressure coefficient for clay (Fig 10)

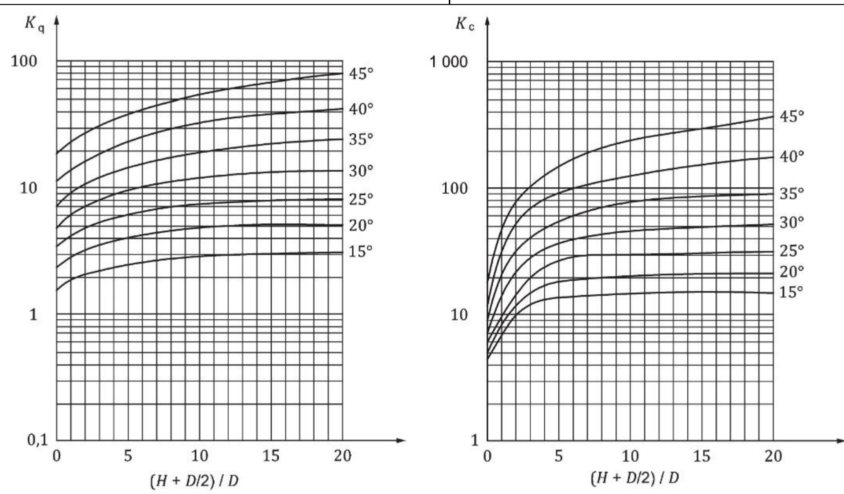


Figure 10 — Soil pressure coefficient K_q (and K_c) for sandy (and clay) soils

In Figure 10 the values on the right side (45°, 30°, etc.) represent the effective internal angle of friction of the soil φ', H is soil cover above pipe (see Figure 5 in EN13941-1) and D is considered as outer diameter of casing Dc (see Figure 13 in EN13941-1).

The ultimate horizontal/lateral displacement v_u is not defined precisely. The results of a number of tests with small diameter pipes are summarized in Table 12.

Table 12 – Ultimate horizontal/lateral displacement v_u

v_u/Z %		
Casing Diameter Dc	Loose sand	Dense sand
75 mm[a]	4.5	2.7
120 mm	3	2
≥ 300 mm	2	1.5
Values obtained by interpolation.		

For buried pipes without expansion cushions, a fair relationship between horizontal pipe movement and corresponding soil restraint is given by

$$\frac{p}{p_u} = \frac{v/v_u}{0.15 + 0.85\, v/v_u} \qquad (15)$$

At 70% of ultimate horizontal load i.e., $p/p_u = 0.7$, the horizontal displacement is calculated as

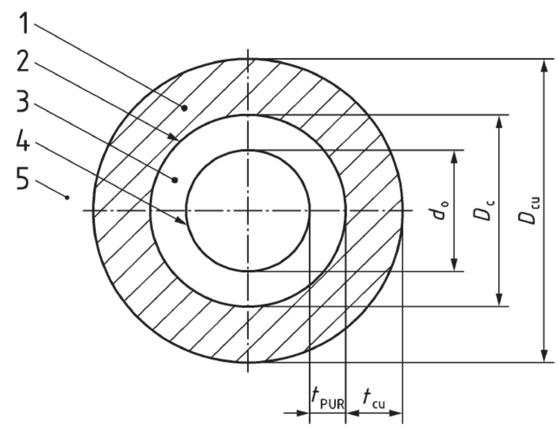
$$0.7(0.15 + 0.85\, v/v_u) = v/v_u$$

$$v_{70\%} = 0.2593\, v_u$$

Vertical soil stiffnesses

To compute vertically upward and downward stiffnesses, the ultimate loads in vertical direction are considered as the same as those for other piping codes in CAEPIPE. For details, refer to the Section titled "Buried Piping" in the Technical Reference Manual. The vertical yield displacement for the soil is assumed to be D/25, where D is the outside diameter of the pipe.

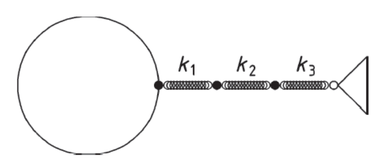
Combined lateral stiffness of PUR, expansion cushions and soil (sec. 6.5.5)



Key

1 cushion
2 casing
3 PUR
4 steel
5 soil

Figure 13 — Symbols for bedding constants



Key

k_1 line bedding constant for PUR
k_2 line bedding constant for expansion cushion
k_3 line bedding constant for surrounding soil

Figure 14 — Combined soil spring constant

PUR	Cushion	Soil	Combined
$k_{h,1} = \frac{E_{pur}}{t_{pur}}$ (19a) $k_1 = k_{h,1} d_o$ (19b)	$k_{h,2} = \frac{E_{cu}}{t_{cu}}$ (20a) $k_2 = k_{h,2} D_c$ (20b)	$k_{h,3} = \frac{0.7\, p_u}{v_{70\%}}$ (21a) $k_3 = k_{h,3} D_{cu}$ (21b)	$\frac{1}{k} = \sum \frac{1}{k_i}$ (22)

where,
d_o = Outside diameter of steel service pipe
D_c = Outer diameter of casing
D_{cu}= Equivalent outside diameter of expansion cushion.

Polyurethane foam thermal insulation (sec. 5.3)

In CAEPIPE, for EN13941-1 code, the insulation for pipe is considered as PUR, and the elastic modulus for PUR is internally set as $E_{PUR} = 10.0\ MPa$.

The elastic modulus E_{cu} for expansion cushion shall be input in soil dialog as per section 5.6.3.

NOTE 1: The above methodology of combining stiffnesses of PUR, expansion cushions and soil is also applied in the vertically downward and upward directions.

NOTE 2: Expansion Cushion is very flexible, whereas PUR is stiffer. Surrounding soil is much stiffer than PUR. So, the line bedding constant 'k_2' for Expansion Cushion is much less than the line bedding constant 'k_1' for PUR, which, in turn, is much less than the line bedding constant 'k_3' for the surrounding soil, where the line bedding constant is the same as stiffness. In short, $k_2 << k_1 <<< k_3$.

The combined stiffness 'k' computed using Equation (22) will be less than the Expansion Cushion stiffness, 'k_2'. Due to this low value of combined stiffness 'k', sometimes non-linear iterative solution may not converge. In such case of non-convergence, re-perform the analysis without including Expansion Cushion. If the solution still not converges, then re-perform with just surrounding soil (i.e., without including stiffnesses of both PUR and Expansion Cushion). In this case, the weight per unit length of insulation PUR shall be input as "Additional weight" in CAEPIPE's Loads dialog.

C.2 Flexibility factors for pipe components (see Annex C)

C.2.1 Bends

Flexibility Factor for bending (in-plane & out-of-plane)	Bend Radius	Equation
$k_b = \frac{1.24 \cdot d_m^2}{4 \cdot t_n \cdot R} \geq 1$	$R \leq 1.5\, d_o$	$(C.1)$
$\frac{1.24 \cdot d_m^2}{4 \cdot t_n \cdot R} < k_b < \frac{1.65 \cdot d_m^2}{4 \cdot t_n \cdot R}$	$1.5\, d_o < R < 2.5 d_o$	$(C.2)$
$k_b = \frac{1.65 \cdot d_m^2}{4 \cdot t_n \cdot R}$	$R \geq 2.5 d_o$	$(C.3)$

The stiffening effect of adjacent straight pipes is included in the factor k_b given by Eq. (C.1). Such stiffening effect by adjacent straight pipes is less for larger radii bends for which Eq. (C.2) and Eq. (C.3) apply.

Intervening values are obtained by interpolation. For bend angles between 90° and 0°, the flexibility factor k_b for bending is linearly interpolated between flexibility factors for 90° bend and for straight pipe $(i.e., k_b = 1)$. The flexibility factors for normal forces, shear forces and torque are equal to 1.0.

For pipe bends, the internal pressure will counteract ovalization. This is considered by dividing k_b with

$$1 + 6\frac{p}{E}\left(\frac{d_m}{2t}\right)^{7/3}\left(\frac{d_m}{2R}\right)^{-1/3} \qquad (C.4)$$

For miter bends, the flexibility factors are not provided in EN 13941-1 (2021). Hence, the flexibility factor as given in ASME B31J (2017) is used for all types of miter bends.

$$k_b = 1.52\left(\frac{d_m^2}{4 \cdot t_n \cdot R}\right)^{5/6}$$

C.2.2 T-pieces

The flexibility factor for T pieces equals 1.

For $d_{bo}/d_{ro} \leq 0.8$ the flexibility of the connection between the branch pipe and run pipe may be taken into account by applying the following spring factor to the branch pipe at the point where the axis of the branch intersects the outside of the run pipe.

For in-plane bending, M_{by},

$$c_y = \frac{E \cdot I_b}{k_y \cdot d_{ro}} \qquad (C.5)$$

$$k_y = 0.2\left(\frac{d_{ro}}{t_r}\right) \cdot \left(\frac{t_r}{t_b} \cdot \frac{d_{bo}}{d_{ro}}\right)^{0.5} \cdot \frac{t_b}{t_r} \qquad (C.6)$$

For out-of-plane bending, M_{bz},

$$c_z = \frac{E \cdot I_b}{k_z \cdot d_{ro}} \qquad (C.7)$$

$$k_z = 0.1\left(\frac{d_{ro}}{t_r}\right)^{1.5} \cdot \left(\frac{t_r}{t_b} \cdot \frac{d_{bo}}{d_{ro}}\right)^{0.5} \cdot \frac{t_b}{t_r} \qquad (C.8)$$

Note: CAEPIPE automatically refines the elements connected to the node point with a defined tee, by adding two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Pipe OD and one (1) node on Branch Pipe at a distance equal to Run pipe OD/2 from the Branch SIF node. Flexibility Factors for Branch Pipe (Leg 3), as stated above in equations (C.5) – (C-8), are applied to the branch pipe. **For Equal TEEs, the Run and Branch should be differentiated in the CAEPIPE model by defining the Branch OD as slightly less than the Run OD through CAEPIPE Sections input.**

C.3 Stress concentration factors in pipe elements

Note: The stress concentration factors $\boldsymbol{i_{a1}}$ to $\boldsymbol{i_{a5}}$ and $\boldsymbol{i_{ap}}$ are either = 0 or >= 1 for all types of stress evaluation. Stress concentration factors = 0, meaning “no contribution of the term in computing stresses”.

C.3.2.1 Stress concentration factors for bends and miter bends: Simplified method

Table C.1 Stress concentration factors for bends

	i_{a1}	i_{a2}	i_{a3}	i_{a4}	i_{a5}	i_{ap}
S_m	1	$0.9 \cdot \left(\frac{d_m^2}{4t_nR}\right)^{2/3}$	1	1	0	$\frac{R-0.25d_i}{R-0.5d_m}$
S_{res}	1	$0.9 \cdot \left(\frac{d_m^2}{4t_nR}\right)^{2/3}$	1	1	$1.8 \cdot \left(\frac{d_m^2}{4t_nR}\right)^{2/3}$	$\frac{R-0.25d_i}{R-0.5d_m}$

If the bracing effect of over pressure has been considered when calculating the flexibility of the pipe bend,

i_{a2} and i_{a5} shall be divided by *f, where*

$$f = 1 + 3.25\frac{p}{E}\left(\frac{d_m}{2t}\right)^{5/2}\left(\frac{d_m}{2R}\right)^{-2/3} \qquad (C.9)$$

with i_{a2} and i_{a5} valued at a minimum of 1.0 after the above division.

C.3.3 T-pieces

Table C.3 Stress concentration factors for membrane stresses in point B of T-pieces (all types)

Membrane stresses S_m	i_{a1}	i_{a2}	i_{a3}	i_{a4}
Run pipe	$r_r \cdot k_2$	$r_r \cdot k_1$	$2r_r \cdot k_1$	$r_r \cdot k_1$
Branch pipe	$r_b \cdot k$	$r_b \cdot k$	$r_b \cdot k$	$r_b \cdot k$

Table C.4 – T-pieces: Stress concentration factors for resulting stresses in point B

Resulting stresses S_{res}	i_{a1}	i_{a2}	i_{a3}	i_{a4}
Directly welded T-piece	**CAEPIPE: Unreinforced fabricated Tee**			
Run pipe	$1.2k_2$	k_1	$2k_1$	k_1
Branch pipe	k	k	k	k
Forged T-piece	**CAEPIPE: Welding Tee**			
Run pipe	$0.7k_2$	$0.6k_1$	$1.2k_1$	$0.6k_1$
Branch pipe	$0.4k$	$0.4k$	$0.4k$	$0.4k$
T-piece with drawn collar	**CAEPIPE: Extruded Tee**			
Run pipe	$0.8k_2$	$0.7k_1$	$1.4k_1$	$0.7k_1$
Branch pipe	$0.7k$	$0.7k$	$0.7k$	$0.7k$

$$k_1 = 0.523\left(\frac{1}{d_{rm}}\right)^{1/3}\left(\frac{1}{t_r}\right)^{2/3} d_{bm} + 2.5\left(1-\frac{d_{bm}}{d_{rm}}\right)^{3/2} \qquad (C.17)$$

$$k_2 = 0.65\left(\frac{1}{d_{rm}}\right)^{5/6}\left(\frac{1}{t_r}\right)^{2/3}(d_{bm})^{3/2} + 2.5\left(1-\frac{d_{bm}}{d_{rm}}\frac{t_b}{t_r}\right)^{9/5}$$

$$k = 0.567 \left(\frac{d_{rm}}{t_r}\right)^{2/3}$$

Reduction factors for membrane stresses:

$$r_r = 0.56 \, \frac{t_b}{t_r} \left(2 - \frac{d_{bm}}{d_{rm}}\right)^{5/3} \quad (C.18)$$

$$r_b = 0.83 \sqrt{\frac{d_{bm}}{d_{rm}}} \text{ for } N_b \leq \frac{1}{d_{bm}}\left(\sqrt{M_{by}^2 + M_{bz}^2}\right) \quad (C.19)$$

$$r_b = 0.83 \text{ for } N_b > \frac{1}{d_{bm}}\left(\sqrt{M_{by}^2 + M_{bz}^2}\right)$$

Reducers

Reducers with defined radius of curvature r

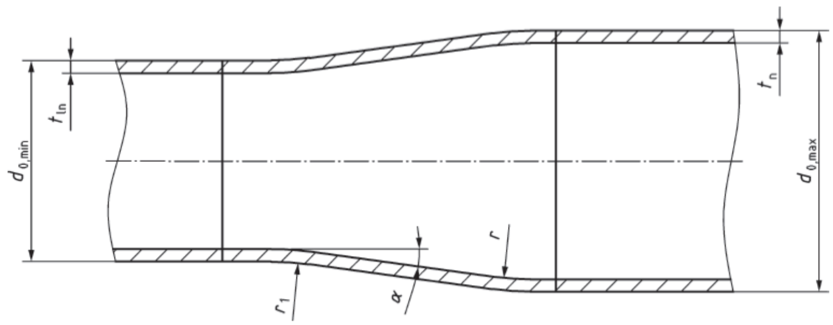


Figure C.2 — Reducer

Table C.6. Stress concentration factors for reducers

	i_{a1}	i_{a2}	i_{a3}	i_{a4}	i_{a5}	i_{ap}
S_m	1	1	1	0	0	1/cos α
S_{res}	k	k	1	0	0	1/cos α

$$k = 0.5 + 0.01 \cdot \alpha \sqrt{\frac{d_{o,min}}{t_{1n}}} \quad (C.21)$$

α is inserted in degrees. The expression for k is only valid if the following requirements are met:

the transitional part is concentric; $\alpha \leq 30^o$ and $d_{o,min}/t_{l,n}$ and $d_{o,max}/t_n$ are both smaller than 100.

Allowable Pressure

A.2.1 Straight pipes: For straight pipes, the allowable internal pressure is calculated from Equations (A.1) and (A.2):

$$P_a = \frac{2\sigma_d z t_{min}}{d_o} \qquad (A.1)$$

where,

$$t_{min} = t_n - (c_1 + c_2) \qquad (A.2)$$

P_a= allowable pressure

d_o= outside diameter of the pipe

z = joint efficiency factor

t_n= nominal wall thickness of the pipe.

c_1 = mill/fabrication tolerance (input as a % of thickness)

c_2= corrosion allowance

σ_d = allowable stress (i.e., design stress) = $R_e(T)$, yield stress at design temperature (sec 5.2.3.1), where design temperature is a CAEPIPE input

Note: The above allowable pressure calculated by CAEPIPE is valid only for pipes and components delivered with the required certificate as per sec. 5.2.2.

For pipes and components delivered without the required certificate, the allowable pressure P_a computed by CAEPIPE should be manually divided by $\gamma_{m,yield}$ = 1.2. (sec. 5.2.3.1)

A.2.2 Bends: The allowable internal pressure for bends is calculated as

$$P_a = \frac{2\sigma_d z\, t_{min}}{d_o I}$$

$$I = \frac{R - 0.25 d_i}{R - 0.5 d_m} \qquad (A.3)$$

d_i= inside diameter of the pipe

d_m= mean diameter of the pipe

A.4 Reducers and extensions: shall withstand the same internal pressure as the connecting pipes where the half angle α, at the apex of the component does not exceed 30 degrees,

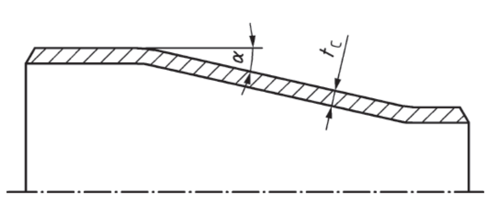


Figure A.2 — Reducer

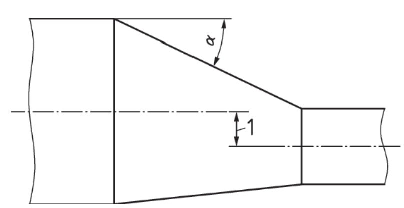


Figure A.3 — Offset reducer

The allowable internal pressure is calculated from

$$P_a = min\left\{\frac{2\sigma_d z\ \cos\alpha\ \ t_{n1,min}}{d_{o1}}, \frac{2\sigma_d z\ \cos\alpha\ \ t_{n2,min}}{d_{o2}}\right\}$$

where:

$t_{n1,min} = t_{n1} - (c_1 + c_2)$
$t_{n2,min} = t_{n2} - (c_1 + c_2)$
$t_{n1}, and\ t_{n2}$ is nominal wall thickness of pipe at inlet and outlet of reducer.
$d_{o1}, and\ d_{o2}$ is nominal outer diameter at inlet and outlet of reducer.

Note: CAEPIPE permits to model the reducers with $\alpha \leq 30^o$. Reducers with $\alpha > 30^o$ cannot be modeled, because the stress concetration factors are not explcitly given in C.3.5 for reducers with $\alpha > 30^o$.

Evaluation of Stresses

Stress components and internal forces as per sec. 6.6.2 of the code are defined as:

Axial stress

$$(\Delta\sigma_a)_+ = i_{a1}\frac{\Delta N_x}{A} + i_{a2}\frac{\sqrt{\Delta {M_y}^2 + \Delta {M_z}^2}}{W}$$

and

$$(\Delta\sigma_a)_- = i_{a1}\frac{\Delta N_x}{A} - i_{a2}\frac{\sqrt{\Delta {M_y}^2 + \Delta {M_z}^2}}{W}$$

Shear Stress

$$(\Delta\tau)_+ = i_{a3}\frac{\Delta M_x}{2W} + i_{a4}\frac{2\sqrt{\Delta {V_y}^2 + \Delta {V_z}^2}}{A}$$ and

$$(\Delta\tau)_- = i_{a3}\frac{\Delta M_x}{2W} - i_{a4}\frac{2\sqrt{\Delta {V_y}^2 + \Delta {V_z}^2}}{A}$$

Membrane Tangential Stress

$$(\Delta\sigma_t)_m = i_{ap}\frac{p \cdot d_i}{2t_{min}}$$

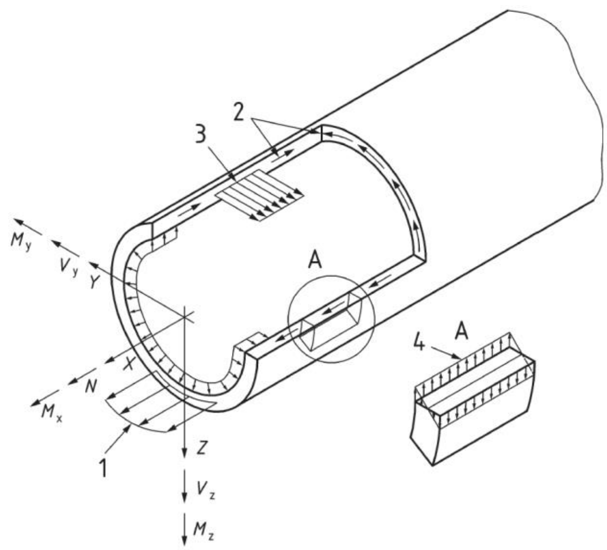


Figure 21 — Stress components and internal forces

(Membrane + Bending) Tangential Stress

$$(\Delta\sigma_t)_{mb} = i_{ap}\frac{p \cdot d_i}{2t_{min}} + i_{a5}\frac{\sqrt{\Delta {M_y}^2 + \Delta {M_z}^2}}{W} + \sigma_q$$

The equivalent stress as per sec. 6.6.3 is calculated from the axial and tangential stress components (calculated with sign) by von Mises for either membrane stress or membrane + bending stress (***m***|***mb***)

$$\boldsymbol{S_{m|mb}} = \boldsymbol{max}\left\{S1_{m|mb}, S2_{m|mb}, S3_{m|mb}, S4_{m|mb}, |(\Delta\sigma_a)_+|, |(\Delta\sigma_a)_-|\right\}$$

where,

$$S1_{m|mb} = \sqrt{(\Delta\sigma_a)_+^2 - (\Delta\sigma_a)_+ \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_+^2}$$

$$S2_{m|mb} = \sqrt{(\Delta\sigma_a)_-^2 - (\Delta\sigma_a)_- \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_+^2}$$

$$S3_{m|mb} = \sqrt{(\Delta\sigma_a)_+^2 - (\Delta\sigma_a)_+ \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)_{m|mb}^2 + 3(\Delta\tau)_-^2}$$

$$S4_{m|mb} = \sqrt{(\Delta\sigma_a)^2 - (\Delta\sigma_a) \cdot (\Delta\sigma_t)_{m|mb} + (\Delta\sigma_t)^2_{m|mb} + 3(\Delta\tau)^2}$$

N_x = Axial force (positive for tension), (pressure, temperature and soil reaction)
M_x = Torsional moment
M_y and M_z = Bending moment
A = Metal area of pipe
W = Section modulus
V_y and V_z = Shear force
p = Internal pressure
d_i = Inside diameter of the steel service pipe.
t_{min} = Minimum pipe wall thickness = $t_n - (c_1 + c_2)$
i_{a1} = Stress concentration factor for axial stresses from normal force
i_{a2} = Stress concentration factor for axial stresses from bending moments
i_{a3} = Stress concentration factor for shear stresses from torsion
i_{a4} = Stress concentration factor for shear stresses from shear force
i_{ap} = Stress concentration factor for hoop stresses from pressure

Area and section modulus are calculated, as per 6.6.2, as follows:

$$A = \pi \times (d_o - t_n) \times t_n \quad (45)$$

$$W = \frac{\pi}{32 \times d_o}[d_o^4 - (d_o - 2t_n)^4] \quad (46)$$

d_o = Outer diameter of the steel service pipe
t_n = nominal pipe wall thickness
c_1 = Correction to wall thickness for fabrication tolerance
c_2 = Correction to wall thickness for corrosion allowance

S_m = Membrane stress
S_{mb} = Resulting stress of membrane stress and bending stress

σ_a = Axial (normal) stress
σ_t = Tangential stress
τ = Shear stress
σ_p = Hoop stress from internal pressure
σ_q = Ovalisation stress from soil pressure, traffic, etc. to be manually computed by the user and input into soil model dialog of CAEPIPE at this time.

Forced Control Action LC2 (sec. 7.2.2.2);

In CAEPIPE, the LC2 case (both S_m and S_{res}) is evaluated for sustained loads (W+P) which include weight (of pipe, fluid, and insulation) ***at maximum operating pressure***. The displacements specified as settlement at anchor and nozzle locations are also included in force-controlled action.

3) **S_m = Membrane stress A1:**

$$S_m \leq S_{ma} \; (= R_e(T)/\gamma_m)$$

S_m = is the equilibrium membrane stress
S_{ma} = is the allowable membrane stress ($= R_e(T)/\gamma_m$)
$R_e(T)$ = Specific minimum yield strength ***at maximum operating temperature***
$\gamma_m = 1.25$ is the partial safety factor for the base material, as per sec. 7.2.2.2.

4) **S_{res} = Membrane + Bending stress A1:**

$$S_{res}(= S_{mb}) \leq S_{resa}$$

S_{res} ($= S_{mb}$) is the resulting stress of equilibrium membrane stress and equilibrium bending stress
S_{resa} = is the allowable resulting stress (including membrane + bending)

$$S_{resa} = \begin{cases} 1.5\,\dfrac{R_e(T)}{\gamma_m} & \text{for} \quad S_m \leq 0.67\,\dfrac{R_e(T)}{\gamma_m} \\ 2.5\,\dfrac{R_e(T)}{\gamma_m} - 1.5\,S_m & \text{for} \quad 0.67\,\dfrac{R_e(T)}{\gamma_m} \leq S_m \leq \dfrac{R_e(T)}{\gamma_m} \end{cases}$$

Note: The above stresses calculated by CAEPIPE is valid only for pipes and components delivered with the required certificate as per sec. 5.2.2, where $\gamma_m = 1.25$.

For pipes and components delivered without the required certificate, the allowable stresses should be calculated manually by the user with $\gamma_m = (1.2 * 1.25)$ as per sec.5.2.3.1

Stepwise plastic deformation LC3 (sec. 7.2.2.3);

In CAEPIPE, the LC3 case is evaluated for each operating load case (Weight of pipe, fluid & insulation + Pressure + Temperature) and ***at each set of operating pressure and temperature***.

S_{pd} = Force + Deformation stress A2

Limit state A2 concerns incremental collapse and stress ratcheting. The limit state for stress ratcheting for fully restrained sections is obtained from:

$$S_{pd} \leq S_{pda}$$

S_{pd} is the maximum of axial stress due to plastic deformation.

$$S_{pd} = \boldsymbol{max}\{(\Delta\sigma_a)_+, (\Delta\sigma_a)_-\}$$

The allowable/limit state for stress ratcheting for fully restrained sections is obtained from:

$$S_{pda} = R_e(T)\left[\sqrt{1 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2} + \sqrt{\gamma^2 - \frac{3}{4}\left(\frac{\sigma_p}{R_e(T)}\right)^2}\right]$$

$R_e(T)$ = Specific minimum yield strength ***at operating temperature***

σ_p ($= Pd_o/2zt_{min}$) = hoop stress ***at operating pressure***. (eqn. 78)

γ = 0.7, is a safety factor

Note: EN13941-1:2019 does not specify stress concentration factors for calculating S_{pd}. In CAEPIPE, the stress concentration factors for S_{pd} calculations are considered the same as those for resulting stresses for each component given in Tables C1, C3, C4, and C6.

TEES

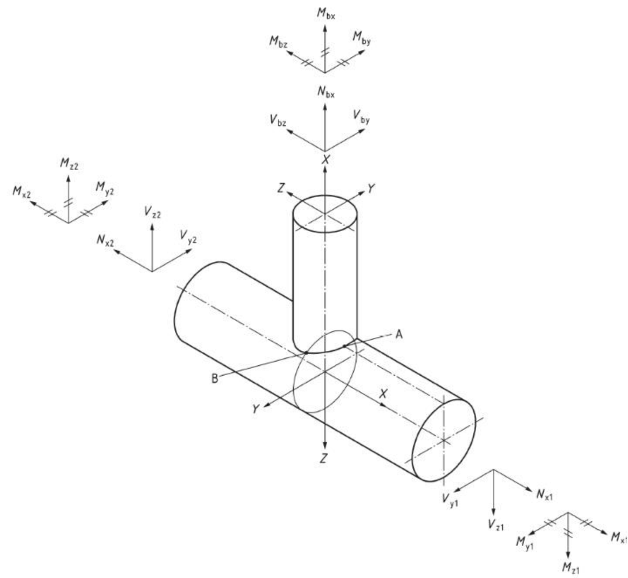


Figure 24 — Symbols for T-pieces

- In CAEPIPE, σ and τ are calculated separately for run pipe and branch pipe with sectional forces chosen as follows:

  For stresses in the run pipe, the forces and moments determined in the run at the intersection between the centerlines of the pipes are used.

  For stresses in the branch pipe, the forces and moments determined in the branch at a distance of $0.5\ d_{ro}$ from the centreline of the run pipe are used.

  Note: CAEPIPE automatically refines the elements connected to the node point with a defined tee. Two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Pipe OD and one (1) node on Branch Pipe at a distance equal to Run pipe OD/2 from the Branch SIF node are internally added with appropriate node numbers.

- As per sec. 6.6.7, the stresses at the intersection of run pipe are calculated after combining the axial and shear stresses from the run pipe and branch element as follows.

$$(\Delta\sigma_a)_{\pm}(run\ intersection) = (\Delta\sigma_a)_{\pm}\ (run) + \ \Delta\sigma_a\ (branch) \qquad (63)$$

$$(\Delta\tau)_{\pm}(run\ intersection) = (\Delta\tau)_{\pm}\ (run) + \Delta\tau\ (branch) \qquad (64)$$

In CAEPIPE,

$$\Delta\sigma_a\ (branch) = \begin{cases} (\Delta\sigma_a)_{+}\ (branch) & if \quad |(\Delta\sigma_a)_{+}| > |(\Delta\sigma_a)_{-}| \\ (\Delta\sigma_a)_{-}\ (branch) & if \quad |(\Delta\sigma_a)_{-}| \geq |(\Delta\sigma_a)_{+}| \end{cases}$$

$$\Delta\tau\ (branch) = \begin{cases} (\Delta\tau)_{+}\ (branch) & if \quad |(\Delta\tau)_{+}| > |(\Delta\tau)_{-}| \\ (\Delta\tau)_{-}\ (branch) & if \quad |(\Delta\tau)_{-}| \geq |(\Delta\tau)_{+}| \end{cases}$$

Modeling buried pipe bilinear restraints

Longitudinal/Axial soil stiffness (sec. 6.5.3.1)

<table>
<tr><th>Cohesionless Soil</th><th>Cohesive Soil</th></tr>
<tr><td>For sandy soils, the ultimate axial load per unit length
$F_u = \mu\left(\frac{1+K_o}{2}\pi D_c \sigma_v + G - \gamma_s \cdot \pi\left(\frac{D_c}{2}\right)^2\right)$ (8)
where,
K_o = coefficient of horizontal soil pressure at rest
$K_o = 1 - \sin\varphi'$
φ' - the effective angle of Internal friction of soil
σ_v - Effective (normal) intergranular soil stress at pipe center level.
$\mu = \tan\delta$ (12)
is the friction coefficient, sec.6.5.3.2
δ = Angle of interface friction between soil and (casing) pipe.</td><td>The ultimate axial/longitudinal load per unit length
$F_u = \pi D_c C_f \cdot C_s$

where
F_u - Ultimate axial soil load
C_s – Cohesion strength.
C_f - Cohesion factor</td></tr>
</table>

For granular soils

$$\sigma_v = \gamma_s H_w + \gamma_{sw}(Z - H_w) \text{ for } H_w < Z \quad (9)$$

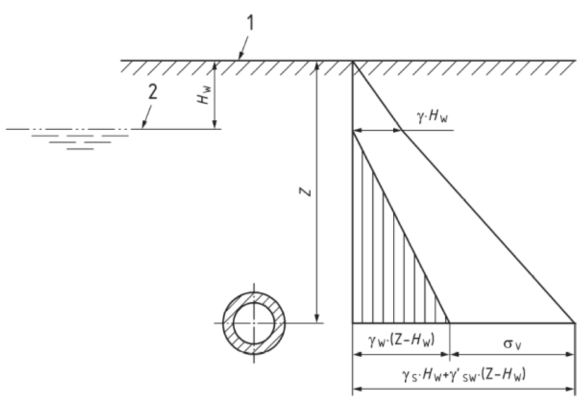
$$\sigma_v = \gamma_s Z \text{ for } H_w \geq Z \quad (10)$$

$$\gamma_{sw} = \gamma'_{sw} - \gamma_w \quad (11)$$

D_c = Outer diameter of the casing
G = Effective self-weight of the factory-made pipe assembly (including pipe fill) per meter of pipe length
γ_s= Effective weight of soil above ground water table
γ_{sw} = Effective weight of soil below ground water table $= \gamma'_{sw} - \gamma_w$
γ'_{sw} = Effective weight of saturated soil below ground water table
γ_w = Effective weight of water
Z = Depth of burial (measured to centerline of pipe assembly)
H_w = Depth of ground water table below grade

For sandy soils, the relative displacement u_u between the pipe and surrounding soil required to reach the maximum friction resistance *f*u is approx. u_u = 3 mm = 0.003m.

Axial soil stiffness = F_u/u_u



Key
1 grade
2 groundwater table

Figure 8 — Calculation of effective soil stress

Horizontal/Lateral soil stiffness (sec. 6.5.4.1)

The coefficient of horizontal/lateral soil reaction or horizontal/lateral bedding constant is defined as the ratio between horizontal/lateral soil pressure and horizontal/lateral movement of the pipe system.

The ultimate horizontal/lateral soil resistance P_u is assessed using the equivalent equation for side support:

Cohesionless Soil	Cohesive Soil
For sandy soils, the ultimate horizontal/lateral load per unit length $P_u = \gamma \cdot Z \cdot K_q \cdot D_c$ (16) γ = Soil density Z = depth of the buried pipe K_q = soil pressure coefficient for sand (Fig 10)	The ultimate horizontal/lateral load per unit length $P_u = \left(K_q \cdot \gamma \cdot Z + 0.7\ \alpha \cdot K_c \cdot c'\right) \cdot D_c$ (17) α = 0.6, in case of open excavation; and α =1.0, in case of jacking methods; $c' = C_f \cdot C_s$ Effective cohesion of the soil K_c = soil pressure coefficient for clay (Fig 10)

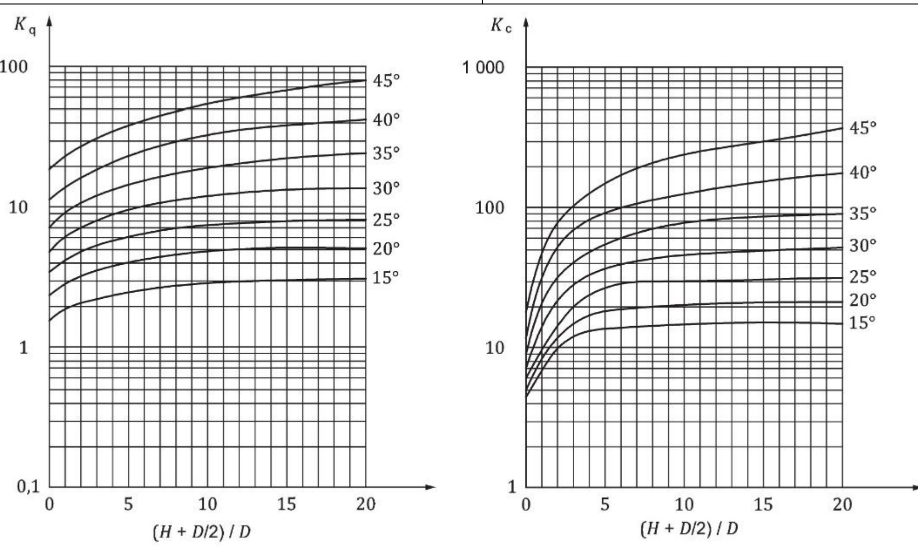


Figure 10 — Soil pressure coefficient K_q (and K_c) for sandy (and clay) soils

In Figure 10 the values on the right side (45°, 30°, etc.) represent the effective internal angle of friction of the soil φ', H is soil cover above pipe (see Figure 5 in EN13941-1) and D is considered as outer diameter of casing Dc (see Figure 13 in EN13941-1).

The ultimate horizontal/lateral displacement v_u is not defined precisely. The results of a number of tests with small diameter pipes are summarized in Table 12.

Table 12 – Ultimate horizontal/lateral displacement v_u

v_u/Z %		
Casing Diameter Dc	Loose sand	Dense sand
75 mm[a]	4.5	2.7
120 mm	3	2
≥ 300 mm	2	1.5
Values obtained by interpolation.		

For buried pipes without expansion cushions, a fair relationship between horizontal pipe movement and corresponding soil restraint is given by

$$\frac{p}{p_u} = \frac{v/v_u}{0.15 + 0.85\, v/v_u} \tag{15}$$

At 70% of ultimate horizontal load i.e., $p/p_u = 0.7$, the horizontal displacement is calculated as

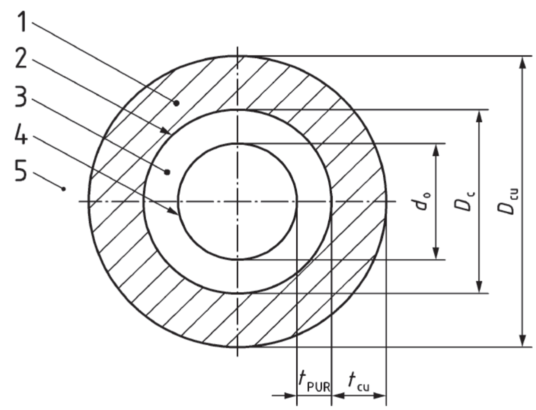
$$0.7(0.15 + 0.85\, v/v_u) = v/v_u$$

$$v_{70\%} = 0.2593\, v_u$$

Vertical soil stiffnesses

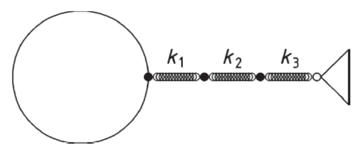
To compute vertically upward and downward stiffnesses, the ultimate loads in vertical direction are considered as the same as those for other piping codes in CAEPIPE. For details, refer to the Section titled "Buried Piping" in the Technical Reference Manual. The vertical yield displacement for the soil is assumed to be D/25, where D is the outside diameter of the pipe.

Combined lateral stiffness of PUR, expansion cushions and soil (sec. 6.5.5)



Key
1 cushion
2 casing
3 PUR
4 steel
5 soil

Figure 13 — Symbols for bedding constants



Key
k_1 line bedding constant for PUR
k_2 line bedding constant for expansion cushion
k_3 line bedding constant for surrounding soil

Figure 14 — Combined soil spring constant

PUR	Cushion	Soil	Combined
$k_{h,1} = \frac{E_{pur}}{t_{pur}}$ (19a) $k_1 = k_{h,1} d_o$ (19b)	$k_{h,2} = \frac{E_{cu}}{t_{cu}}$ (20a) $k_2 = k_{h,2} D_c$ (20b)	$k_{h,3} = \frac{0.7\, p_u}{v_{70\%}}$ (21a) $k_3 = k_{h,3} D_{cu}$ (21b)	$\frac{1}{k} = \sum \frac{1}{k_i}$ (22)

where,
d_o = Outside diameter of steel service pipe
D_c = Outer diameter of casing
D_{cu}= Equivalent outside diameter of expansion cushion.

Polyurethane foam thermal insulation (sec. 5.3)

In CAEPIPE, for EN13941-1 code, the insulation for pipe is considered as PUR, and the elastic modulus for PUR is internally set as $E_{PUR} = 10.0\ MPa$.

The elastic modulus E_{cu} for expansion cushion shall be input in soil dialog as per section 5.6.3.

NOTE 1: The above methodology of combining stiffnesses of PUR, expansion cushions and soil is also applied in the vertically downward and upward directions.

NOTE 2: Expansion Cushion is very flexible, whereas PUR is stiffer. Surrounding soil is much stiffer than PUR. So, the line bedding constant 'k_2' for Expansion Cushion is much less than the line bedding constant 'k_1' for PUR, which, in turn, is much less than the line bedding constant 'k_3' for the surrounding soil, where the line bedding constant is the same as stiffness. In short, $k_2 << k_1 <<< k_3$.

The combined stiffness 'k' computed using Equation (22) will be less than the Expansion Cushion stiffness, 'k_2'. Due to this low value of combined stiffness 'k', sometimes non-linear iterative solution may not converge. In such case of non-convergence, re-perform the analysis without including Expansion Cushion. If the solution still not converges, then re-perform with just surrounding soil (i.e., without including stiffnesses of both PUR and Expansion Cushion). In this case, the weight per unit length of insulation PUR shall be input as "Additional weight" in CAEPIPE's Loads dialog.

C.2 Flexibility factors for pipe components (see Annex C)

C.2.1 Bends

Flexibility Factor for bending	Bend Radius	Equation
$k_b = \frac{1.24 \cdot d_m^2}{4 \cdot t_n \cdot R} \geq 1$	$R \leq 1.5\, d_o$	$(C.1)$
$\frac{1.24 \cdot d_m^2}{4 \cdot t_n \cdot R} < k_b < \frac{1.65 \cdot d_m^2}{4 \cdot t_n \cdot R}$	$1.5\, d_o < R < 2.5 d_o$	$(C.2)$
$k_b = \frac{1.65 \cdot d_m^2}{4 \cdot t_n \cdot R}$	$R \geq 2.5 d_o$	$(C.3)$

Intervening values are obtained by interpolation. For bend angles between 90° and 0°, the flexibility factor k_b for bending is linearly interpolated between flexibility factor at 90° and for straight pipe $(i.e., k_b = 1)$. The flexibility factor for normal forces, shear forces and torque equals 1.

For pipe bends, the internal pressure will counteract ovalization. This is considered by dividing k_b with

$$1 + 6\frac{p}{E}\left(\frac{d_m}{2t}\right)^{7/3}\left(\frac{d_m}{2R}\right)^{-1/3} \qquad (C.4)$$

For miter bends, the flexibility factors are not provided in EN 13941-1 (2019). Hence, the flexibility factor as given in ASME B31J (2017) is used for all types of miter bends.

$$k_b = 1.52\left(\frac{d_m^2}{4 \cdot t_n \cdot R}\right)^{5/6}$$

C.2.2 T-pieces

The flexibility factor for T pieces equals 1.

For $d_{bo}/d_{ro} \leq 0.8$ the flexibility of the connection between the branch pipe and run pipe may be taken into account by applying the following spring factor to the branch pipe at the point where the axis of the branch intersects the outside of the run pipe.

For in-plane bending, M_{by},

$$c_y = \frac{E \cdot I_b}{k_y \cdot d_{ro}} \qquad (C.5)$$

$$k_y = 0.2\left(\frac{d_{ro}}{t_r}\right) \cdot \left(\frac{t_r}{t_b} \cdot \frac{d_{bo}}{d_{ro}}\right)^{0.5} \cdot \frac{t_b}{t_r} \qquad (C.6)$$

For out-of-plane bending, M_{bz},

$$c_z = \frac{E \cdot I_b}{k_z \cdot d_{ro}} \qquad (C.7)$$

$$k_z = 0.1\left(\frac{d_{ro}}{t_r}\right)^{1.5} \cdot \left(\frac{t_r}{t_b} \cdot \frac{d_{bo}}{d_{ro}}\right)^{0.5} \cdot \frac{t_b}{t_r} \qquad (C.8)$$

Note: CAEPIPE automatically refines the elements connected to the node point with a defined tee, by adding two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Pipe OD and one (1) node on Branch Pipe at a distance equal to Run pipe OD/2 from the Branch SIF node. Flexibility Factors for Branch Pipe (Leg 3), as stated above in equations (C.5) – (C-8), are applied to the branch pipe. **For Equal TEEs, the Run and Branch should be differentiated in the CAEPIPE model by defining the Branch OD as slightly less than the Run OD through CAEPIPE Sections input.**

C.3 Stress concentration factors in pipe elements

Note: The stress concentration factors $\boldsymbol{i_{a1}}$ to $\boldsymbol{i_{a5}}$ and $\boldsymbol{i_{ap}}$ are either = 0 or >= 1 for all types of stress evaluation. Stress concentration factors = 0, meaning "no contribution of the term in computing stresses".

C.3.2.1 Stress concentration factors for bends and miter bends: Simplified method

Table C.1 Stress concentration factors for bends

	i_{a1}	i_{a2}	i_{a3}	i_{a4}	i_{a5}	i_{ap}
S_m	1	$0.9 \cdot \left(\frac{d_m^2}{4t_nR}\right)^{2/3}$	1	1	0	$\frac{R-0.25d_i}{R-0.5d_m}$
S_{res}	1	$0.9 \cdot \left(\frac{d_m^2}{4t_nR}\right)^{2/3}$	1	1	$1.8 \cdot \left(\frac{d_m^2}{4t_nR}\right)^{2/3}$	$\frac{R-0.25d_i}{R-0.5d_m}$

If the bracing effect of over pressure has been considered when calculating the flexibility of the pipe bend,

$\boldsymbol{i_{a2}}$ and $\boldsymbol{i_{a5}}$ shall be divided by *f*

$$f = 1 + 3.25\frac{p}{E}\left(\frac{d_m}{2t}\right)^{5/2}\left(\frac{d_m}{2R}\right)^{-2/3} \qquad (C.9)$$

With $\boldsymbol{i_{a2}}$ and $\boldsymbol{i_{a5}}$ valued at a minimum of 1.0 after the above division.

C.3.3 T-pieces

Table C.3 Stress concentration factors for membrane stresses in point B of T-pieces (all types)

Membrane stresses $\boldsymbol{S_m}$	$\boldsymbol{i_{a1}}$	$\boldsymbol{i_{a2}}$	$\boldsymbol{i_{a3}}$	$\boldsymbol{i_{a4}}$
Run pipe Branch pipe	$r_r \cdot k_2$ $r_b \cdot k$	$r_r \cdot k_1$ $r_b \cdot k$	$2r_r \cdot k_1$ $r_b \cdot k$	$r_r \cdot k_1$ $r_b \cdot k$

Table C.4 – T-pieces: Stress concentration factors for resulting stresses in point B

Resulting stresses $\boldsymbol{S_{res}}$	$\boldsymbol{i_{a1}}$	$\boldsymbol{i_{a2}}$	$\boldsymbol{i_{a3}}$	$\boldsymbol{i_{a4}}$
Directly welded T-piece	**CAEPIPE: Unreinforced fabricated Tee**			
Run pipe Branch pipe	$1.2k_2$ k	k_1 k	$2k_1$ k	k_1 k
Forged T-piece	**CAEPIPE: Welding Tee**			
Run pipe Branch pipe	$0.7k_2$ $0.4k$	$0.6k_1$ $0.4k$	$1.2k_1$ $0.4k$	$0.6k_1$ $0.4k$
T-piece with drawn collar	**CAEPIPE: Extruded Tee**			
Run pipe Branch pipe	$0.8k_2$ $0.7k$	$0.7k_1$ $0.7k$	$1.4k_1$ $0.7k$	$0.7k_1$ $0.7k$

$$k_1 = 0.523\left(\frac{1}{d_{rm}}\right)^{1/3}\left(\frac{1}{t_r}\right)^{2/3} d_{bm} + 2.5\left(1 - \frac{d_{bm}}{d_{rm}}\right)^{3/2} \qquad (C.17)$$

$$k_2 = 0.65\left(\frac{1}{d_{rm}}\right)^{5/6}\left(\frac{1}{t_r}\right)^{2/3} (d_{bm})^{3/2} + 2.5\left(1 - \frac{d_{bm}}{d_{rm}}\frac{t_b}{t_r}\right)^{9/5}$$

$$k = 0.567\left(\frac{d_{rm}}{t_r}\right)^{2/3}$$

Reduction factors for membrane stresses:

$$r_r = 0.56\,\frac{t_b}{t_r}\left(2 - \frac{d_{bm}}{d_{rm}}\right)^{5/3} \qquad (C.18)$$

$$r_b = 0.83\sqrt{\frac{d_{bm}}{d_{rm}}} \qquad (C.19)$$

Reducers

Reducers with defined radius of curvature r

Table C.6. Stress concentration factors for reducers

	i_{a1}	i_{a2}	i_{a3}	i_{a4}	i_{a5}	i_{ap}
S_m	1	1	1	0	0	1/cos α
S_{res}	k	k	1	0	0	1/cos α

$$k = 0.5 + 0.01 \cdot \alpha \sqrt{\frac{d_{o,min}}{t_{1n}}} \qquad (C.21)$$

α is inserted in degrees. The expression for k is only valid if the following requirements are met:

the transitional part is concentric; $\alpha \leq 30^o$ and $d_{o,min}/t_{l,n}$ and $d_{o,max}/t_n$ are both smaller than 100.

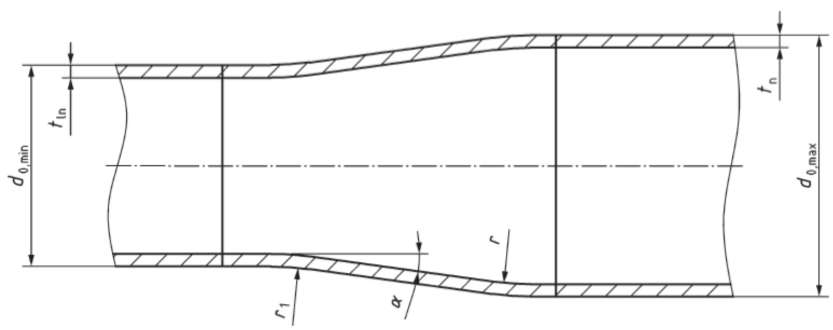


Figure C.2 — Reducer

Allowable Pressure

The allowable pressure for straight pipes is calculated from equation (6.1-1) or (6.1-3) depending on the ratio between outer and inner diameters.

For $D_o/D_i \leq 1.7$

$$P = \frac{2fze}{D_o - e}$$

For $D_o/D_i > 1.7$

$$P = fz\frac{(1-a^2)}{(1+a^2)}$$

where

P = allowable pressure

f = allowable stress at Design Temperature as input into CAEPIPE Material properties

z = joint factor (input as material property in CAEPIPE)

e = pipe wall thickness without allowances and tolerances

= nominal pipe thickness × (1 – mill tolerance/100 – corrosion allowance "c")

(In the pipe section where higher nominal thickness is ordered in order to accommodate either threading or grooving or erosion or any other thinning allowance, then such additional thickness required for threading/grooving/erosion/thinning etc. should be included in corrosion allowance "c" in CAEPIPE to compute allowable pressure for that pipe section.)

D_o = outer diameter

D_i = un-corroded inner diameter

a $= 1 - \frac{2e}{D_o}$

For pipe bends

Clause 6.2.1 of the code explicitly states "These calculation rules take into account that upon applying internal pressure to a pipe bend, higher stresses occur on the intrados of the bend (and lower stresses on the extrados of the bend) than on a straight pipe with identical wall thickness."

So, for pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}

$$e_{equi} = \frac{e}{t_f}$$

where

$$t_f = \left[\frac{R/D_o - 0.25}{R/D_o - 0.50}\right]$$

R = radius of bend

For closely spaced miter bends, the allowable pressure is calculated from equations (6.3.4-1) and (6.3.4-2).

$$P = min\left[\frac{fze^2}{r\left(e + 0.643\, tan\,\theta\,\sqrt{re}\right)}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] with\ \theta \leq 22.5^0$$

For widely spaced miter bends, the allowable pressure is calculated from equations (6.3.4-1), (6.3.4-2) and (6.3.5-1)

$$P = min\left[\frac{fze^2}{r\left(e + 0.643\, tan\,\theta\,\sqrt{re}\right)}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] with\ \theta \leq 22.5^0$$

$$P = \frac{fze^2}{r\left(e + 1.25\, tan\,\theta\,\sqrt{re}\right)} with\ \theta > 22.5^0$$

where

r = mean radius of pipe = $(D_o - \mathrm{e})/2$

R_S = effective bend radius of the miter

θ = miter half angle

Sustained Stress

The primary stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from equation (12.3.2-2)

$$\sigma_1 = \sqrt{\left|\frac{i_{QA}Q_{xA}}{A_c} + \frac{\sqrt{(0.75 i_i M_{iA})^2 + (0.75 i_o M_{oA})^2}}{Z_c}\right|^2 + \left[\frac{i_t M_{tA}}{Z_c}\right]^2} \leq f_f$$

where

Q_{xA} = max$\left[|Q_{xS}|, \left|\frac{P_c \pi d_{ic}^2}{4} + Q_{xS}\right|\right]$

$\frac{P_c \pi d_{ic}^2}{4}$ = internal pressure forces due to unrelieved axial expansion joints etc.

Q_{xS} = axial force from other sustained mechanical loads (such as pipe weight, fluid weight etc.) [excluding that from pressure]

P_c = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

d_{ic} = corroded inside diameter = d_o – (2.e_c)

d_o = outside diameter

e_c = corroded thickness = e_n – corrosion allowance

e_n = nominal pipe thickness

A_c = area of cross section of the corroded pipe = $\frac{\pi}{4}(d_o^2 - d_{ic}^2)$

M_{iA} = in-plane bending moment from the sustained mechanical loads [excluding that from pressure]

M_{oA} = out-of-plane bending moment from the sustained mechanical loads [excluding that from pressure]

M_{tA} = torsional moment from the sustained mechanical loads [excluding that from pressure]

i_{QA} = stress intensification factor for axial forces for sustained mechanical loads = 1.0

i_i = In-plane stress intensification factor from the Tables given at the end of this section

i_o = Out-of-plane stress intensification factor from the Tables given at the end of this section

i_t = stress intensification factor for torsional moments = 1.0

Z_c = corroded section modulus for pipe = $\frac{\pi}{32 d_o}(d_o^4 - d_{ic}^4)$;

for branch connections/reduced outlets, as per Table H.3 of EN 13480-3:2017/A2:2020,

$$Z_c = min\left[i\frac{\pi\left(\left(d_{m,b}+e_{n,b}\right)^4-\left(d_{m,b}+e_{n,b}-2e_{c,b}\right)^4\right)}{32\left(d_{m,b}+e_{n,b}\right)}, \frac{\pi}{4}\left(d_{m,b}+e_{n,b}\right)^2 e_c\right]$$

where i is taken as In-plane SIF i_i

f_f = min(f; f_{cr}) = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

f = min(Rp0.2t/1.5 ; Rm/2.4) at max(T1 through T10); f is input into CAEPIPE material properties

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into CAEPIPE material properties

Rp0.2t = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note: *Starting Version 7.50 of CAEPIPE, the value of "ff" is no longer input in the material properties table. Instead, the value of "f" which is calculated as min(Rp0.2t/1.5; Rm/2.4) is input for each temperature.*

If a stress model created using CAEPIPE version earlier than 7.50 is read into CAEPIPE Version 7.50 or later version, the material properties should be updated appropriately by the CAEPIPE User.

Sustained plus Occasional Stress

The primary stress (σ_2) due to sustained and occasional loads is calculated from equation (12.3.3-4) as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind. Wind and earthquake are not considered to act concurrently.

$$\sigma_2 = \sqrt{\left[\frac{i_{QA}Q_x}{A_c} + \frac{\sqrt{[0.75 i_i(M_{iA}+M_{iB})]^2 + [0.75 i_o(M_{oA}+M_{oB})]^2}}{Z_c}\right]^2 + \left[\frac{i_t M_{tA} + i_t M_{tB}}{Z_c}\right]^2} \leq k f_f$$

where

M_{iB} = in-plane bending moment from occasional or exceptional loads

M_{oB} = out-of-plane bending moment from occasional or exceptional loads

M_{tB} = torsional moment from occasional or exceptional loads

For reversing loads (unsigned occasional load cases, e.g. earthquake)

$Q_x = \max\left[|Q_{xA}| + |Q_{xB}|, \left|\frac{P_b \pi d_{ic}^2}{4} + Q_{xA}\right| + |Q_{xB}|\right]$ as per equation (12.3.3-2)

Both signs of M_{iB} and M_{oB} are considered

For non-reversing loads (signed occasional load cases, e.g. wind)

$Q_x = \max\left[|Q_{xA}|, |Q_{xA} + Q_{xB}|, \left|\frac{P_b \pi d_{ic}^2}{4} + Q_{xA}\right|, \left|\frac{P_b \pi d_{ic}^2}{4} + Q_{xA} + Q_{xB}\right|\right]$ as per equation (12.3.3-3)

P_b = Peak pressure during occasional loading = Peak Pressure Factor x P_c

P_c = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

Q_{xA} = axial force due to sustained mechanical loads [excluding that from pressure]

Q_{xB} = axial force due to occasional loads [excluding that from pressure]

A_c = area of cross section of the corroded pipe = $\frac{\pi}{4}(d_o^2 - d_{ic}^2)$

Z_c = corroded section modulus = $\frac{\pi}{32 d_o}(d_o^4 - d_{ic}^4)$;

for branch connections/reduced outlets, as per Table H.3 of EN 13480-3:2017/A2:2020,

$Z_c = min\left[i\frac{\pi\left((d_{m,b}+e_{n,b})^4 - (d_{m,b}+e_{n,b}-2e_{c,b})^4\right)}{32(d_{m,b}+e_{n,b})}, \frac{\pi}{4}\left(d_{m,b}+e_{n,b}\right)^2 e_c\right]$

where i is taken as In-plane SIF i_i

f_f = min(f; fcr) = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

f = min(Rp0.2t/1.5 ; Rm/2.4) at max(T1 through T10); f is input into CAEPIPE material properties

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into CAEPIPE material properties

Rp0.2t = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

k=1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE, the default value for k=1.2; user can change this default value through Layout window > Options > Analysis > Code > EN13480.

Note: *Starting Version 7.50 of CAEPIPE, the value of "ff" is no longer input in the material properties table. Instead, the value of "f" which is calculated as min(Rp0.2t/1.5; Rm/2.4) is input for each temperature.*

If a stress model created using CAEPIPE version earlier than 7.50 is read into CAEPIPE Version 7.50 or later version, the material properties should be updated appropriately by the CAEPIPE User.

Expansion Stress

The secondary stress (σ_3) due to thermal expansion is calculated from equation (12.3.4-3)

$$\sigma_3 = \sqrt{\left[\frac{i_{QC}Q_{xC}}{A} + \frac{\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}}{Z}\right]^2 + \left[\frac{i_t M_{tC}}{Z}\right]^2} \leq f_a$$

where
M_{iC} = in-plane moment range due to thermal expansion and alternating loads
M_{oC} = out-of-plane moment range due to thermal expansion and alternating loads
M_{tC} = torsional moment range due to thermal expansion and alternating loads
i_{QC} = stress intensification factor for axial forces due to thermal expansion and alternating loads = 1.0

Q_{xC} = range of axial force due to thermal expansion and alternating loads

e_n = nominal pipe thickness

d_o = outside diameter

d_i = inside diameter = $d_o - 2\ e_n$

A = un-corroded nominal area of cross-section = $\frac{\pi}{4}(d_o^2 - d_i^2)$
Z = un-corroded section modulus for pipe = $\frac{\pi}{32 d_o}(d_o^4 - d_i^4)$;

for branch connections/reduced outlets, as per Table H.3 of EN 13480-3:2017/A2:2020,

$$Z = min\left[i\frac{\pi\left(\left(d_{m,b}+e_{n,b}\right)^4 - \left(d_{m,b}-e_{n,b}\right)^4\right)}{32\left(d_{m,b}+e_{n,b}\right)}, \frac{\pi}{4}\left(d_{m,b} + e_{n,b}\right)^2 e_n\right]$$

where i is taken as In-plane SIF i_i

$f_a = U(1.25 f_c + 0.25 f_h)\frac{E_h}{E_c}$ as per equation (12.1.3-1)

U = cyclic stress range reduction factor taken from Table 12.1.3-1
E_C = modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

E_h = modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

f_c = min(R_m/3; f), where f = min($R_{p0.2t}$/1.5 ; R_m/2.4) at room temperature (T_{ref}) as per equation (12.1.3-2)

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration = min(f_c; f; f_{cr}) as per equation (12.1.3-3), with f_c determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration.

$\mathbf{f_{cr}}$ = design stress in creep range at max(T1 through T10); f_{cr} is input into CAEPIPE material properties

For example, for the thermal range (T1-T2), with T1 = 300^0 C, T2 = 100^0 C and T_{ref} = 21^{0}C, E_c is determined at T2 = 100^{0}C and E_h is determined at T1 =300^{0}C.

f_c as per Equation (12.1.3-2) listed above is determined at T_{ref} = 21^{0}C.

The value of f_c used in calculating f_h is determined at T2 = 100^{0}C [= min(100, 300)]; the value of f used in calculating f_h is determined at T1 = 300^0 C [= max(100, 300)] and the value of f_{cr} is taken at T1 = 300^{0}C (if available)

If the above condition in equation (12.3.4-3) is not met, equation (12.3.4-2) as listed below may be used.

$$\sigma_4 = \sigma_1 + \sigma_3 \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_5) , due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-2) below.

$$\sigma_5 = \sigma_1 + \sqrt{\left[\frac{i_{QC}Q_{xC}}{3A} + \frac{\sqrt{(0.75i_iM_{iC})^2 + (0.75i_oM_{oC})^2}}{3Z}\right]^2 + \left[\frac{i_tM_{tC}}{3Z}\right]^2} \leq f_{cr}$$

where

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into material properties.

Stresses due to a single non-repeated Support Movement (settlement)

The stress (σ_6) due to a single non-repeated support movement (settlement) is calculated from equation (12.3.6-2)

$$\sigma_6 = \sqrt{\left[\frac{i_{QD}Q_{xD}}{A} + \frac{\sqrt{(i_iM_{iD})^2 + (i_oM_{oD})^2}}{Z}\right]^2 + \left[\frac{i_tM_{tD}}{Z}\right]^2} \leq f_D$$

where

M_{iD} = in-plane moment due to non-repeated anchor/restraint movement
M_{oD} = out-of-plane moment due to non-repeated anchor/restraint movement
M_{tD} = torsional moment due to non-repeated anchor/restraint movement
i_{QD} = stress intensification factor for axial forces due to non-repeated anchor/restraint movement = 1.0

Q_{xD} = axial force due to non-repeated anchor/restraint movement

A and Z are the same as defined under Expansion Stress given above

f_D = allowable stress = min(2$R_{p0.2t}$; R_m)

Since only f and R_m are input into CAEPIPE, the above allowable stress criterion can be rewritten as follows.

f_D = 3f, if [f < (R_m/2.4)]; otherwise

f_D = R_m ,if [f = (R_m/2.4)]

where
f = allowable stress @ Reference Temperature (T_{ref}) entered in CAEPIPE.

Stresses on Buried Piping as per EN 13480-6 (2017)

The axial stress (S_L) due to combined pressure and temperature change effects is calculated from equation 1 of Clause 5.2.4 of EN 13480-6 (2017).

$$S_L = \eta S_P - E\alpha(\Delta_T) \leq 0.9 S_y$$

where

S_P = circumferential stress due to maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]
η= Poisson's ratio
Δ_T= maximum temperature range
S_y= Yield Strength = 1.5 x f (when not input in CAEPIPE Material property)

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

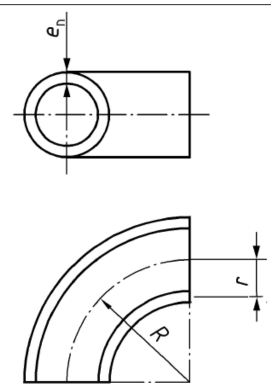
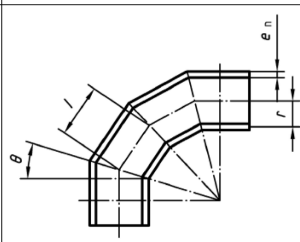
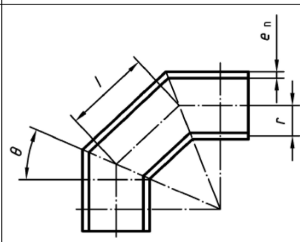
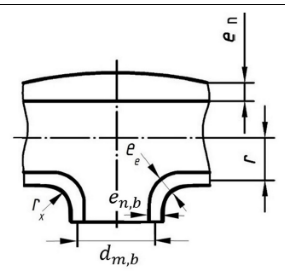
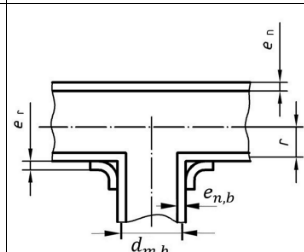
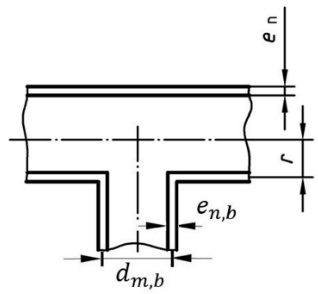
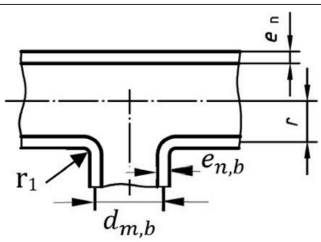
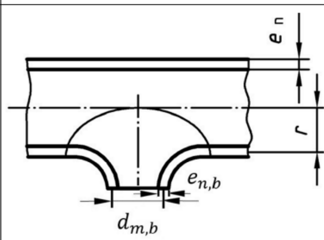
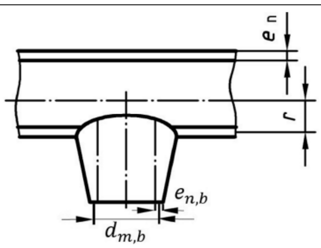
N°	Component designation	Sketch	Flexibility characteristic h	Stress intensification factor	
				Out-of-plane i_o	In-plane I_i
1	Welding elbow or pipe bend		$\dfrac{e_n R}{r^2}$	$\dfrac{0,75}{h^{2/3}}$ a b c j	$\dfrac{0,9}{h^{2/3}}$ a b c j
2	Closely spaced mitre bend $l < r\,(1 + \tan\theta)$ $(l = 2\,R\tan\theta)$		$\dfrac{\cot\theta}{2}\,\dfrac{e_n l}{r^2}$	$\dfrac{0,9}{h^{2/3}}$ a b c j	$\dfrac{0,9}{h^{2/3}}$ a b c j
3	Single mitre bend or widely spaced mitre bend $l \geq r\,(1 + \tan\theta)$		$\dfrac{e_n}{r}\left(\dfrac{1+\cot\theta}{2}\right)$	$\dfrac{0,9}{h^{2/3}}$ a b c j	$\dfrac{0,9}{h^{2/3}}$ a b c j
4	Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes		$\dfrac{4,4 e_n}{r}$	$\dfrac{0,9}{h^{2/3}}$ a e f g i k	$0,75\, i_o + 0,25$ a e f g i k
5	Reinforced fabricated tee with pad or saddle		$\dfrac{\left(e_n + 0,5 e_r\right)^{5/2}}{r\left(e_n^{3/2}\right)}$	$\dfrac{0,9}{h^{2/3}}$ a d e i k	$0,75\, i_o + 0,25$ a d e i k

Table H.3 (*continued*)

N°	Component designation	Sketch	Flexibility characteristic h	Stress intensification factor	
				Out-of-plane I_o	In-plane i_i
6	Unreinforced fabricated tee		$\frac{e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a d e i k	$0,75\ i_o + 0,25$ a d e i k
7	Extruded welding tee		$\left(1+\frac{r_1}{r}\right)\frac{e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a e i k	$0,75\ i_o + 0,25$ a e i k
8	Welded in contour insert		$\frac{4,4e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a e f g i k	$0,75\ i_o + 0,25$ a e f g i k
9	Branch welded on fitting (integrally reinforced)		$\frac{3,3e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a d f h k	$\frac{0,9}{h^{2/3}}$ a d f h k

(to be continued)

Table H.3 (*concluded*)

[a] The factors i_o and i_i apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[b] If these components are fitted with:

- flange at one extremity, i_o and i_i are multiplied by $h^{1/6}$;
- flange at each of the extremities, i_o and i_i are multiplied by $h^{1/3}$.

[c] If the pressure is likely to correct ovality (large diameter, small thickness), the factors i_o and i_i shall be divided by:

$1 + 3,25 \left(\frac{p_o}{E_c}\right)\left(\frac{r}{e_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

[d] For a nozzle with a ratio of branch diameter to pipe diameter exceeding 0,5, the out-of-plane stress intensification factor may be non-conservative. In addition a smooth transition by a concave shaped weld is proved to reduce the value of this factor. Consequently the selection of an appropriate value for this factor remains the responsibility of the designer.

[e] The stress intensification factors regarding the branch connections are based on tests carried out with at least two diameters of straight pipe on either side of the branch axis. The case of closer branches requires a particular attention.

[f] The forgings shall be suitable with regard to the operating conditions.

[g] When the limitations with respect to radius ($r_x \geq r_{mb}/4$) and thickness ($e_e \geq 1,5\, e_n$) are not met and reliable data are not available, the flexibility characteristic is taken as $h = \frac{3,1\, e_n}{r}$.

[h] The designer shall check that the design against pressure is at least equivalent to that for a straight pipe.

[i] The factors only apply to nozzles with convergent axes, and is not applicable for instance for configurations according to Figure 8.4.3–5.

[j] The relevant wall thickness of bends should be taken at the crown (neutral axis). If unspecified, the average wall thickness of intrados and extrados may be used. For elbows, the wall thickness series from EN 10253 may be used. If the pressure is likely to reduce ovality (large diameter, small thickness), the factor k shall be divided by:

$1 + 6 \left(\frac{p_o}{E_c}\right)\left(\frac{r}{e_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

[k] The sectional modulus for the branch shall be calculated as:

$$Z = \min\left(i\frac{\pi((d_{m,b}+e_{n,b})^4-(d_{m,b}-e_{n,b})^4)}{32(d_{m,b}+e_{n,b})}, \frac{\pi}{4}(d_{m,b}+e_{n,b})^2 e_n\right)$$ or for corrosion

$$Z_c = \min\left(i\frac{\pi((d_{m,b}+e_{n,b})^4-(d_{m,b}+e_{n,b}-2e_{c,b})^4)}{32(d_{m,b}+e_{n,b})}, \frac{\pi}{4}(d_{m,b}+e_{n,b})^2 e_c\right)$$

SIFs for Reducer and Welds are computed as per Table H.1 as given below.

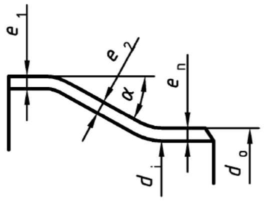
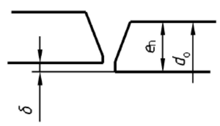
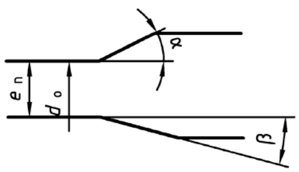
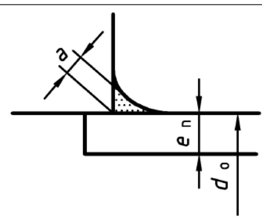
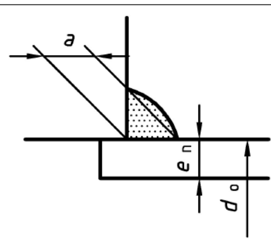
5	forged welded-in reducer		Shape conditions: $\alpha \le 60°$ $e_n \ge d_o/100$ $e_2 \ge e_1$	1	$0,5 + \frac{\alpha}{100}\left(\frac{d_o}{e_n}\right)^{1/2}$ max. 2,0 (α in deg.) d
9	butt weld		$e_n \ge 5$ mm and $\delta \le 0,1\ e_n$ $e_n < 5$ mm or $\delta > 0,1\ e_n$	1 1	1,0 [f] 1,8 [f]

Table H.1 *(concluded)*

N°	Component designation	Sketch	Flexibility characteristic ***h***	Flexibility factor k_B [a]	Stress intensification factor ***i***
10	wall thickness transitions		$\alpha \le 30°$ $\beta \le 15°$ (without circumferential weld at transitions $\delta = 0$)	1	$1,3 + 0,0036\frac{d_o}{e_n} + 3,6\frac{\delta}{e_n}$ max 1,9 [f]
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3 [k]
12				1	2,1 [k]

See Notes given at the end of this Section

SIFs for Flanges and Threaded Joints are computed as given below.

Sl. No.	Designation	Flexibility factor	Stress intensification factor i
1	Weld Neck Flange	1	1.0
2	Double Welded Slip on Flange	1	1.2
3	Single Welded Slip on Flange	1	1.3
4	Fillet Welded Flange	1	1.3
5	Socket Welded Flange	1	1.3
6	Lap Joint Flange	1	1.6
7	Threaded Flange	1	2.3
8	Threaded Joint	1	2.3

Note:
In-plane and out-of-plane SIF values are the same for Reducers, Welds, Flanges and Threaded Joints (computed as per Table H.1 as well as the Table provided above).

CAEPIPE internally incorporates the SIF values and Flexibility factors as given by the above three (3) Tables for any stress model.

Allowable Pressure

The allowable pressure for straight pipes is calculated from equation 6.1-1 or 6.1-3 depending on the ratio between inner and outer diameter.

For $D_o/D_i \leq 1.7$

$$P = \frac{2fze}{D_o - e}$$

For $D_o/D_i > 1.7$

$$P = fz\frac{(1-a^2)}{(1+a^2)}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness × (1 – mill tolerance %/100 – corrosion allowance)"c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

D_o = outer diameter

D_i = inner diameter

a = $1 - \frac{2e}{D_o}$

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}–

$$e_{equi} = \frac{e}{t_f}$$

where

t_f = $\left(\frac{R/D - 0.25}{R/D - 0.50}\right)$

R = radius on bend

For closely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1 and 6.3.4-2.

$$P = min\left[\frac{fze^2}{r\left(e + 0.643\,tan\,\theta\,\sqrt{re}\right)}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] with\ \theta \leq 22.5$$

For widely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1, 6.3.4-2 and 6.3.5-1

$$P = min\left[\frac{fze^2}{r\left(e + 0.643\,tan\,\theta\,\sqrt{re}\right)}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] with\ \theta \leq 22.5$$

$$P = \frac{fze^2}{r\left(e + 1.25\,tan\,\theta\,\sqrt{re}\right)} with\theta \leq 22.5$$

where

r = mean radius of pipe = $(D - \mathrm{t})/2$

R_S = effective bend radius of the miter

θ = miter half angle

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation (12.3.2-1)

$$\sigma_1 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} \leq f_f$$

where

P = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

Do = outside diameter

e_n = nominal pipe thickness

i = stress intensification factor; the product of 0.75ishall not be less than 1.0

M_A = resulting bending moment due to sustained loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

f_f = min(f; fcr) = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

f = min(Rp0.2t/1.5 ; Rm/2.4)

f_{cr} = design stress in creep range at max(T1 through T10)

Rp0.2t = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note: Starting Version 7.50 of CAEPIPE, the value of "ff" is no longer input in the material properties table. Instead, the value of "f" which is calculated as min(Rp0.2t/1.5; Rm/2.4) is input for each temperature.

If a stress model created using an earlier version of CAEPIPE is read into Version 7.50 of CAEPIPE, then in the 7.50 model file, the material properties should be updated appropriately.

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated from equation (12.3.3-1) as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently

$$\sigma_2 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kf_f$$

where

M_B = resultant bending moment due to occasional load

k=1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE k=1.2; user can change this input in Layout window > Options > Analysis > Code > EN13480.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from equation (12.3.4-1)

$$\sigma_3 = \frac{iM_C}{Z} \leq f_a$$

where

M_C = resultant moment due to thermal expansion and alternating loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

$$f_a = U(1.25f_C + 0.25f_h)\frac{E_h}{E_c} \text{ as per Equation (12.1.3-1)}$$

U = cyclic stress range reduction factor taken from Table 12.1.3-1

E_C = modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

E_h = modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

f_c = min(R_m/3; f), where f = min($R_{p0.2t}$/1.5 ; R_m/2.4) at room temperature (T_{ref}) as per Equation (12.1.3-2)

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration = min(f_c; f; f_{cr}) as per Equation 12.1.3-3, with fc determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration.

For example, for the thermal range (T1-T2), with T1 = 300^0 C, T2 = 100^0 C and Tref = 21^0C,E_c is determined at T2 = 100^0C and E_h is determined at T1 =300^0C
f_c as per Equation (12.1.3-2) listed above is determined at Tref = 21^0C, the value of fc used in calculating f_h is determined at T2 = 100^0C the value of f used in calculating f_h is determined at T1 = 300 0C andthe value of f_{cr} is taken at T1 = 300^0C (if available)

If the above condition in equation (12.3.4-1) is not met, equation (12.3.4-2) may be used.

$$\sigma_4 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_3) , due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-1) below.

$$\sigma_5 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_C}{3Z} \leq f_{cr}$$

where

f_{cr} = design stress in creep range at max(T1 through T10)

Stresses due to single non-repeated Support Movement (settlement)

The stress (σ_6) due to a single non-repeated support movement (settlement) is calculated from equation (12.3.6-1)

$$\sigma_6 = \frac{iM_D}{3Z} \leq \sigma_{6a}$$

where

$M_D =$ resultant moment from a single non-repeated anchor movement (settlement)

σ_{6a} = allowable stress = min(2$R_{p0.2t}$; R_m)

Since only f and R_m are input into CAEPIPE, the above allowable stress criterion can be rewritten as follows.

$\sigma_{6a} =$ 3f, if [f < (R_m/2.4)]; otherwise

σ_{6a} = R_m ,if [f = (R_m/2.4)]

where
f = allowable stress @ Reference Temperature (T_{ref}) entered in CAEPIPE.

Stresses on Buried Piping as per EN 13480-6 (2017)

The axial stress (S_L) due to combined pressure and temperature change effects is calculated from equation 1 of Clause 5.2.4 of EN 13480-6 (2017).

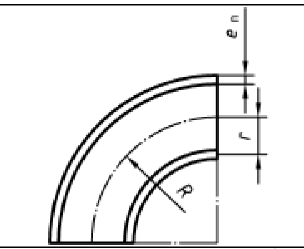
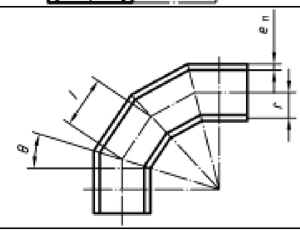
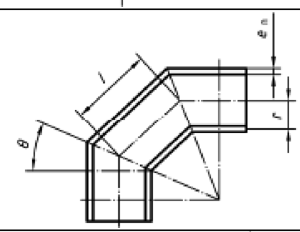
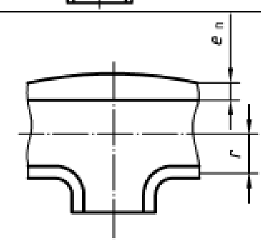
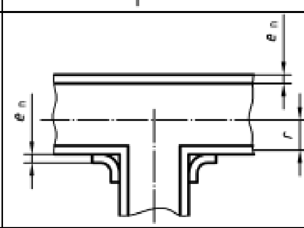
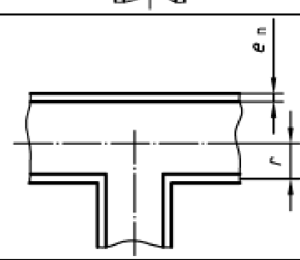
$$S_L = \eta S_P - \mathrm{E}\alpha(\Delta_T) \leq 0.9S_y$$

where

S_P = circumferential stress due to maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]
η= Poisson's ratio
Δ_T= maximum temperature range

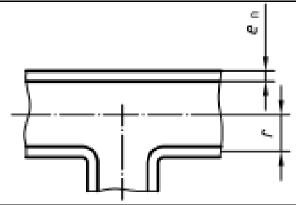
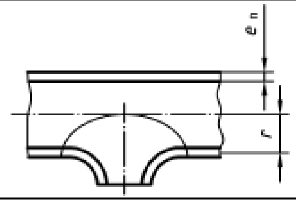
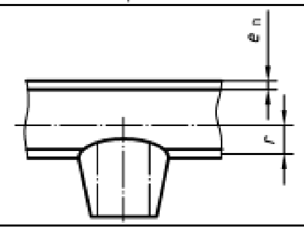
S_y= Yield Strength = 1.5 x f

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0{,}75}{h^{2/3}}$ a b c j	$\frac{0{,}9}{h^{2/3}}$ a b c j	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r(1 + \tan\theta)$ $(l = 2R\tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ a b c j	$\frac{0{,}9}{h^{2/3}}$ a b c j	$\frac{\cot\theta}{2}\frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ a b c j	$\frac{0{,}9}{h^{2/3}}$ a b c j	$\frac{e_n}{r}\left(\frac{1+\cot\theta}{2}\right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0{,}9}{h^{2/3}}$ a e f g i	$0{,}75 i_o + 0{,}25$ a e f g i	$\frac{4{,}4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0{,}9}{h^{2/3}}$ a d e i	$0{,}75 i_o + 0{,}25$ a d e i	$\frac{(e_n + 0{,}5 e_r)^{5/2}}{r(e_n^{3/2})}$	
Unreinforced fabricated tee	$\frac{0{,}9}{h^{2/3}}$ a d e i	$0{,}75 i_o + 0{,}25$ a d e i	$\frac{e_n}{r}$	

(to be continued)

Table H.3 *(continued)*

Component description	Out-of-plane i_0	In-plane i_i	Flexibility characteristic	Sketch
Extruded welding tee	$\frac{0,9}{h^{2/3}}$ [a, e, i]	$0,75 i_o + 0,25$ [a, e, i]	$\left(1+\frac{r_1}{r}\right)\frac{e_n}{r}$	
Welded in contour insert	$\frac{0,9}{h^{2/3}}$ [a, e, f, g, i]	$0,75 i_o + 0,25$ [a, e, f, g, i]	$\frac{4,4 e_n}{r}$	
Branch welded on fitting (integrally reinforced)	$\frac{0,9}{h^{2/3}}$ [a, d, f, h]	$0,75 i_o + 0,25$ [a, d, f, h]	$\frac{3,3 e_n}{r}$	

SIFs for Reducer and Weldsare computed as per Table H.1 as given below.

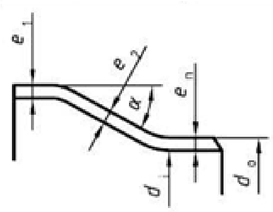
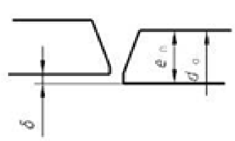
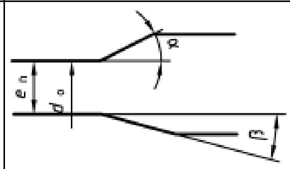
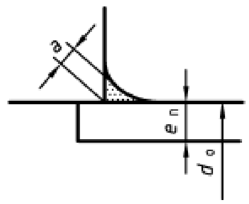
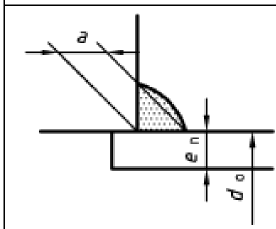
N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
5	forged welded-in reducer		Shape conditions : $\alpha \leq 60°$ $e_n \geq d_o/100$ $e_2 \geq e_1$	1	$0,5+\frac{\alpha}{100}\left(\frac{d_o}{e_n}\right)^{1/2}$ max. 2,0 (α in deg.) [d]	
9	butt weld		$e_n \leq$ 5mm and $\delta \leq 0,1 e_n$ [f]	1	1,0 [f]	
			$e_n <$ 5mm and $\delta > 0,1 e_n$ [f]	1	1,8 [f]	

Table H.1 *(concluded)*

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
10	wall thickness transitions		$\alpha \leq 30°$ $\beta \leq 15°$ (without circumferential weld at transitions $\delta = 0$)	1	$1{,}3 + 0{,}0036\frac{d_o}{e_n} + 3{,}6\frac{\delta}{e_n}$ max 1,9 [f]	$\frac{\pi}{32}\frac{d_o^4 - d_i^4}{d_o}$
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3	smaller value of $\frac{\pi}{32}\frac{d_o^4 - d_i^4}{d_o}$ and $\frac{\pi}{4}d_o^2 a$
12				1	2,1	

SIFs for Flanges and Threaded Joints are computed as given below.

Sl. No.	Designation	Flexibility factor	Stress intensification factor i
1	Weld Neck Flange	1	1.0
2	Double Welded Slip on Flange	1	1.2
3	Single Welded Slip on Flange	1	1.3
4	Fillet Welded Flange	1	1.3
5	Socket Welded Flange	1	1.3
6	Lap Joint Flange	1	1.6
7	Threaded Flange	1	2.3
8	Threaded Joint	1	2.3

Note:
In-plane and out-of-plane SIF values are the same for Reducers, Welds, Flanges and Threaded Joints (computed as per Table H.1 as well as the Table provided above).

CAEPIPE internally incorporates the SIF values and Flexibility factors as given by the above three (3) Tables in any stress model.

Allowable Pressure

The allowable pressure for straight pipes is calculated from equation 6.1-1 or 6.1-3 depending on the ratio between inner and outer diameter.

For $D_o/D_i \leq 1.7$

$$P = \frac{2fze}{D_o - e}$$

For $D_o/D_i > 1.7$

$$P = fz\frac{(1 - a^2)}{(1 + a^2)}$$

where

P = allowable pressure
f = allowable stress
z = joint factor (input as material property in CAEPIPE)
e = nominal pipe thickness × (1 – mill tolerance %/100 – corrosion allowance)"c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

D_o = outer diameter
D_i = inner diameter
a $= 1 - \frac{2e}{D_o}$

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}–

$$e_{equi} = \frac{e}{t_f}$$

where

t_f $= \left(\frac{R/D - 0.25}{R/D - 0.50}\right)$

R = radius on bend

<u>For closely spaced miter bends</u>, the allowable pressure is calculated from equations 6.3.4-1 and 6.3.4-2.

$$P = min\left[\frac{fze^2}{r\left(e + 0.643\, tan\,\theta\,\sqrt{re}\right)}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] with\; \theta \leq 22.5$$

For widely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1, 6.3.4-2 and 6.3.5-1

$$P = min\left[\frac{fze^2}{r\left(e + 0.643\, tan\,\theta\,\sqrt{re}\right)}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] with\,\theta \le 22.5$$

$$P = \frac{fze^2}{r\left(e + 1.25\, tan\,\theta\,\sqrt{re}\right)} with\theta \le 22.5$$

where

r = mean radius of pipe = $(D - \mathrm{t})/2$

R_S = effective bend radius of the miter

θ = miter half angle

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation (12.3.2-1)

$$\sigma_1 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} \le f_f$$

where

P = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

Do = outside diameter

e_n = nominal pipe thickness

i = stress intensification factor; the product of 0.75ishall not be less than 1.0

M_A = resulting bending moment due to sustained loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

f_f = min(f; fcr) = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

f = min(Rp0.2t/1.5 ; Rm/2.4)

f_{cr} = design stress in creep range at max(T1 through T10)

Rp0.2t = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note: Starting Version 7.50 of CAEPIPE, the value of “ff” is no longer input in the material properties table. Instead, the value of “f” which is calculated as min(Rp0.2t/1.5; Rm/2.4) is input for each temperature.

If a stress model created using an earlier version of CAEPIPE is read into Version 7.50 of CAEPIPE, then in the 7.50 model file, the material properties should be updated appropriately.

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated from equation (12.3.3-1) as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently

$$\sigma_2 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \le kf_f$$

where

$M_B =$ resultant bending moment due to occasional load

k=1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPEk=1.2; user can change this input in Layout window> Options > Analysis > Code >EN13480.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from equation (12.3.4-1)

$$\sigma_3 = \frac{iM_C}{Z} \le f_a$$

where

$M_C =$ resultant moment due to thermal expansion and alternating loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

$$f_a = U(1.25f_C + 0.25f_h)\frac{E_h}{E_c} \text{ as per Equation (12.1.3-1)}$$

U = cyclic stress range reduction factor taken from Table 12.1.3-1

$E_C =$ modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

$E_h =$ modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

$f_c =$ min(R_m/3; f), where f = min($R_{p0.2t}$/1.5 ; R_m/2.4) at room temperature (T_{ref}) as per Equation (12.1.3-2)

$f_h =$ basic allowable stress at maximum metal temperature consistent with the loading under consideration = min(f_c; f; f_{cr}) as per Equation 12.1.3-3, with fc determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration.

For example, for the thermal range (T1-T2), with T1 = 300^0 C, T2 = 100^0 C and Tref = 21^0C,E_c is determined at T2 = 100^0C and E_h is determined at T1 =300^0C
f_c as per Equation (12.1.3-2) listed above is determined at Tref = 21^0C, the value of fc used in calculating f_h is determined at T2 = 100^0C the value of f used in calculating f_h is determined at T1 = 300 0C andthe value of f_{cr} is taken at T1 = 300^0C (if available)

If the above condition in equation (12.3.4-1) is not met, equation (12.3.4-2) may be used.

$$\sigma_4 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_3) , due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-1) below.

$$\sigma_5 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_C}{3Z} \leq f_{cr}$$

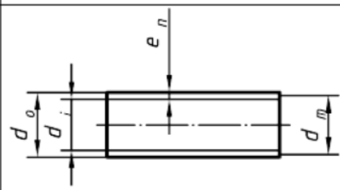
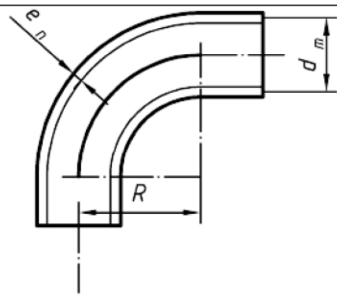
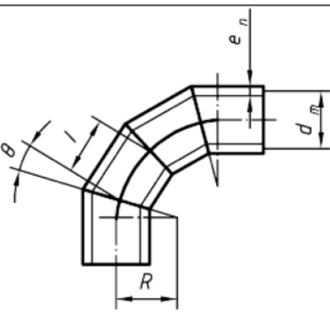
where

f_{cr} = design stress in creep range at max(T1 through T10)

Stresses due to single non-repeated Support Movement (settlement)

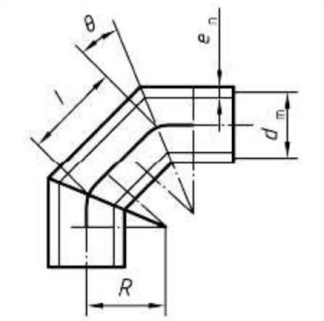
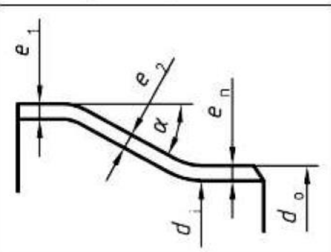
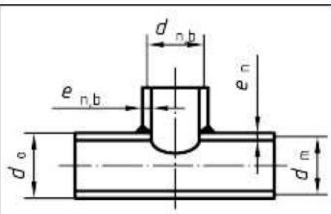
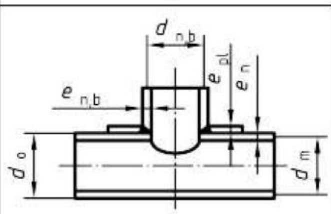
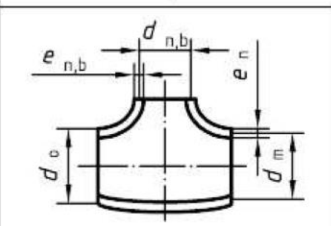
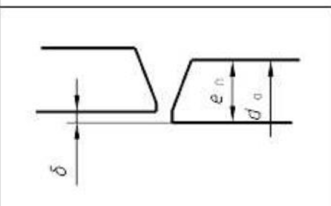
Settlement evaluation as per Equation (12.3.6-1) of EN 13480-3 (2012) is not yet implemented in CAEPIPE.

Table H.1 — Flexibility characteristics, flexibility and stress intensification factors and section moduli for general cases

N°	**Designation**	**Sketch**	**Flexibility characteristic *h***	**Flexibility factor k_B [a]**	**Stress intensification factor *i***	**Section modulus *Z***
1	straight pipe		1	1	1	
2	plain bend		$\frac{4Re_n}{d_m^2}$	$\frac{1{,}65}{h}$	$\frac{0{,}9}{h^{2/3}}$ b c	$\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$
3	Closely spaced mitre bend $l < r\,(1 + \tan\theta)$ $(l = 2\,R\tan\theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{l\cot\theta}{2}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$ b c	

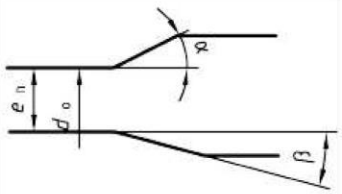
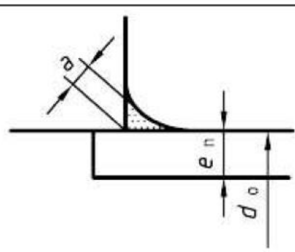
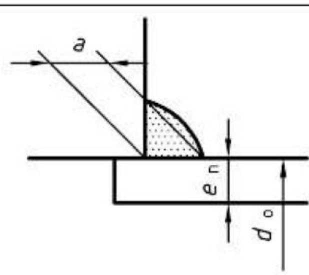
(to be continued)

Table H.1 *(continued)*

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
4	Single mitre bend or widely spaced mitre bend $l \geq r\,(1 + \tan\theta)$		$\dfrac{4Re_n}{d_m^2}$ with $R = \dfrac{d_m(1+\cot\theta)}{4}$	$\dfrac{1{,}52}{h^{5/6}}$	$\dfrac{0{,}9}{h^{2/3}}$ [b]	
5	forged welded-in reducer		Shape conditions : $\alpha \leq 60°$ $e_n \geq d_o/100$ $e_2 \geq e_1$	1	$0{,}5 + \dfrac{\alpha}{100}\left(\dfrac{d_o}{e_n}\right)^{1/2}$ max. 2,0 (α in deg.) [d]	
6	tee with welded-on, welded-in or extruded nozzle		$\dfrac{2e_n}{d_m}$	1	$\dfrac{0{,}9}{h^{2/3}}$ [b e]	Header : $\dfrac{\pi}{32}\dfrac{d_o^4 - d_i^4}{d_o}$
7	as above, however, with additional reinforcing ring		$\dfrac{2(e_n + 0{,}5e_{pl})^{5/2}}{d_m e_n^{3/2}}$ with $e_{pl} \leq e_n$	1	$\dfrac{0{,}9}{h^{2/3}}$ [b e]	Nozzle $\dfrac{\pi}{4} d_{n,b}^2 e_x$
8	forged welded-in tee with e_n and $e_{n,b}$ as connecting wall thickness		$\dfrac{8{,}8e_n}{d_m}$	1	$\dfrac{0{,}9}{h^{2/3}}$ [b g]	with e_x as smaller value of $e_{x1} = e_n$ and $e_{x2} = i\,e_{n,b}$ resp.
9	butt weld		$e_n \leq 5$mm and $\delta \leq 0{,}1e_n$ [f] $e_n < 5$mm and $\delta > 0{,}1e_n$ [f]	1 1	1,0 [f] 1,8 [f]	

(to be continued)

Table H.1 *(concluded)*

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
10	wall thickness transitions		$\alpha \leq 30°$ $\beta \leq 15°$ (without circumferential weld at transitions $\delta = 0$)	1	$1{,}3 + 0{,}0036 \dfrac{d_o}{e_n} + 3{,}6 \dfrac{\delta}{e_n}$ max 1,9 [f]	$\dfrac{\pi}{32} \dfrac{d_o^4 - d_i^4}{d_o}$
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3	smaller value of $\dfrac{\pi}{32} \dfrac{d_o^4 - d_i^4}{d_o}$ and $\dfrac{\pi}{4} d_o^2 a$
12				1	2,1	

[a] The flexibility factor k_B applies to bending in all planes. The factor related to torsion is equal to 1 in all cases.

[b] The factors k_B and i apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[c] If these components are fitted with :

- flange at one extremity, k_B and i are multiplied by $h^{1/6}$;
- flange at each of the extremities, k_B and i are multiplied by $h^{1/3}$.

[d] The wall thickness of the reducer is not less than e_1 except in the vicinity of the small end where however the thickness is not less than e_n.

[e] Other values may be used subject to justification.

[f] The factor applies if the fabrication tolerances are met. Otherwise the determination of the factors is the responsibility of the designer.

[g] The factors only apply to nozzles with convergent axes.

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bendin

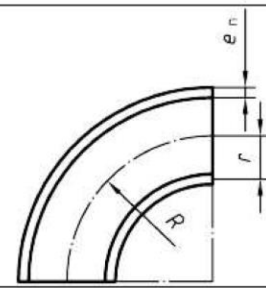
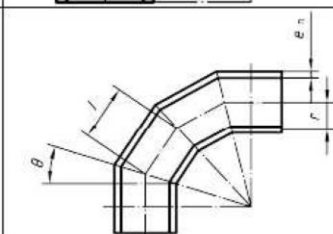
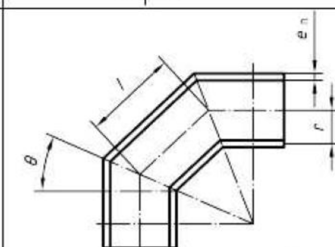
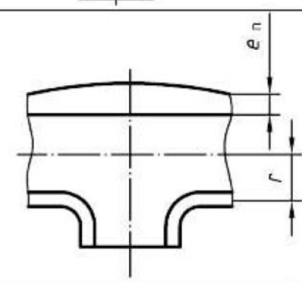
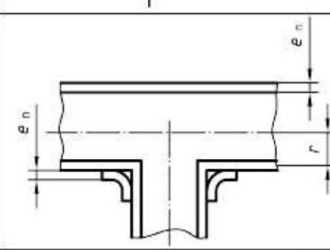
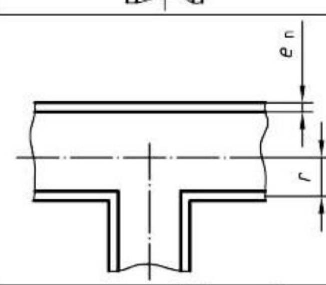
Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0{,}75}{h^{2/3}}$ [a,b,c]	$\frac{0{,}9}{h^{2/3}}$ [a,b,c]	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r\,(1 + \tan\theta)$ $(l = 2\,R\tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ [a,b,c]	$\frac{0{,}9}{h^{2/3}}$ [a,b,c]	$\frac{\cot\theta}{2}\,\frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r\,(1 + \tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ [a,b,c]	$\frac{0{,}9}{h^{2/3}}$ [a,b,c]	$\frac{e_n}{r}\left(\frac{1+\cot\theta}{2}\right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0{,}9}{h^{2/3}}$ [a,e,f,g,i]	$0{,}75 i_o + 0{,}25$ [a,e,f,g,i]	$\frac{4{,}4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0{,}9}{h^{2/3}}$ [a,d,e,i]	$0{,}75 i_o + 0{,}25$ [a,d,e,i]	$\frac{(e_n + 0{,}5 e_r)^{5/2}}{r\left(e_n^{3/2}\right)}$	
Unreinforced fabricated tee	$\frac{0{,}9}{h^{2/3}}$ [a,d,e,i]	$0{,}75 i_o + 0{,}25$ [a,d,e,i]	$\frac{e_n}{r}$	
				(to be continued)

Table H.3 (*continued*)

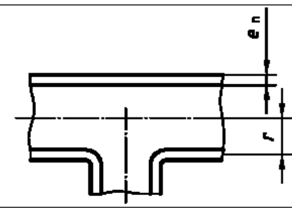
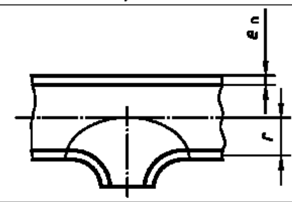
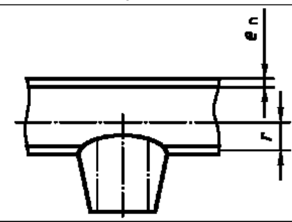
Component description	**Out-of-plane** i_o	**In-plane** i_i	**Flexibility characteristic**	**Sketch**
Extruded welding tee	$\frac{0,9}{h^{2/3}}$ [a,e,i]	$0,75 i_o + 0,25$ [a,e,i]	$\left(1 + \frac{r_1}{r}\right)\frac{e_n}{r}$	
Welded in contour insert	$\frac{0,9}{h^{2/3}}$ [a,e,f,g,i]	$0,75 i_o + 0,25$ [a,e,f,g,i]	$\frac{4,4 e_n}{r}$	
Branch welded on fitting (integrally reinforced)	$\frac{0,9}{h^{2/3}}$ [a,d,f,h]	$0,75 i_o + 0,25$ [a,d,f,h]	$\frac{3,3 e_n}{r}$	

Table H.3 (*concluded*)

[a] The factors i_O and i_I apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[b] If these components are fitted with :

- flange at one extremity, i_O and i_I are multiplied by $h^{1/6}$;
- flange at each of the extremities, i_O and i_I are multiplied by $h^{1/3}$.

[c] If the pressure is likely to correct ovality (large diameter, small thickness), the factors i_O and i_I shall be divided by:

$1 + 3{,}25 \left(\frac{p_o}{E_c}\right)\left(\frac{r}{e_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

[d] For a nozzle with a ratio of branch diameter to pipe diameter exceeding 0,5, the out-of-plane stress intensification factor may be non-conservative. In addition a smooth transition by a concave shaped weld is proved to reduce the value of this factor. Consequently the selection of an appropriate value for this factor remains the responsibility of the designer.

[e] The stress intensification factors regarding the branch connections are based on tests carried out with at least two diameters of straight pipe on either side of the branch axis. The case of closer branches requires a particular attention.

[f] The forgings shall be suitable with regard to the operating conditions.

[g] When the limitations with respect to radius and thickness are not met and reliable data are not available, the flexibility characteristic is taken as $\frac{e_n}{r}$.

[h] The designer shall check that the design against pressure is at least equivalent to that for a straight pipe.

[i] The factors only apply to nozzles with convergent axes, and is not applicable for instance for configurations according to Figure 8.4.3-5.

[j] If the pressure is likely to correct ovality (large diameter, small thickness), the factor k shall be devided by:

$1 + 6\left(\frac{p_o}{E_c}\right)\left(\frac{r}{e_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 6.3.

$$p = \frac{2fz_L T_{eff}}{Dm - T_{eff}}$$

where
p = allowable pressure
f = allowable stress
z_L = joint efficiency of longitudinal weld (input as material property)
T_{eff} = nominal pipe thickness × (1 – mill tolerance/100) – corrosion allowance
D = outside diameter
d = inside diameter
m = pressure coefficient
= 1.0 for $D/\text{d}<1.6$
= $0.25(D/\text{d})+0.6$ for $1.6 \leq D/\text{d} \leq 2.0$

Sustained Stress

Stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 9.32.

$$S_L = \frac{pD}{4T_{eff}z_C} + \frac{0.75k_1M_A}{W} \leq f_2$$

where
p = maximum pressure
z_C = joint efficiency of circumferential weld (input as material property)
k_1 = stress intensification factor. The product $0.75k_1$ shall not be less than 1.0
M_A = resultant bending moment due to sustained loads
W = section modulus, for reduced outlets, effective section modulus
f_2 = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of the stress due to sustained loads (S_L) and the stress (S_O) due to occasional loads such as earthquake or wind from Equation 9.33. Wind and earthquake are not considered concurrently.

$$S_{LO} = \frac{pD}{4T_{eff}z_C} + \frac{0.75k_1(M_A + M_B)}{W} \leq 1.2f_2$$

where
M_B = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 9.34.

$$S_E = \frac{k_1 M_C}{W} \le S_r$$

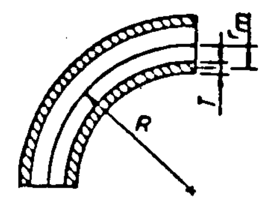
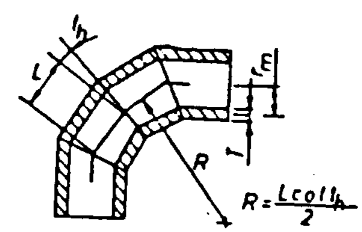
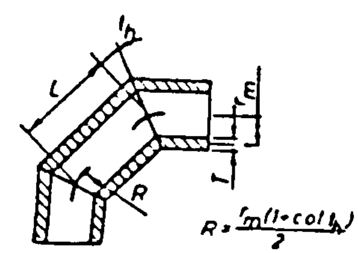
Alternatively, Equation 9.35 may be used.

$$S_L + S_E \le f_2 + S_r$$

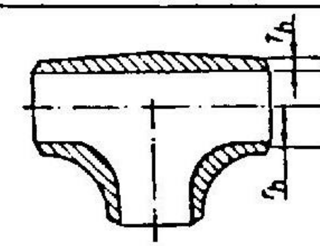
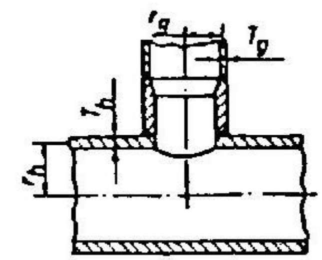
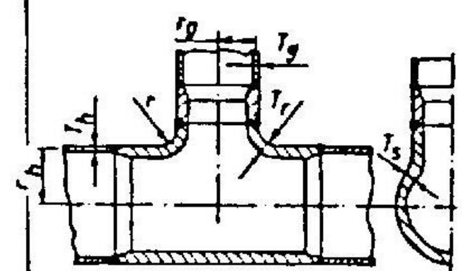
where
M_C = resultant bending moment due to thermal expansion.
S_r = $f_r(1.17R_1 + 0.17R_2)$
f_r = stress range reduction factor taken from Table 9.1.
R_1 = smaller of f_1 and $0.267R_\mathrm{m}$
R_2 = smaller of f_2 and $0.367R_\mathrm{m}$
f_1 = allowable stress at cold condition
f_2 = allowable stress at hot condition
R_m = tensile strength at room temperature
At moderate temperatures (up to 370º C) for carbon steel, low alloy steel and chromium steel (specified as CS material type) and up to 425º C for austenitic stainless steel (specified as AS material type), the limits $0.267R_\mathrm{m}$ and $0.367R_\mathrm{m}$ are disregarded andS_r is selected as smaller of $S_r'$and S_r'',

where
S_r' = $1.17f_1 + 0.20f_2$
S_r'' = $290f_\mathrm{r} - f_2$

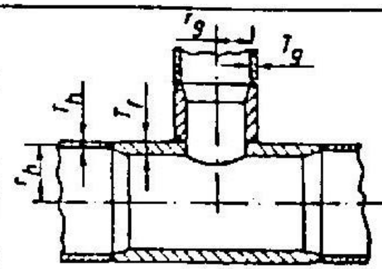
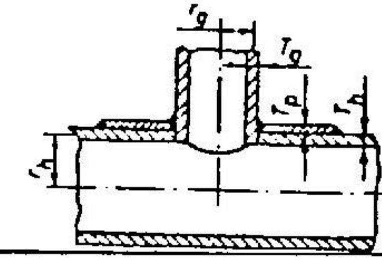
Table 9.2 Stress and flexibility coefficients for pipe and pipe components (fittings)

Item	Type of pipe component	Characteristic value h	Flexibility coefficient k	Stress coefficient k_1	Figure
1	Pipe bend, see notes 1 and 2	$\frac{T \cdot R}{r_m^2}$	$\frac{1.65}{h}$	$\frac{0,9}{h^{2/3}}$	
2	Pipe bend of welded segments with a segment length $L < r_m (1 + \tan t_h)$ see notes 1 and 2	$\frac{L \cdot T \cdot \cot t_h}{2 r_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$	
3	Pipe bend of welded segments with a segment length $L \geq r_m (1 + \tan t_h)$ or inclined circumferential welds, see notes 1 and 3	$\frac{T (1 + \cot t_h)}{2 r_m}$	1	$\frac{0,9}{h^{2/3}}$	

Stress and flexibility coefficients for pipe and pipe components (fittings)

Item	Type of pipe component	Characteristic value h	Flexibility coefficient k	Stress coefficient k_1	Figure
4	Tee bend according to NS 5594, see note 1	$4{,}4 \frac{T_h}{r_h}$	1	$\frac{0{,}9}{h^{2/3}}$	
5	Branch without local reinforcement of the main pipe, see note 1	$\frac{T_h}{r_h}$	1	$\frac{0{,}9}{h^{2/3}}$	
6	Branch or main pipe with raised edges radiused at joint between main pipe and branch, see note 1	$(\frac{T_e}{T_h})^{3/2} \quad \frac{T_e \cdot R_e}{r_h}$	1	$\frac{0{,}9}{h^{2/3}}$	

Stress and flexibility coefficients for pipe and pipe components (fittings)

Item	Type of pipe component	Characteristic value h	Flexibility coefficient k	Stress coefficient k_1	Figure
7	Branch on locally thickened main pipe, see note 1				
	$L < \frac{d_1}{2} + 1{,}8\sqrt{D \cdot T_f}$	$\frac{(\frac{T_h}{2} + \frac{T}{2})^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0{,}9}{h^{2/3}}$	
	$L \geq \frac{d_i}{2} + 1{,}8\sqrt{D \cdot T_f}$	$\frac{T_f^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0{,}9}{h^{2/3}}$	
8	Branch with plate reinforcement, see notes 1 and 4	$\frac{(T_h + \frac{T_p}{2})^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0{,}9}{h^{2/3}}$	

Symbols (items 4 - 8)

r = fillet radius (mm)

r_g = mean radius of branch = $(\frac{d - t_g}{2})$ (mm)

R_e = effective radius = $r + r_h$ (mm)

r_h = mean radius of main pipe $(\frac{D - T_h}{2})$ (mm)

T_g = specified wall thickness of branch (mm)

T_h = specified wall thickness of main (mm)

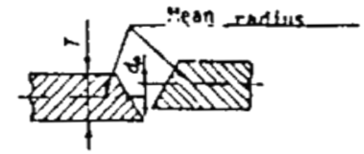
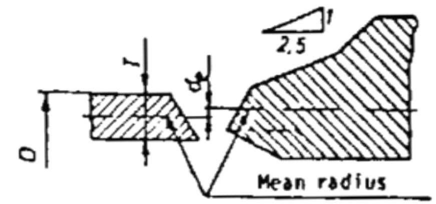
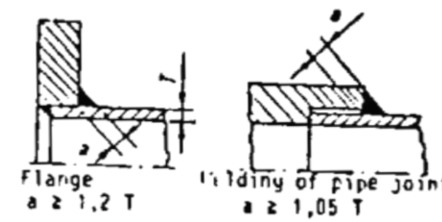
T_e = effective wall thickness = $1/2\ (T_r + T_s)$ (mm)

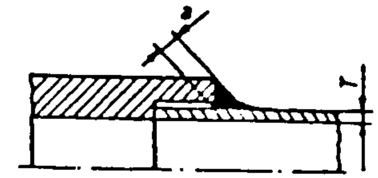
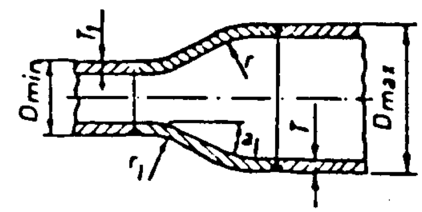
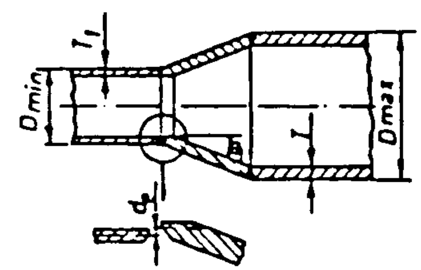
T_r = wall thickness at fillet radius (see item 5) (mm)

T_s = wall thickness of main pipe at a point located diametrically opposite of the branch (see item 5) (mm)

T_f = wall thickness of locally thickened main pipe (mm)

T_p = thickness of plate reinforcement (mm)

Item	Type of pipe component	Flexibility coefficient k	Stress coefficient k_1	Figure
9	Butt weld $T > 4,5$ mm and $d_e/T_{nom} \leq 0,1$ $T \leq 4,5$ mm or $d_e/T_{nom} > 0,1$	1 1	1,0 1,8 (If the weld is ground flush inside and out, the value 1,0 may be used)	
10	Butt weld between components of unequal thickness	1	$1,3-0,0036 \frac{D}{T} + 3,6 \frac{d_e}{T}$ but not over 1,9	
11	Fillet weld (spigot type)	1	2,1	

Item	Type of pipe component	Flexibility coefficient k	Stress coefficient k_1	Figure
12	Concave fillet weld (spigot type) with even transition to the pipe. (no undercut permitted)	1	1,3	 a ≥ 1,05 T
13	Conical reducer with defined knuckles r and r_1	1	$0{,}5 + 0{,}01 \cdot a_1\sqrt{\frac{D_{min}}{T_1}}$ but not over 2,0	
14	Conical reducer without knuckles, see notes 1 and 5 $T_1 > 4{,}5$ mm and $d_e/T_1 \leq 0{,}1$ $T_1 \leq 4{,}5$ mm or $d_e/T_1 > 0{,}1$		$0{,}9 + 0{,}17 \cdot a_1\sqrt{\frac{D_{min}}{T_1}}$ $1{,}25 + 0{,}023 \cdot a_1\sqrt{\frac{D_{min}}{T_1}}$ but not less than 1,8	

Item	Type of component	Flexibility coefficient k	Stress coefficient k_1
15	Threaded joint or connection to threaded flange	1	2,3

Symbols (items 13 - 14)

D_{min}, D_{maks}, a_1 see clause 6.5

T_1 = specified wall thickness of the smaller pipe (mm)

T = specified wall thickness of the larger pipe (mm)

d_e = difference in mean radius at each side of the welding groove (mm)

Notes relating to illustrations shown in table 9.2

All dimensions are nominal

1. The coefficients k and k_1 apply to bending in any plane and shall never be given a value less than 1. For plain bends and bends made of welded segments, the coefficients shall be applied to the effective length of the arc (shown by a heavy centreline in the illustrations). For branches and tees, they shall be applied up to the intersection point between the main pipe and the branch, see fig. 9.3.

   k and k_1 as functions of h can be taken from fig. 9.4.

2. If a flange is joined to one end or both, the coefficients k and k_1 shall be multiplied by the factor F as shown below.

   $F = h^{1/6}$ if one end has a flange

   $F = h^{1/3}$ if both ends have flanges

   F as function of h can be taken from fig. 9.5.

3. An inclined circumferential weld at the angle t_h degrees so that

   $$t_h \leq 9 \cdot \sqrt{\frac{T}{r_m}}$$

   may be considered as a perpendicular circumferential weld.

4. When $T_p \geq 2{,}5\ T_h$ is set to $h = 4{,}05 \cdot \frac{T_h}{r_h}$

5. The formula for k_1 applies only when the following conditions are satisfied:

   - the reducer is concentric
   - the angle a_1 does not exceed 60^0
   - neither D_{max}/T nor D_{min}/T_1 exceeds 100.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 6.3.

$$p = \frac{2 f z_L T_{eff}}{Dm - T_{eff}}$$

where

p = allowable pressure
f = allowable stress
z_L = joint efficiency of longitudinal weld (input as material property)
T_{eff} = nominal pipe thickness × (1 – mill tolerance/100) – corrosion allowance
D = outside diameter
d = inside diameter
m = pressure coefficient
= 1.0 for $D/\mathrm{d} < 1.6$
= $0.25(D/\mathrm{d}) + 0.6$ for $1.6 \leq D/\mathrm{d} \leq 2.0$

Sustained Stress

Stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 10.7.

$$S_L = \frac{pD}{4T_{eff} z_C} + \frac{0.75 k_1 M_A}{W} \leq f_2$$

where

p = maximum pressure
z_C = joint efficiency of circumferential weld (input as material property)
k_1 = stress intensification factor. The product $0.75k_1$ shall not be less than 1.0
M_A = resultant bending moment due to sustained loads
W = section modulus, for reduced outlets, effective section modulus
f_2 = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of the stress due to sustained loads (S_L) and the stress (S_O) due to occasional loads such as earthquake or wind from Equation 10.8. Wind and earthquake are not considered concurrently.

$$S_{LO} = \frac{pD}{4T_{eff} z_C} + \frac{0.75 k_1 (M_A + M_B)}{W} \leq 1.2 f_2$$

where

M_B = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 10.9.

$$S_E = \frac{k_1 M_C}{W} \le S_r$$

Alternatively, Equation 10.10 may be used.

$$S_L + S_E \le f_2 + S_r$$

where

M_C = resultant bending moment due to thermal expansion.

S_r = smaller of S_r' and S_r''

S_r' = $1.25 f_1 + 0.25 f_2$

S_r'' = $f_r R_s - f_2$

f_r = stress range reduction factor

f_1 = allowable stress at cold condition

f_2 = allowable stress at hot condition

R_s = permissible extent of stress for 7000 load cycles for different materials. R_s is determined by material type as follows:

Material	Type	R_S
Carbon and low alloy steel	CS	290
Austenitic stainless steel	AS	400
Copper alloys, annealed	CA	150
Copper alloys, cold worked	CC	100
Aluminum	AL	130
Titanium	TI	200

The stress range reduction factor f_r depends on the number of thermal cycles (NE). For moderate high temperatures (≤ 370º C for carbon, low alloy and chromium steel and ≤ 425º C for austenitic stainless steel), f_r is calculated from

$$f_r = (7000/N_E)^{0.2} N_E > 100\ (i.e., f_r \le 2.34)$$

At higher temperatures, S_r shall not be greater than $f_r(1.25R_1 + 0.25R_2)$ and f_r shall not be greater than 1.0.

where

R_1 = smaller of f_1 and $0.25R_m$

R_2 = smaller of f_2 and $0.25R_m$

R_m = tensile strength at room temperature

Tabell 10.1 Spennings- og fleksibilitets-koeffisient for rør og rørdeler

Table 10.1 Stress and flexibility coefficients for pipe and pipe components (fittings)

Betegnelser (detalj 4 - 8)

Symbols (item 4-8)

r	= hulkilradius (mm)	r	= fillet radius (mm)
r_g	= grenens middelradius = $(d - T_g)/2$ (mm)	r_g	= mean radius of branch = $(d - T_g)/2$ (mm)
r_h	= hovedrørets middelradius = $(d - T_h)/2$ (mm)	r_h	= mean radius of main pipe = $(d - T_h)/2$ (mm)
R_e	= $r + r_h$ (mm)	R_e	= $r + r_h$ (mm)
T_e	= $0{,}5 \times (T_r + T_s)$ (mm)	T_e	= $0{,}5 \times (T_r + T_s)$ (mm)
T_f	= veggtykkelse i lokalt tykkere hovedrør (mm)	T_f	= wall thickness of locally thickened main pipe
T_g	= grenens nominelle veggtykkelse (mm)	T_g	= nominal wall thickness of branch (mm)
T_h	= hovedrørets nominelle veggtykkelse (mm)	T_h	= nominal wall thickness of main pipe (mm)
T_p	= tykkelsen av plateforsterkning (mm)	T_p	= thickness of plate reinforcement (mm)
T_r	= veggtykkelse ved hulkilradien (se detalj 6) (mm)	T_r	= wall thickness at fillet radius (see item 6) (mm)
T_s	= veggtykkelse i hovedrørets side rett ovenfor grenen (se detalj 6) (mm)	T_s	= wall thickness of pipe at a point located diametrically opposite of the branch (see item 6) (mm)

Betegnelser (detalj 13 -14)

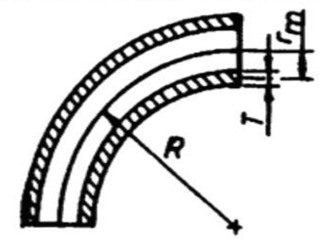
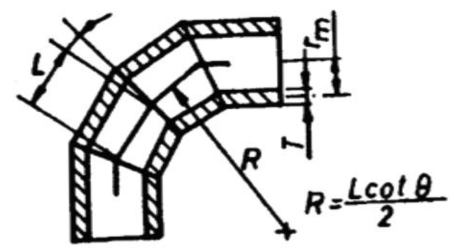
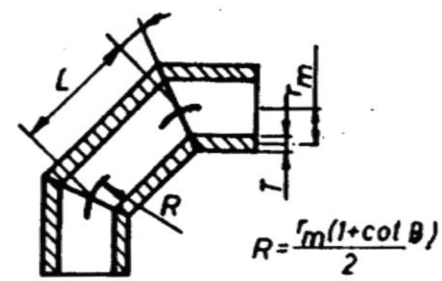
Symbols (item 13-14)

D_{min} og D_{maks}, se punkt 7.5

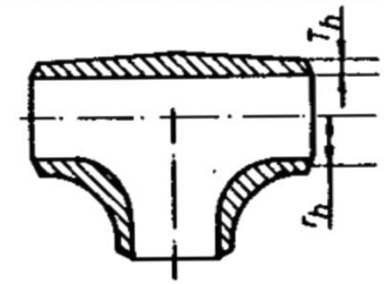
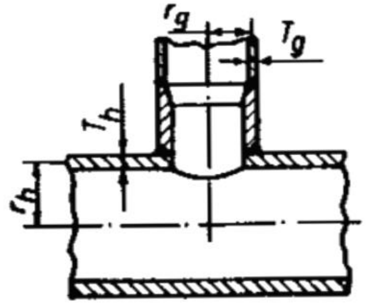
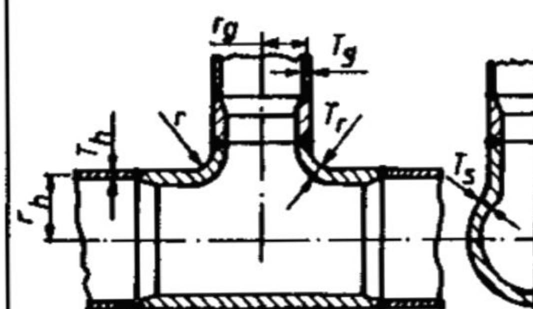
D_{min} and D_{maks}, see clause 7.5.

d_e	= forskjell i middelradius på hver side av sveisefuge (mm)	d_e	= difference in mean radius on each side of the welding grove (mm)
T	= nominell veggtykkelse i det største røret (mm)	T	= nominal wall thickness of the larger pipe (mm)
T_1	= nominell veggtykkelse i det minste røret (mm)	T_1	= nominal wall thickness of the smaller pipe (mm)
α	= vinkel, i grader	α	= angle, in degrees

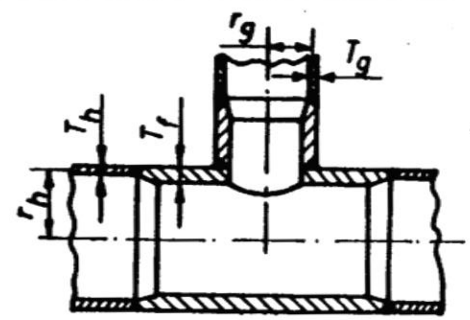
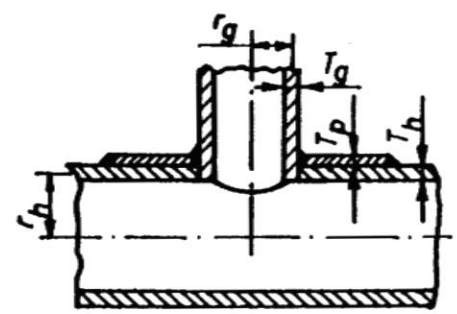
Tabell 10.1 Spennings- og fleksibilitetskoeffisient for rør og rørdeler
Table 10.1 Stress and flexibility coefficient for pipe and pipe components (fittings)

Detalj Item	Type rørdel Type of pipe component	Karakteristisk verdi h Characteristic value h	Fleksibilitets-koeffisient k Flexibility coefficient k	Spennings-koeffisient k_1 Stress coefficient k_1	Figur Figure
1	Rørbend, se fotnote 1, 2 og 3 Pipe bend, see notes 1, 2 and 3	$\frac{T \cdot R}{r_m^2}$	$\frac{1{,}65}{h}$	$\frac{0{,}9}{h^{2/3}}$	
2	Segmentsveist rørbend med segmentlengde $L < r_m \cdot (1 + \tan\theta)$ se fotnote 1, 2 og 3 Pipe bend of welded segments with a segment length $L < r_m \cdot (1 + \tan\theta)$ see notes 1, 2 and 3	$\frac{L \cdot T \cdot \cot\theta}{2 \cdot r_m^2}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$	
3	Segmentsveist rørbend med segmentlengde $L \geq r_m \cdot (1 + \tan\theta)$ eller skrå rundsveis, se fotnote 1 og 4 Pipe bend of welded segments with a segment length $L \geq r_m \cdot (1 + \tan\theta)$ or inclined circum-ferential welds, see notes 1 and 4	$\frac{T \cdot (1 + \cot\theta)}{2 \cdot r_m}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$	

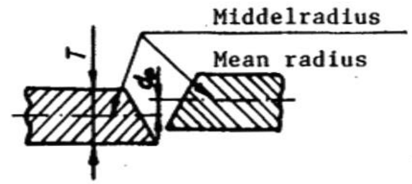
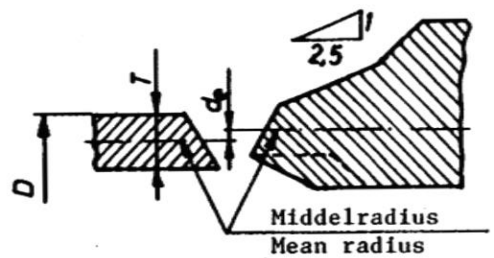
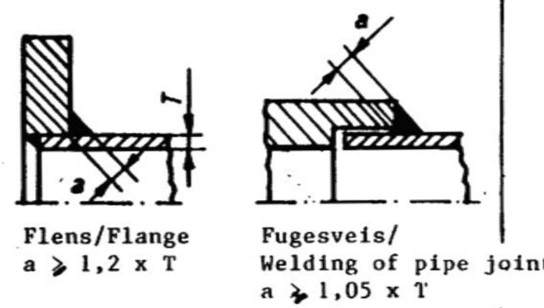
Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Karakteristisk verdi h Characteristic value h	Fleksibilitets-koeffisient k Flexibility coefficient k	Spennings-koeffisient k_1 Stress coefficient k_1	Figur Figure
4	T-rør etter NS 5594, se fotnote 1 Tee bend according to NS 5594, see note 1	$4{,}4 \cdot \frac{T_h}{r_h}$	1	$\frac{0{,}9}{h^{2/3}}$	
5	Gren uten lokal forsterkning av hovedrøret, se fotnote 1 Branch without local reinforcement of the main pipe, see note 1	$\frac{T_h}{r_h}$	1	$\frac{0{,}9}{h^{2/3}}$	
6	Gren eller utkraging med radius i overgang mellom hovedrør og grenrør, se fotnote 1 Branch or main pipe with raised edges radiuse at joint between main pipe and branch, see note 1	$(\frac{T_e}{T_h})^{3/2} \cdot \frac{T_e \cdot R_e}{r_h^2}$	1	$\frac{0{,}9}{h^{2/3}}$	

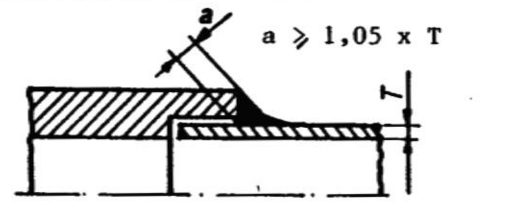
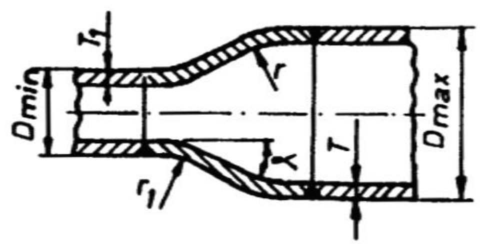
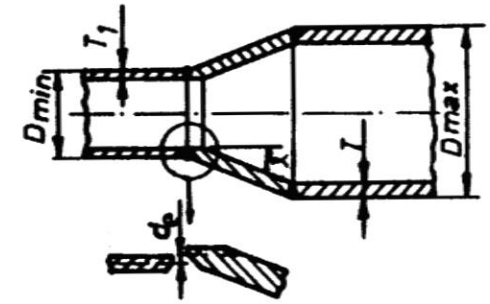
Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Karakteristisk verdi h Characteristic value h	Fleksibilitets-koeffisient k Flexibility coefficient k	Spennings-koeffisient k_1 Stress coefficient k_1	Figur Figure
7	Gren med lokalt tykkere hoved-rør, se fotnote 1 Branch on locally thickened main pipe, see note 1 $L < \frac{d_1}{2} + 1{,}8\sqrt{D \cdot T_f}$	$\frac{(\frac{T_h}{2} + \frac{T_f}{2})^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0{,}9}{h^{2/3}}$	
	$L \geq \frac{d_i}{2} + 1{,}8\sqrt{D \cdot T_f}$	$\frac{T_f^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0{,}9}{h^{2/3}}$	
8	Gren med plateforsterkning, se fotnote 1 og 5 Branch with plate reinforcement, see notes 1 and 5	$\frac{(T_h + \frac{T_p}{2})^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0{,}9}{h^{2/3}}$	

Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Fleksibilitets-koeffisient k Flexibility coefficient k	Spenningskoeffisient k_1 Stress coefficient k_1	Figur Figure
9	Buttsveis/Butt weld $T > 4{,}5$ mm og/and $d_e/T \leq 0{,}1$	1	1,0	
	$T \leq 4{,}5$ mm eller/or $d_e/T > 0{,}1$	1	1,8 (Slipes sveisen jevn inn-vendig og utvendig kan verdien 1,0 brukes) (If the weld is ground flush inside and out, the value 1,0 may be used)	
10	Buttsveis ved ulik godstykkelse etter avstnitt 11.3.6 Butt weld between components of unequal thickness accodring to clause 11.3.6	1	$1{,}3 - 0{,}0036 \cdot \frac{D}{T} + 3{,}6 \cdot \frac{d_e}{T}$ men maks/but max. 1,9	
11	Kilsveis (Innstikksveis) Fillet weld (spigot type)	1	2,1	

Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Fleksibilitets-koeffisient k Flexibility coefficient k	Spenningskoeffisient k_1 Stress coefficient k_1	Figur Figure
12	Konkav kilsveis (innstikksveis) med jevn overgang til røret (smelte "diken" ikke tillatt) Concave fillet weld (spigot type) with even transition to the pipe. (no undercut permitted)	1	1,3	
13	Konisk rørovergang med definerte hulkiler r og r_1, se fotnote 1 og 4 Conical reducer with defined knuckles r and r_1, see note 1 and 4	1	$0{,}5 + 0{,}01 \cdot \alpha \sqrt{\frac{D_{min}}{T_1}}$ men maks./but max. 2,0	
14	Konisk rørovergang uten hulkil, se fotnote 1 og 4 Conical reducer without knuckles, see notes 1 and 4 $T_1 > 4{,}5$ mm og/and $d_e/T_1 \leq 0{,}1$ $T_1 \leq 4{,}5$ mm eller/or $d_e/T_1 > 0{,}1$	1	$0{,}9 + 0{,}017 \cdot \alpha \sqrt{\frac{D_{min}}{T_1}}$ $1{,}25 + 0{,}023 \cdot \alpha \sqrt{\frac{D_{min}}{T_1}}$ men min./but min. 1,8	

Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Fleksibilitetskoeffisient k Flexibility coefficient k	Spenningskoeffisient k_1 Stress coefficient k_1
15	Gjengeforbindelse eller tilslutning til gjengeflens Threaded joint or connection to threaded flange	1	2,3

Fotnoter til figurene i tabell 10.1

Alle dimensjoner er nominelle.

1) Koeffisientene k og k_1 gjelder for bøying i vilkårlig plan og skal aldri være mindre enn 1. For glatte og segmentsveiste rørbend skal koeffisientene gjelde over den effektive buelengde (markert med tykk senterlinje i figurene). For gren og T-rør skal de gjelde frem til skjærings-punktet mellom hovedrør og gren, se figur 10.5.

   k og k_1 som funksjon av h kan tas fra figur 10.3. Tilatte verdier for h er angitt i figur 10.3.

2) Hvis en eller begge ender har standard flenstilslutning skal koeffisientene k og k_1 multipliseres med faktoren F som vist nedenfor

   $F = h^{1/6}$ om en ende har flens

   $F = h^{1/3}$ om begge ender har flens

   F som funksjon av h kan tas fra figur 10.4. Tilatte verdier for h er angitt i figur 10.4.

3) For albuer under innvendig trykk kan k endres på følgende måte:

   Under innvirkning av det innvendige overtrykk p minsker koeffisienten k til k_p.

Notes relating to illustrations shown in table 10.1

All dimensions are nominal.

1) The coefficients k and k_1 apply to bending in any plane and shall never be given a value less than 1. For plain bends and bends made of welded segments, the coefficients shall be applied to the effective length of the arc (shown by a heavy centre-line in the illustrations). For branches and tees, they shall be applied up to the intersection point between the main pipe and the branch, see figure 10.5.

   k and k_1 as functions of h can be taken from figure 10.3. Permissible values for h is given in figure 10.3.

2) If a standard flange is joined to one end or both, the coefficients k and k_1 shall be multiplied by the factor F as shown below.

   $F = h^{1/6}$ if one end has a flange

   $F = h^{1/3}$ if both ends have flanges

   F as function of h can be taken from figure 10.4. Permissible values for h is given in figure 10.4.

3) For elbows under internal pressure k may be changed in the following way:

   The coefficient k is reduced to k_p due to the effect of the internal pressure, p:

$$k_p = \frac{k}{1 + \frac{R_t}{E} \cdot 6\left(\frac{r_m}{T}\right)^{4/3} \cdot \left(\frac{R}{r_m}\right)^{1/3}}$$

der

E = elastisitetsmodul (N/mm^2)

p = innvendig overtrykk (MPa)

where

E = modulus of elasticity (N/mm^2)

p = internal pressure (MPa)

r_m = (D - T)/2, rørtverrsnittets middelradius (mm)

R_t = (p x r_m)/T, tangentiell spenning

Minste verdi for k_p er 1.

4) Skrå rundsveis med vinkelen θ i grader slik at

$$\theta \leq 9 \cdot \sqrt{\frac{T}{r_m}}$$

kan betraktes som rett rundsveis.

5) Når $T_p \geq 2{,}5 \times T_h$ settes $h = 4{,}05 \times (T_h/r_h)$

6) Formelen for k_1 gjelder bare under forutsetning av at følgende krav er oppfylt:

- overgangsstykket er konsentrisk
- vinkelen $\alpha \leq 60°$
- D_{maks}/T respektive D_{min}/T_1 ikke er større enn 100.

r_m = (D-T)/2, mean radius of the pipe section (mm)

R_t = (p x r_m)/T, tangential stress (mm)

The minimum value of k_p is 1.

4) An inclined circumferential weld with the angle θ in degrees so that

may be considered as a perpendicular circumferential weld.

5) When $T_p \geq 2{,}5 \times T_h$ is set $h = 4{,}05 \times (T_h/r_h)$

6) The formula for k_1 applies only when the following conditions are satisfied:

- the reducer is concentric
- the angle $\alpha \leq 60°$
- neither D_{maks}/T nor D_{min}/T_1 exceeds 100

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated using eq. (2) in para. C 3641.1.

$$P_a = \frac{2St_a}{(D_o - 2Yt_a)}$$

where

P_a = allowable pressure

S = allowable stress for the material at the design temperature (i.e., at T_{design} input into CAEPIPE). This value is given in the applicable tables of Annex Z I.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

Y = coefficient = 0.4.

$Y = \frac{d}{(d+D_o)}$ when $D_o/t_a < 6$

where, d = nominal inside diameter

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from eq. (6) of para. C 3652.

$$S_L = |S_{lp}| + \frac{0.75iM_A}{Z} \leq S_h$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal pressure including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

Z = un-corroded section modulus and should be computed as stated in para. C 3658 (b) and (d)

$Z = \pi r^2 t_n$; for reduced outlets; $Z = \pi(r_m')t_s$

r = mean cross-sectional radius; for reduced outlet, r_m'= branch mean cross-sectional radius

t_n= nominal wall thickness

t_s= effective branch wall thickness = lesser of T_r or i.T_b

T_b = nominal branch wall thickness

T_r = nominal run pipe wall thickness

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal metal area

Occasional Stress

The stress S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind, shall meet eq. (10) of para. C 3654 (a). Wind and earthquake are not considered to act concurrently.

$$S_{LO} = S_L + \left|S_{lpo}\right| + \frac{0.75iM_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress = $\left|\frac{(P_O-P)d^2}{D^2-d^2}\right|$ or $\left|\frac{(P_O-P)D}{4t_n}\right|$ This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

k = 1.2 for Level B

k = 1.8 for Level C

k = 2.4 for Level D

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. = $\sqrt{(M_{Bx})^2 + \left(M_{By}\right)^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lpo}\right|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

where

F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

A = nominal metal Area

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (7) in para. C 3653.2 (a).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where
i = stress intensification factor from C 3680.
M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + \left(M_{Cy}\right)^2 + (M_{Cz})^2}$
Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

$S_A = f(1.25S_c + 0.25S_h)$ as per C 3653.3 (a)

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table C 3653.3 (c)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

where

F_C = axial force due to thermal load range under analysis.

A = nominal metal area

Sustained + Expansion Stress

The sum of Sustained Stress due to pressure, weight, other sustained loads and Stress range due to thermal expansion is calculated using eq. (8) of para. C 3653.2 (b).

$$S_{TE} = \left|S_{lp}\right| + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_h + S_A$$

Where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal pressure including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + \left(M_{Ay}\right)^2 + (M_{Az})^2}$

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + \left(M_{Cy}\right)^2 + (M_{Cz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

$S_A = f(1.25S_c + 0.25S_h)$ as per C 3653.3 (a)

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table C 3653.3 (c)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$ and term $\frac{iM_C}{Z}$ with $\left|\frac{F_C}{A}\right| + \frac{iM_C}{Z}$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

F_C = axial force due to thermal load range under analysis

A = nominal metal area

Settlement Stress

The stress range (S_S) due to single, noncyclic displacement stress range (e.g., predicted settlement or uplift or movement of pipe support structures such as buildings, pipe racks, anchors, etc.) is calculated from eq. (9) in para. C 3653.2 (c).

$$S_E = \frac{iM_D}{Z} \leq 3S_C$$

where

i = stress intensification factor from C 3680.

M_D = resultant bending moment due to any single noncyclic anchor movement (e.g., predicted building settlement) $= \sqrt{(M_{Dx})^2 + \left(M_{Dy}\right)^2 + (M_{Dz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_C = basic allowable stress at room temperature (i.e., Tref in CAEPIPE)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_S as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_D}{Z} \leq 3S_C$$

where

F_C = axial force due to any single noncyclic anchor movement (e.g., predicted building settlement)

A = nominal metal area

Hydrotest Stress

The sum of longitudinal stress (S_{LT}) due to test pressure and dead loads for test condition is calculated from eq. (10) in para. C 3657.

$$S_{LT} = \left|S_{lp}\right| + \frac{0.75i(M_A + M_B)}{Z} \leq 1.6S_h$$

where

S_{lp} = pressure stress = $\frac{P_{max}D}{4t_n}$ or $\frac{P_{max}d^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_{max} =Test pressure = hydrotest pressure input into CAEPIPE

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and test fluid (excluding pressure) = $\sqrt{(M_{Ax})^2 + \left(M_{Ay}\right)^2 + (M_{Az})^2}$

M_B = resultant bending moment due to occasional loads = 0 (as occasional loads are not to be considered during the test condition)

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_h = hot allowable stress at test temperature (i.e., at T_{ref} in CAEPIPE)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and test fluid (excluding pressure)

A = nominal metal area

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

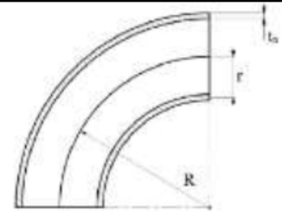
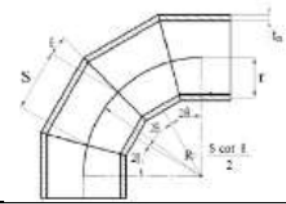
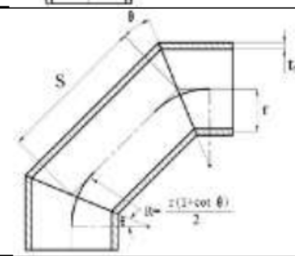
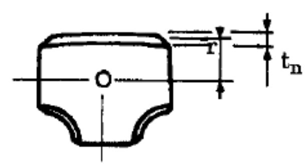
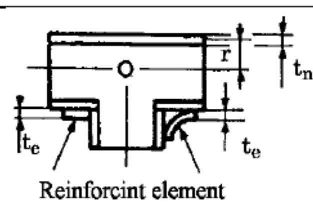
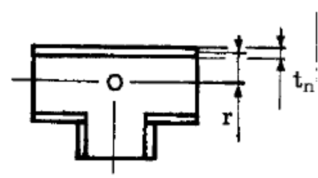
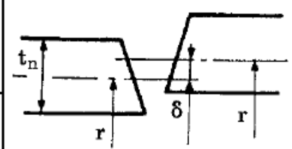
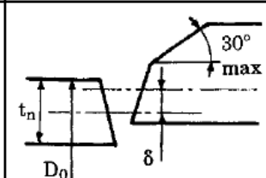
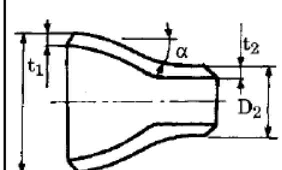
Description	Flexibility characteristic h	Flexibility factor k	Stress intensification factor i	Sketch
Welding elbow or pipe bend (1), (2), (3), (9)	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend (1), (2), (3) s < r (1 + tan θ)	$\frac{s t_n \cot\theta}{2 r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend (1), (2), (4) s ≥ r (1 + tan θ)	$\frac{t_n (1+\cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B 16.9 (1), (2)	$\frac{4.4\, t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee (1), (2), (5)	$\frac{(t_n + t_e/2)^{5/2}}{r t_n^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee (1), (2)	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility factor k	Stress intensification factor i	Sketch
Branch connections (2), (6)	1	- Analysis of run pipe: $Z=\pi R_m^2 T_r$ $i=0.4\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \geq 1.5$ - Analysis of branch pipe $Z=\pi (r'_m)^2 T'_b$ $i=1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$	Figure C 3680.2
Butt welds (1) t_n>4.75mm and $\frac{\delta}{t_n} \leq 0.1$	1	1.0	
Butt welds (1) $t_n \leq$ 4.75mm or $\frac{\delta}{t_n} > 0.1$	1	for flush weld 1.0 for as-welded 1.8	
Fillet welded joint, socket welded flange or single welded slip-on flange	1	2.1	Figure C 3661.2.a sketch (c) Figure C 3661.2.b Figure C 3661.2.c Figure C 3661.2.d sketches (a) to (c)
Brazed joint	1	2.1	Conformity to C 3671.4.b
Full fillet weld	1	1.3	Figure C 3661.2.d sketch (d)
Tapered transition ≤ 30° (ANSI B 16.25) (1)	1	1.9 max or : $1.3 + 0.0036 \frac{D_o}{T_n} + 3.6 \frac{\delta}{T_n}$	
Concentric reducers (ANSI B 16.9 or MSS SP 43) (2), (7)	1	2.0 max or : $0.5 + 0.01\,\alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend (8)	5	2.5	

NOTES TO FIGURE C 3680.1 :

(1)The following nomenclature applies:

r	=	mean radius of pipe (matching pipe for tees and elbows),
t_n	=	nominal wall thickness of pipe (matching pipe for tees and elbows, see note (9)).
R	=	bend radius of elbow or pipe bend.
θ	=	one-half angle between adjacent miter axes,
s	=	miter spacing at centreline,
t_e	=	reinforced thickness,
δ	=	mismatch
D_o	=	outside diameter.

(2)The flexibility factors k and stress intensification factors i apply to bending in any plane for fitting and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centrelines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(3)Where flanges are attached to one or both ends the values of k and i shall be corrected by the factor c given below:

one end flanged $c = h^{1/6}$

both ends flanged $c = h^{1/3}$

(4)Also includes single miter joints

(5)When $t_e > 1.5\ t_n$, $h = 4.05\ t_n/r$.

(6)The equations apply only if the following conditions are met:

a) The reinforcement area requirements of C 3643 are met.

b) The axis of the branch pipe is normal to the surface of run pipe wall.

c) For branch connections in a pipe, the arc distance measured between the centres of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times

d) The inside corner radius r_1 (figure C 3680.2) is between 10% and 50% of T_r.

e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + y)/2$ (fig. C 3680.2 sketch (c)) or $T_r/2$.

f) The outer radius r_3, is not less than the larger of

(1) $0.002 \theta d_o$
(2) 2 $(\sin \theta)^3$ times the offset for the configurations shown in fig. C 3680.2. sketches (a) and (b).

g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$

(7) The equations apply only if the following conditions are met:

a) Cone angle α does not exceed 60°, and the reducer is concentric,

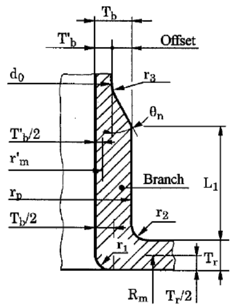
b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100,

c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

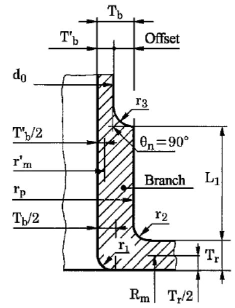
(8) Factors shown apply to bending, flexibility factor for tension equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used.

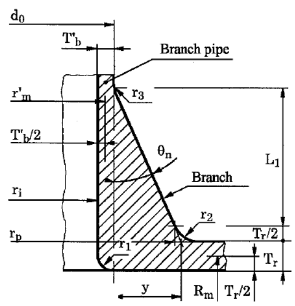
Large errors may be introduced unless the effect of these greater thicknesses is considered.



(a)



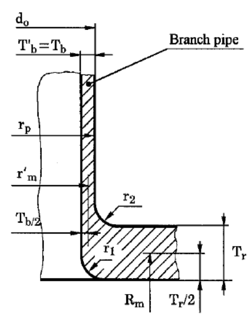
(b)



$T_b = T'_b + 0.667\,y$

$\theta \leq 45°$

(c)



(d)

Notes :

r'_m = average radius of branch pipe,
T'_b = nominal thickness of branch pipe,
R_m = average radius of run pipe,
T_r = nominal thickness of run pipe,
d_o = outer diameter of branch pipe.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated using eq. (2) in para. C 3641.1.

$$P_a = \frac{2St_a}{(D_o - 2Yt_a)}$$

where

P_a = allowable pressure

S = allowable stress for the material at the design temperature (i.e., at T_{design} input into CAEPIPE). This value is given in the applicable tables of Annex Z I.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

Y = coefficient = 0.4.

$Y = \frac{d}{(d+D_o)}$ when $D_o/t_a < 6$

where, d = nominal inside diameter

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from eq. (6) of para. C 3652.

$$S_L = |S_{lp}| + \frac{0.75iM_A}{Z} \leq S_h$$

where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal pressure including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

Z = un-corroded section modulus and should be computed as stated in para. C 3658 (b) and (d)

$Z = \pi r^2 t_n$; for reduced outlets; $Z = \pi(r'_m)t_s$

r =mean cross-sectional radius; for reduced outlet, r'_m= branch mean cross-sectional radius

t_n= nominal wall thickness

t_s= effective branch wall thickness = lesser of T_r or i.T_b

T_b = nominal branch wall thickness

T_r = nominal run pipe wall thickness

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal metal area

Occasional Stress

The stress S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind, shall meet eq. (10) of para. C 3654 (a). Wind and earthquake are not considered to act concurrently.

$$S_{LO} = S_L + \left|S_{lpo}\right| + \frac{0.75 i M_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress = $\left|\frac{(P_o - P)d^2}{D^2 - d^2}\right|$ or $\left|\frac{(P_o - P)D}{4t_n}\right|$ This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

k = 1.2 for Level B

k = 1.8 for Level C

k = 2.4 for Level D

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. = $\sqrt{(M_{Bx})^2 + \left(M_{By}\right)^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option “Include axial force in stress calculations” is turned ON, then CAEPIPE will replace the term $\left|S_{lpo}\right|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

where

F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

A = nominal metal Area

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (7) in para. C 3653.2 (a).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from C 3680.

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + \left(M_{Cy}\right)^2 + (M_{Cz})^2}$

Z = un-corroded section modulus as defined above (see write-up for “Sustained Stress”)

$S_A = f(1.25S_c + 0.25S_h)$ as per C 3653.3 (a)

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table C 3653.3 (c)

Note:

When the option “Include axial force in stress calculations” is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

where

F_C = axial force due to thermal load range under analysis.

A = nominal metal area

Sustained + Expansion Stress

The sum of Sustained Stress due to pressure, weight, other sustained loads and Stress range due to thermal expansion is calculated using eq. (8) of para. C 3653.2 (b).

$$S_{TE} = \left|S_{lp}\right| + \frac{0.75 i M_A}{Z} + \frac{i M_C}{Z} \leq S_h + S_A$$

Where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal pressure including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + \left(M_{Ay}\right)^2 + (M_{Az})^2}$

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + \left(M_{Cy}\right)^2 + (M_{Cz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

$S_A = f(1.25S_c + 0.25S_h)$ as per C 3653.3 (a)

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table C 3653.3 (c)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$ and term $\frac{iM_C}{Z}$ with $\left|\frac{F_C}{A}\right| + \frac{iM_C}{Z}$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

F_C = axial force due to thermal load range under analysis

A = nominal metal area

Settlement Stress

The stress range (S_S) due to single, noncyclic displacement stress range (e.g., predicted settlement or uplift or movement of pipe support structures such as buildings, pipe racks, anchors, etc.) is calculated from eq. (9) in para. C 3653.2 (c).

$$S_E = \frac{iM_D}{Z} \leq 3S_C$$

where

i = stress intensification factor from C 3680.

M_D = resultant bending moment due to any single noncyclic anchor movement (e.g., predicted building settlement) $= \sqrt{(M_{Dx})^2 + (M_{Dy})^2 + (M_{Dz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_C = basic allowable stress at room temperature (i.e., Tref in CAEPIPE)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_S as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_D}{Z} \leq 3S_C$$

where

F_C = axial force due to any single noncyclic anchor movement (e.g., predicted building settlement)

A = nominal metal area

Hydrotest Stress

The sum of longitudinal stress (S_{LT}) due to test pressure and dead loads for test condition is calculated from eq. (10) in para. C 3657.

$$S_{LT} = |S_{lp}| + \frac{0.75i(M_A + M_B)}{Z} \leq 1.6S_h$$

where

S_{lp} = pressure stress = $\frac{P_{max}D}{4t_n}$ or $\frac{P_{max}d^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_{max} =Test pressure = hydrotest pressure input into CAEPIPE

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and test fluid (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

M_B = resultant bending moment due to occasional loads = 0 (as occasional loads are not to be considered during the test condition)

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_h = hot allowable stress at test temperature (i.e., at T_{ref} in CAEPIPE)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and test fluid (excluding pressure)

A = nominal metal area

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

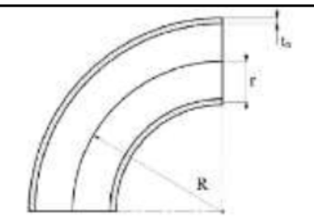
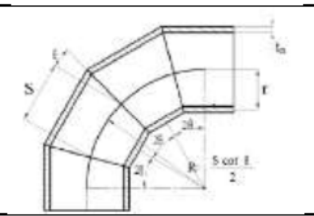
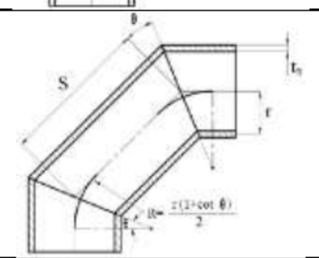
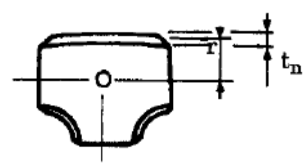
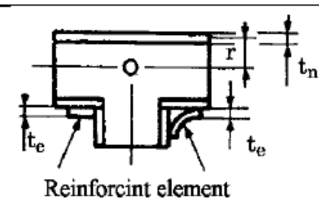
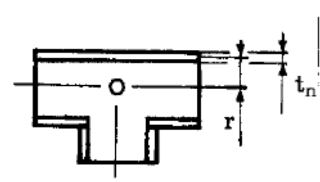
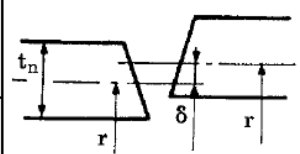
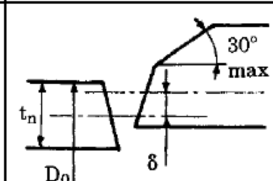
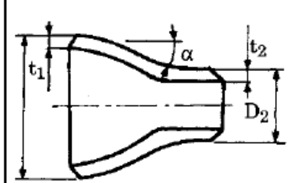
Description	Flexibility characteristic h	Flexibility factor k	Stress intensification factor i	Sketch
Welding elbow or pipe bend (1), (2), (3), (9)	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend (1), (2), (3) s < r (1 + tan θ)	$\frac{s t_n \cot\theta}{2 r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend (1), (2), (4) s ≥ r (1 + tan θ)	$\frac{t_n (1+\cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B 16.9 (1), (2)	$\frac{4.4\, t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee (1), (2), (5)	$\frac{(t_n + t_e/2)^{5/2}}{r t_n^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee (1), (2)	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility factor k	Stress intensification factor i	Sketch
Branch connections (2), (6)	1	- Analysis of run pipe: $Z=\pi R_m^2 T_r$ $i=0.4\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \geq 1.5$ - Analysis of branch pipe $Z=\pi (r'_m)^2 T'_b$ $i=1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$	Figure C 3680.2
Butt welds (1) $t_n > 4.75mm$ and $\frac{\delta}{t_n} \leq 0.1$	1	1.0	
Butt welds (1) $t_n \leq 4.75mm$ or $\frac{\delta}{t_n} > 0.1$	1	for flush weld 1.0 for as-welded 1.8	
Fillet welded joint, socket welded flange or single welded slip-on flange	1	2.1	Figure C 3661.2.a sketch (c) Figure C 3661.2.b Figure C 3661.2.c Figure C 3661.2.d sketches (a) to (c)
Brazed joint	1	2.1	Conformity to C 3671.4.b
Full fillet weld	1	1.3	Figure C 3661.2.d sketch (d)
Tapered transition ≤ 30° (ANSI B 16.25) (1)	1	1.9 max or : $1.3 + 0.0036 \frac{D_o}{T_n} + 3.6 \frac{\delta}{T_n}$	
Concentric reducers (ANSI B 16.9 or MSS SP 43) (2), (7)	1	2.0 max or : $0.5 + 0.01\, \alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend (8)	5	2.5	

NOTES TO FIGURE C 3680.1 :

(1)The following nomenclature applies:

- r = mean radius of pipe (matching pipe for tees and elbows),
- t_n = nominal wall thickness of pipe (matching pipe for tees and elbows, see note (9)).
- R = bend radius of elbow or pipe bend.
- θ = one-half angle between adjacent miter axes,
- s = miter spacing at centreline,
- t_e = reinforced thickness,
- δ = mismatch
- D_o = outside diameter.

(2)The flexibility factors k and stress intensification factors i apply to bending in any plane for fitting and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centrelines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(3)Where flanges are attached to one or both ends the values of k and i shall be corrected by the factor c given below:

one end flanged $c = h^{1/6}$

both ends flanged $c = h^{1/3}$

(4)Also includes single miter joints

(5)When $t_e > 1.5\ t_n$, $h = 4.05\ t_n/r$.

(6)The equations apply only if the following conditions are met:

a) The reinforcement area requirements of C 3643 are met.

b) The axis of the branch pipe is normal to the surface of run pipe wall.

c) For branch connections in a pipe, the arc distance measured between the centres of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times

d) The inside corner radius r_1 (figure C 3680.2) is between 10% and 50% of T_r.

e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + y)/2$ (fig. C 3680.2 sketch (c)) or $T_r/2$.

f) The outer radius r_3, is not less than the larger of

(1) 0.002 θ d_o
(2) 2 $(\sin\ \theta)^3$ times the offset for the configurations shown in fig. C 3680.2. sketches (a) and (b).

g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$

(7) The equations apply only if the following conditions are met:

a) Cone angle α does not exceed 60°, and the reducer is concentric,

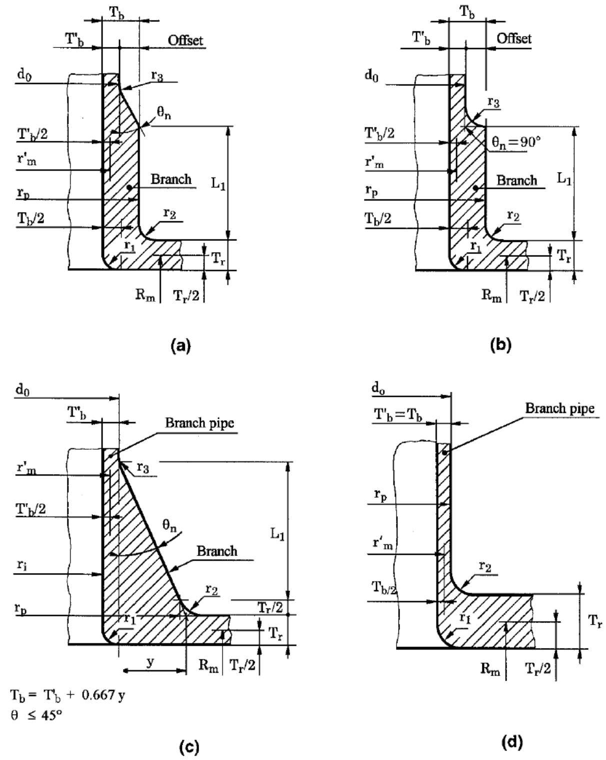
b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100,

c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(8) Factors shown apply to bending, flexibility factor for tension equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used.

Large errors may be introduced unless the effect of these greater thicknesses is considered.



Notes :

r'_m	=	average radius of branch pipe,
T'_b	=	nominal thickness of branch pipe,
R_m	=	average radius of run pipe,
T_r	=	nominal thickness of run pipe,
d_o	=	outer diameter of branch pipe.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated using eq. (2) in para. C 3641.1.

$$P_a = \frac{2St_a}{(D_o - 2Yt_a)}$$

where
P_a = allowable pressure
S = allowable stress for the material at the design temperature (i.e., at T_{design} input into CAEPIPE). This value is given in the applicable tables of Annex Z I.

t_a= available thickness for pressure design = t_n × (1 - mill tolerance/100) - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance in CAEPIPE)

t_n= nominal pipe thickness

D_o= nominal outside diameter of pipe

Y = coefficient = 0.4.

$Y = \frac{d}{(d+D_o)}$ when $D_o/t_a < 6$

where, d = nominal inside diameter

Sustained Stress

The stress S_L due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from eq. (6) of para. C 3652.

$$S_L = |S_{lp}| + \frac{0.75iM_A}{Z} \leq S_h$$

where
S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.
P = internal pressure including the effects of static head = maximum of CAEPIPE input pressures P1 through P10
D = nominal outside diameter
d = nominal inside diameter
i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0
M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$
Z = un-corroded section modulus and should be computed as stated in para. C 3658 (b) and (d)
$Z = \pi r^2 t_n$; for reduced outlets; $Z = \pi(r_m')t_s$
r =mean cross-sectional radius; for reduced outlet, r_m'= branch mean cross-sectional radius

t_n= nominal wall thickness

t_s= effective branch wall thickness = lesser of T_r or i.T_b

T_b = nominal branch wall thickness

T_r = nominal run pipe wall thickness

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

A = nominal metal area

Occasional Stress

The stress S_{LO}, calculated as the sum of stress due to sustained loads S_L and stress due to occasional loads S_O such as earthquake or wind, shall meet eq. (10) of para. C 3654 (a). Wind and earthquake are not considered to act concurrently.

$$S_{LO} = S_L + \left|S_{lpo}\right| + \frac{0.75 i M_B}{Z} \leq k.S_h$$

S_{lpo}= peak pressure stress = $\left|\frac{(P_o - P)d^2}{D^2 - d^2}\right|$ or $\left|\frac{(P_o - P)D}{4t_n}\right|$ This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_o = peak pressure = (peak pressure factor in CAEPIPE) x P

P = Maximum of CAEPIPE input pressures P1 through P10

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

k = 1.2 for Level B

k = 1.8 for Level C

k = 2.4 for Level D

M_B = resultant bending moment due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc. = $\sqrt{(M_{Bx})^2 + \left(M_{By}\right)^2 + (M_{Bz})^2}$

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $|S_{lpo}|$ with $\left|S_{lpo} + \frac{F_B}{A}\right|$

where

F_B = axial force due to occasional loads such as thrusts from pressure/safety relief valve loads, from pressure and flow transients, earthquake/wind, etc.

A = nominal metal Area

Expansion Stress Range

Stress range (S_E) due to thermal expansion is calculated using eq. (7) in para. C 3653.2 (a).

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

i = stress intensification factor from C 3680.

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + (M_{Cy})^2 + (M_{Cz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

$S_A = f(1.25S_c + 0.25S_h)$ as per C 3653.3 (a)

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table C 3653.3 (c)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_E as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_C}{Z} \leq S_A$$

where

F_C = axial force due to thermal load range under analysis.

A = nominal metal area

Sustained + Expansion Stress

The sum of Sustained Stress due to pressure, weight, other sustained loads and Stress range due to thermal expansion is calculated using eq. (8) of para. C 3653.2 (b).

$$S_{TE} = \left|S_{lp}\right| + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_h + S_A$$

Where

S_{lp} = pressure stress = $\frac{PD}{4t_n}$ or $\frac{Pd^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P = internal pressure including the effects of static head = maximum of CAEPIPE input pressures P1 through P10

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and other sustained mechanical loads (excluding pressure) = $\sqrt{(M_{Ax})^2 + \left(M_{Ay}\right)^2 + (M_{Az})^2}$

M_C = resultant bending moment due to the thermal load range under analysis = $\sqrt{(M_{Cx})^2 + \left(M_{Cy}\right)^2 + (M_{Cz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_h = hot allowable stress at maximum CAEPIPE temperature [i.e., at max (T_{ref}, T1 through T10)]

$S_A = f(1.25S_c + 0.25S_h)$ as per C 3653.3 (a)

S_C = basic allowable stress at minimum metal temperature expected during the thermal stress range under analysis

S_h = basic allowable stress at maximum metal temperature expected during the thermal stress range under analysis

f = stress range reduction factor from Table C 3653.3 (c)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$ and term $\frac{iM_C}{Z}$ with $\left|\frac{F_C}{A}\right| + \frac{iM_C}{Z}$

where

F_A = axial force due to weight and other sustained mechanical loads excluding pressure

F_C = axial force due to thermal load range under analysis

A = nominal metal area

Settlement Stress

The stress range (S_S) due to single, noncyclic displacement stress range (e.g., predicted settlement or uplift or movement of pipe support structures such as buildings, pipe racks, anchors, etc.) is calculated from eq. (9) in para. C 3653.2 (c).

$$S_E = \frac{iM_D}{Z} \leq 3S_C$$

where

i = stress intensification factor from C 3680.

M_D = resultant bending moment due to any single noncyclic anchor movement (e.g., predicted building settlement) $= \sqrt{(M_{Dx})^2 + (M_{Dy})^2 + (M_{Dz})^2}$

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_C = basic allowable stress at room temperature (i.e., Tref in CAEPIPE)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will compute S_S as given below.

$$S_E = \left|\frac{F_C}{A}\right| + \frac{iM_D}{Z} \leq 3S_C$$

where

F_C = axial force due to any single noncyclic anchor movement (e.g., predicted building settlement)

A = nominal metal area

Hydrotest Stress

The sum of longitudinal stress (S_{LT}) due to test pressure and dead loads for test condition is calculated from eq. (10) in para. C 3657.

$$S_{LT} = |S_{lp}| + \frac{0.75i(M_A + M_B)}{Z} \leq 1.6S_h$$

where

S_{lp} = pressure stress = $\frac{P_{max}D}{4t_n}$ or $\frac{P_{max}d^2}{D^2-d^2}$. This pressure option can be selected in CAEPIPE through Layout Window > Options > Analysis > Pressure.

P_{max} = Test pressure = hydrotest pressure input into CAEPIPE

D = nominal outside diameter

d = nominal inside diameter

i = stress intensification factor from C 3680 and 0.75i shall not be less than 1.0

M_A = resultant bending moment due to weight and test fluid (excluding pressure) = $\sqrt{(M_{Ax})^2 + (M_{Ay})^2 + (M_{Az})^2}$

M_B = resultant bending moment due to occasional loads = 0 (as occasional loads are not to be considered during the test condition)

Z = un-corroded section modulus as defined above (see write-up for "Sustained Stress")

S_h = hot allowable stress at test temperature (i.e., at T_{ref} in CAEPIPE)

Note:

When the option "Include axial force in stress calculations" is turned ON, then CAEPIPE will replace the term $\left|S_{lp}\right|$ with $\left|S_{lp} + \frac{F_A}{A}\right|$

where

F_A = axial force due to weight and test fluid (excluding pressure)

A = nominal metal area

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

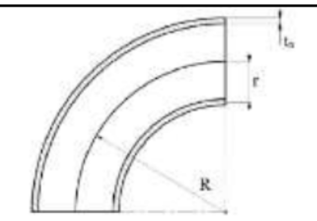
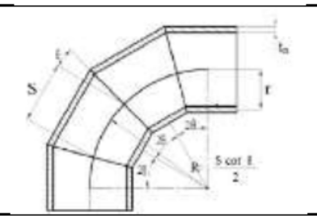
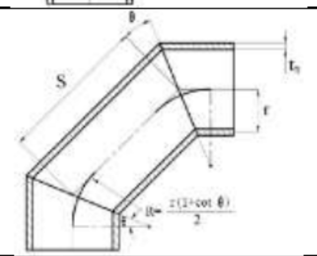
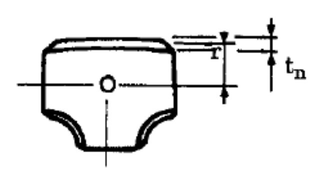
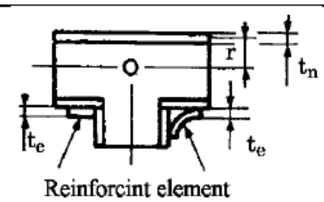
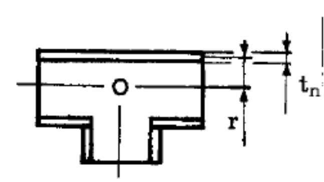
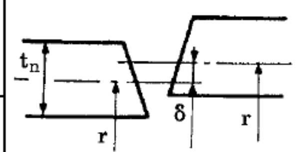
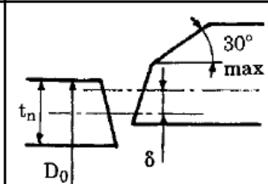
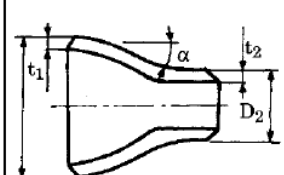
Description	Flexibility characteristic h	Flexibility factor k	Stress intensification factor i	Sketch
Welding elbow or pipe bend (1), (2), (3), (9)	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend (1), (2), (3) s < r (1 + tan θ)	$\frac{s t_n \cot\theta}{2 r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend (1), (2), (4) s ≥ r (1 + tan θ)	$\frac{t_n (1+\cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B 16.9 (1), (2)	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee (1), (2), (5)	$\frac{(t_n + t_e/2)^{5/2}}{r t_n^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee (1), (2)	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility factor k	Stress intensification factor i	Sketch
Branch connections (2), (6)	1	- Analysis of run pipe: $Z=\pi R_m^2 T_r$ $i=0.4\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right) \geq 1.5$ - Analysis of branch pipe $Z=\pi (r'_m)^2 T'_b$ $i=1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$	Figure C 3680.2
Butt welds (1) t_n>4.75mm and $\frac{\delta}{t_n} \leq 0.1$	1	1.0	
Butt welds (1) $t_n \leq$ 4.75mm or $\frac{\delta}{t_n} > 0.1$	1	for flush weld 1.0 for as-welded 1.8	
Fillet welded joint, socket welded flange or single welded slip-on flange	1	2.1	Figure C 3661.2.a sketch (c) Figure C 3661.2.b Figure C 3661.2.c Figure C 3661.2.d sketches (a) to (c)
Brazed joint	1	2.1	Conformity to C 3671.4.b
Full fillet weld	1	1.3	Figure C 3661.2.d sketch (d)
Tapered transition $\leq$ 30° (ANSI B 16.25) (1)	1	1.9 max or : 1.3 + 0.0036 $\frac{D_o}{T_n} + 3.6\frac{\delta}{T_n}$	
Concentric reducers (ANSI B 16.9 or MSS SP 43) (2), (7)	1	2.0 max or : 0.5 + 0.01 α $\left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend (8)	5	2.5	

NOTES TO FIGURE C 3680.1 :

(1)The following nomenclature applies:

- r = mean radius of pipe (matching pipe for tees and elbows),
- t_n = nominal wall thickness of pipe (matching pipe for tees and elbows, see note (9)).
- R = bend radius of elbow or pipe bend.
- θ = one-half angle between adjacent miter axes,
- s = miter spacing at centreline,
- t_e = reinforced thickness,
- δ = mismatch
- D_o = outside diameter.

(2)The flexibility factors k and stress intensification factors i apply to bending in any plane for fitting and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centrelines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(3)Where flanges are attached to one or both ends the values of k and i shall be corrected by the factor c given below:

one end flanged $c = h^{1/6}$

both ends flanged $c = h^{1/3}$

(4)Also includes single miter joints

(5)When $t_e > 1.5\ t_n$, $h = 4.05\ t_n/r$.

(6)The equations apply only if the following conditions are met:

a) The reinforcement area requirements of C 3643 are met.

b) The axis of the branch pipe is normal to the surface of run pipe wall.

c) For branch connections in a pipe, the arc distance measured between the centres of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times

d) The inside corner radius r_1 (figure C 3680.2) is between 10% and 50% of T_r.

e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + y)/2$ (fig. C 3680.2 sketch (c)) or $T_r/2$.

f) The outer radius r_3, is not less than the larger of

(1) $0.002\ \theta\ d_o$

(2) $2\ (\sin\ \theta)^3$ times the offset for the configurations shown in fig. C 3680.2. sketches (a) and (b).

g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$

(7) The equations apply only if the following conditions are met:

a) Cone angle α does not exceed 60°, and the reducer is concentric,

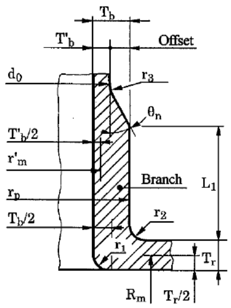
b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100,

c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

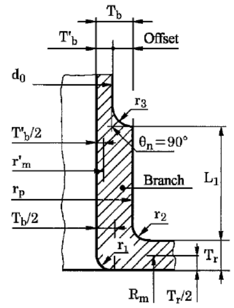
(8) Factors shown apply to bending, flexibility factor for tension equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used.

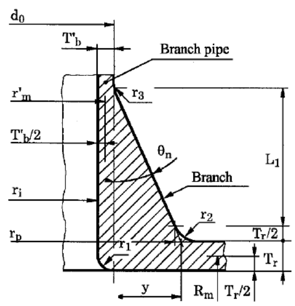
Large errors may be introduced unless the effect of these greater thicknesses is considered.



(a)



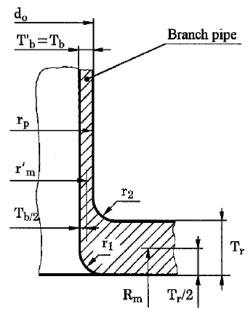
(b)



$T_b = T'_b + 0.667\,y$

$\theta \leq 45°$

(c)



(d)

Notes :

r'_m = average radius of branch pipe,
T'_b = nominal thickness of branch pipe,
R_m = average radius of run pipe,
T_r = nominal thickness of run pipe,
d_o = outer diameter of branch pipe.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 2 of C 3641.1.

$$P = \frac{2SEt_m}{D - 2Yt_m}$$

where

P = allowable pressure
S = allowable stress
E = joint factor (input as material property)
t_m = minimum required thickness, including mechanical and corrosion allowance
= $t\ \times$(1 – mill tolerance/100) – corrosion allowance
t = nominal pipe thickness
D = outside diameter
d = inside diameter
Y = pressure coefficient
= 0.4 for $t < D/6$
= $d/(D+d)$ for $t \geq D/6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 6 of C 3652.

$$S_L = \frac{PD}{4t} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum pressure
D = outside diameter
t = nominal wall thickness
i = stress intensification factor. The product $0.75i$, shall not be less than 1.0
M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
Z = section modulus, for reduced outlets, effective section modulus
S_h = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O), such as earthquake or wind from Equation 10 of C 3654. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (SE) due to thermal expansion is calculated from Equation 7 of C 3653.2.

$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

M_C = resultant moment due to thermal expansion
S_A = $f(1.25S_c + 0.25S_h)$
S_c = allowable stress at cold temperature
f = stress range reduction factor from Table C 3653.3

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 8 of C 3653.2.

$$S_{TE} = S_L + S_E \leq S_h + S_A$$

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

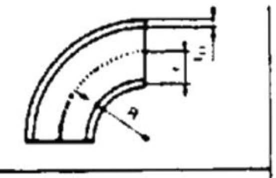
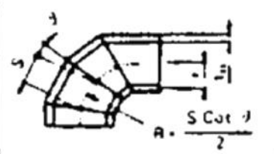
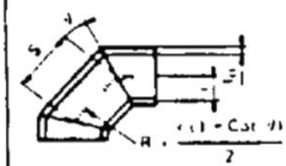
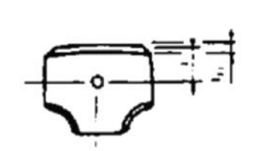
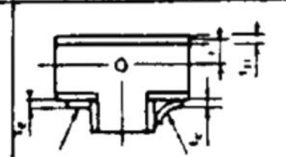
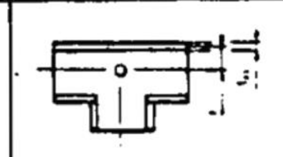
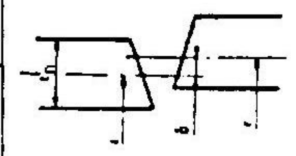
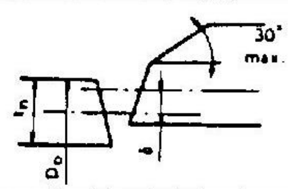
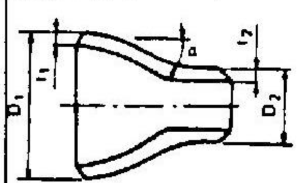
Description	Flexibility characteristic h	Flexibility factor k	Stress intensification factor i	Sketch
Welding elbow or pipe bend. (Notes (1), (2), (3)).	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend. (Notes (1), (2), (3)) $s < r(1 + \tan\theta)$	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend. (Notes (1), (2), (4). $s \geq r(1 + \tan\theta)$	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B.16.9 (Notes (1), (2).	$\frac{4.4\, t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee (Notes (1), (2), (5)).	$\frac{(t_n + \frac{t_e}{2})^{5/2}}{r t_n^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee (Notes (1) (2)).	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIGURE C 3680.1

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS (cont'd)

Description	Flexibility factor K	Stress intensification factor i	Sketch
Branch connections [Note (6)]	1	– Analysis of run pipe: $Z = \pi (R_m)^2 T_r$ $i = 0,4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)$ with a minimum value of 1,5 – Analysis of branch pipe $Z = \pi (r'_m)^2 T'_b$ $i = 1,5 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T'_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$	Fig. C 3680.2
Butt welds [Note (1)] $t_n > 4,75$ mm and $\frac{\delta}{t_n} \leq 0,1$	1	1,0	
Butt weld [Note (1)] $t_n \leq 4,75$ mm or $\frac{\delta}{t_n} > 0,1$	1	for flush weld .... 1,0 for as-welded 1,8	
Fillet welded joint, socket welded flange or single welded slip-on flange	1	2,1	Figure C 3661.2 Sketches (C), (D), (E), (F) and (G)
Brazed joint	1	2,1	Conformity to C 3671.4 b)
Full fillet weld	1	1,3	Figure C 3661.2 Sketch (H)
Tapered transition $\leq 30°$ (ANSI B 16.25) [Note (1)]	1	1,9 max. or : $1,3 + 0,0036 \frac{D_o}{t_n} + 3,6 \frac{\delta}{t_n}$	
Concentric reducers (ANSI B.16.9 or MSS SP 48) [Note (7)]	1	2,0 max. or : $0,5 + 0,01\,\alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2,3	—
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2,5	—

NOTES TO FIGURE C 3680.1:

(1) The following nomenclature applies

- r = mean radius of pipe (matching pipe for tees and elbows)
- t_n = nominal wall thickness of pipe (matching pipe for tees and elbows, see note (9))
- R = bend radius of elbow or pipe bend
- θ = one-half angle between adjacent miter axes
- s = miter spacing at centreline
- t_e = reinforced thickness
- δ = mismatch
- D_o = outside diameter

(2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centrelines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(3) Where flanges are attached to one or both ends the values of k and i shall be corrected by the factors c given below

one end flanged $c = h^{1/6}$

both ends flanged $c = h^{1/3}$

(4) Also includes single miter joints

(5) When $t_e > 1.5\ t_n$, $h = 4.05\ t_n/r$

(6) The equation applies only if the following conditions are met

a) The reinforcement area requirements of C 3643 are met

b) The axis of the branch pipe is normal to the surface of run pipe wall

c) For branch connections in a pipe, the arc distance measured between the centres of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their inside radii along the circumference of the run pipe

d) The inside corner radius r_1 (figure C 3680.2) is between 10% and 50% of T_r

e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + y)/2$ (fig. C 3680.2 sketch (c)) or $T_r/2$

f) The outer radius r_3 is not less than the larger of

(1) $0.002\ \theta\ d_o$

(2) $2\ (\sin\theta)^3$ times the offset for the configurations shown in fig. C 3680.2, sketches (a) and (b)

g) $R_m/T_r \leq 50$ and $r_m/R_m \leq 0.5$

(7) The equations apply only if the following conditions are met

a) Cone angle α does not exceed 60° and the reducer is concentric

b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100

c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cyclindrical portion on the small end, where the thickness shall not be less than t_2

(8) Factors shown apply to bending; flexibility factor for tension equals 0.9

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Allowable Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (C2.2.2-2) for straight pipes and Eq. (C2.3.2-1) for bends from paras. C2.2.2. and C2.3.2.respectively

$$P = \frac{2fze}{D - e}$$

where

P = allowable pressure
f = allowable stress
z = joint factor (input as material property in CAEPIPE)
e = nominal pipe thickness× (1 – mill tolerance/100) – corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. shouldbe included in corrosion allowance in CAEPIPE)

D = outside diameter

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}

$$e_{equi} = \frac{e}{t_f}$$

where

$$t_f = \left[\frac{R/D_o - 0.25}{R/D_o - 0.50}\right]$$

<u>For closely spaced miter bends</u>, the allowable pressure is calculated from

$$P = \min\left[\left(\frac{2fze}{D_m}.\frac{e}{e + 0.643\tan\theta\sqrt{0.5D_m e}}\right), \left(\frac{2fze}{D_m}.\frac{R - 0.5D_m}{R - 0.25D_m}\right)\right] \text{ with } \theta \le 22.5$$

<u>For widely spaced miter bends</u>, the allowable pressure is calculated from

$$P = \min\left[\left(\frac{2fze}{D_m}.\frac{e}{e + 0.643\tan\theta\sqrt{0.5D_m e}}\right), \left(\frac{2fze}{D_m}.\frac{R - 0.5D_m}{R - 0.25D_m}\right)\right] \text{ with } \theta \le 22.5$$

$$P = \left(\frac{2fze}{D_m}.\frac{e}{e + 1.25\tan\theta\sqrt{0.5D_m e}}\right) \text{ with } \theta \le 22.5$$

where

D_m = mean diameter of pipe = D-t_n
R = effective bend radius of the miter

θ = miter half angle
t_n = nominal thickness

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eq. (C10.3.2) from para. C10.3.2.

$$\sigma_1 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} \leq f_h$$

Where

P = maximum of CAEPIPE input pressures P1 through P10
D_o = outside diameter
e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance “c”
i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0
M_A = resulting bending moment due to sustained loads
Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
f_h = hot allowable stress

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently (see para. C10.3.3)

$$\sigma_2 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kf_h$$

where,

P = maximum of CAEPIPE input pressures P1 through P10
D_o = outside diameter
M_B = resultant bending moment due to occasional load
k = 1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE k =1.2 is used for occasional loading.
e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance “c”

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from Eq. C10.3.4-1from para. C10.3.4.

$$\sigma_3 = \frac{iM_C}{Z} + \leq f_a$$

where,

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of thermal anchor movements

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

f_a = $U(1.25f_C + 0.25f_h)\frac{E_h}{E_c}$ Eq. (C10.2.4.2-1) of para. C10.2.4.2.

i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0

U = cyclic stress range reduction factor from Table C10.2.4.3 and are mentioned below.

Number of cycle	Stress range reduction factor U
$f_a <= 7000$	1.0
7001 to 140000	0.9
14001 to 220000	0.8
22001 to 0.7	0.7
45001 to 100000	0.6
100001 to 2000000	0.5

f_C = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis

f_h = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis

E_C = elastic modulus at cold temperature

E_h = elastic modulus at hot temperature

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation C10.3.4-2 of para. C10.3.4.

$$\sigma_4 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_H + f_a$$

where,

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance "c"

M_A = resulting bending moment due to sustained loads

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of thermal anchor movements

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0

f_a = $U(1.25f_C + 0.25f_h)\frac{E_h}{E_c}$ Eq. (C10.2.4.2-1) of para. C10.2.4.2.

f_C = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis

f_h = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis

E_C = elastic modulus at cold temperature

E_h = elastic modulus at hot temperature
f_H = allowable stress at Maximum of CAEPIPE input temperatures T1 through T10

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_5) , due to sustained, thermal and alternating loadings shall satisfy the Eq. C10.3.4-3 of para. C10.3.4.

$$\sigma_5 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_C}{3Z} \leq f_{cr}$$

where,

P = maximum of CAEPIPE input pressures P1 through P10
D_o = outside diameter
e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance "c"
M_A = resulting bending moment due to sustained loads
M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of thermal anchor movements
Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0
f_{cr} = allowable creep stress value

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte

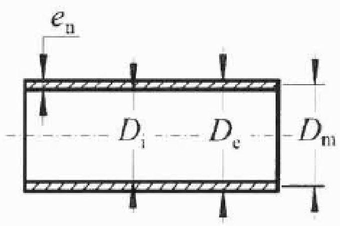
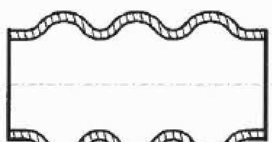
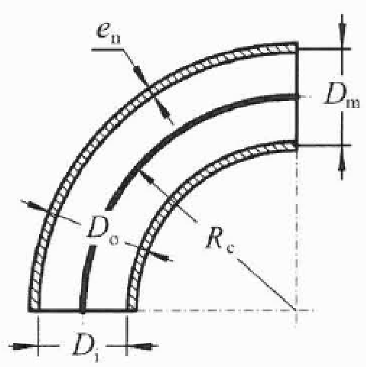
Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	Z
1. Tuyau droit soudé bout-à-bout 		1	1	1	1	$\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$
2. Tuyau droit ondulé ou coude ondulé 		5	2,5	2,5	2,5	
3. Coude ou cintre soudé bout-à-bout  Note : Pour les intersections tubulure-coude voir § C5.5.4.	$\frac{4\,e_n\,R_c}{D_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$ Notes (2) & (3)	$\frac{0,75}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0,9}{h^{2/3}}$	$\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

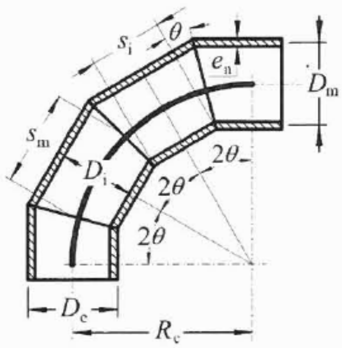
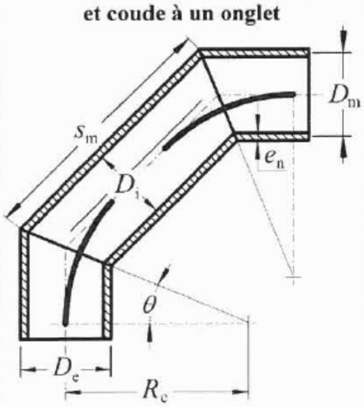
Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	Z
4.1. Coude à sections rapprochées ou à sections multiples  $s_m \leq \frac{D_m}{2}\left(1+\tan\theta\right)$ $R_c = \frac{s_m \cot\theta}{2}$	$\frac{4\ R_c\ e_n}{D_m^2}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$ $s_i \geq 6\ e_n$ $\theta \leq 22{,}5°$ Notes (2) & (3)	$\frac{0{,}9}{h^{2/3}}$ Notes (2),(3) & (4)	$\frac{0{,}9}{h^{2/3}}$	$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$
4.2. Coude à sections espacées et coude à un onglet  $s_m > \frac{D_m}{2}\left(1+\tan\theta\right)$ $R_c = \frac{D_m\left(1+\cot\theta\right)}{4}$	$\frac{4\ R_c\ e_n}{D_m^2}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$ $\theta \leq 22{,}5°$ Note (2)	$\frac{0{,}9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0{,}9}{h^{2/3}}$	$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

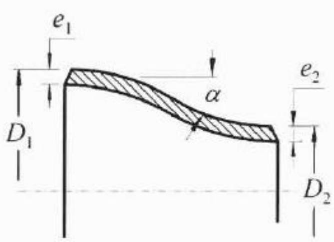
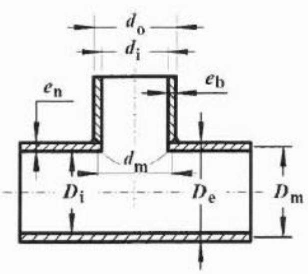
Composant	Caracté-ristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte i	i_0 hors du plan	i_i dans le plan	Module d'inertie Z
5.1. Réduction forgée 		1		$0,5 + \frac{\alpha}{100}\left(\frac{D_2}{e_2}\right)^{1/2}$ MAX = 2,0 (α en °) $\alpha \leq 60°$ $D_1/e_1 \leq 100$ $D_2/e_2 \leq 100$ Note (5)		
5.2. Réduction chaudronnée voir Figure C2.5				Note (14)		
6. Té reconstitué non renforcé avec tubulure posée ou pénétrante 	$\frac{2\,e_n}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ Notes (2), (12) & (16)	$\frac{0,9}{h^{2/3}\left(\sin\alpha\right)^{3/2}}$ α = angle d'inclinaison de la tubulure par rapport au collecteur Notes (2), (6), (7) & (11)	$\frac{3\,i_0}{4} + 0,25$	Collecteur $\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$ Dérivation $\frac{\pi}{4}d_m^2\ e_x$ e_x = MIN (e_f ; $i\ e_b$)

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

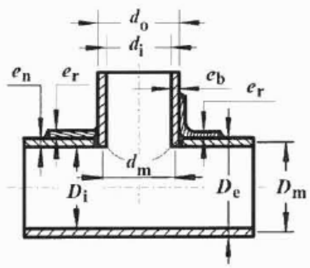
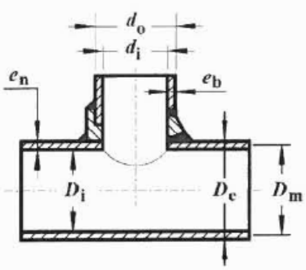
Composant	Caractéristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	Z
7. Té reconstitué avec tubulure posée ou pénétrante et renforcé par anneau ou selle de renfort  avec anneau renfort — avec selle de renfort	si $e_r \le 1,5\, e_n$ $\frac{2\left(e_n + 0,5\, e_r\right)^{5/2}}{e_n^{3/2}\, D_m}$ si $e_r > 1,5\, e_n$ $8\,\frac{e_r}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ Notes (2), (12) & (16)	$\frac{0,9}{h^{2/3}\left(\sin\alpha\right)^{3/2}}$ α = angle d'inclinaison de la tubulure par rapport au collecteur Notes (2), (6), (7) & (11)	$\frac{3\, i_0}{4} + 0,25$	Collecteur $\frac{\pi}{32}\,\frac{D_e^4 - D_i^4}{D_e}$ Dérivation $\frac{\pi}{4}\, d_m^2\, e_x$ e_x =MIN (e_f ; $i\, e_b$)
8. Piquage avec pièces forgées  Type manchon forgé — Type weldolets® etc.	$6,6\,\frac{e_n}{D_m}$	1 Type manchon forgé		2,1	2,1	
		1 Type weldolets® etc.		$\frac{0,9}{h^{2/3}}$ Notes (2), (6), (8) & (10)	$\frac{3\, i_0}{4} + 0,25$	

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

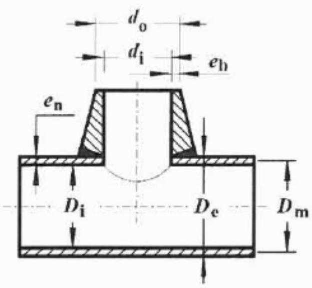
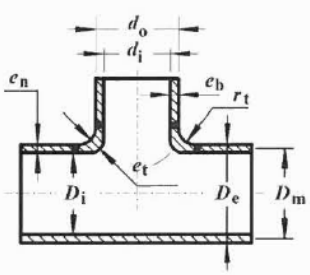
Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	Z
9. Piquage posé intégralement renforcé 	$6,6\,\dfrac{e_n}{D_m}$	1		$\dfrac{0,9}{h^{2/3}}$	$\dfrac{0,9}{h^{2/3}}$	
				Notes (2), (6), (8) & (10)		
10. Piquage avec selle de renfort insérée 	$\dfrac{8,8\,e_n}{D_m}$	1	$\dfrac{0,9}{h^{2/3}}$ et Tableau C10.2.6-2 Note 16	$\dfrac{0,9}{h^{2/3}}$	$\dfrac{3\,i_0}{4}+0,25$	
				$r_t \geq d_o/8$ $e_t \geq 1,5\,e_n$ Notes (2), (7), (8), (9) & (11)		

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

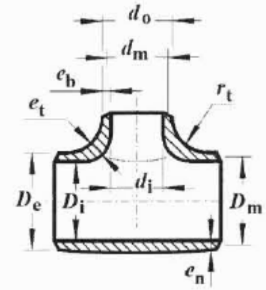
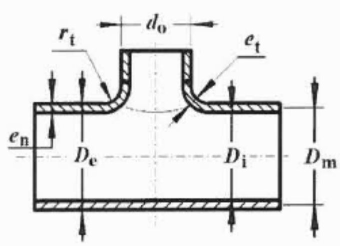
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte i	 i_0 hors du plan	 i_i dans le plan	Module d'inertie Z
11. Té forgé 	$\frac{8{,}8\ e_n}{D_m}$	1	$\frac{0{,}9}{h^{2/3}}$ Notes (2) & (12)	$\frac{0{,}9}{h^{2/3}}$ $e_t \geq 1{,}5\ e_n$ Notes (2), (7), (8), (9) & (11)	$\frac{3\ i_0}{4} + 0{,}25$	Collecteur $\frac{\pi}{32} \frac{D_e^4 - D_i^4}{D_e}$ Dérivation $\frac{\pi}{4} d_m^2\ e_x$ $e_x = \text{MIN}\ (e_f\ ;\ i\ e_b)$
12. Té à souder extrudé 	$\left(1+\frac{2\ r_t}{D_m}\right)\frac{2\ e_n}{D_m}$	1	Note (13)	$\frac{0{,}9}{h^{2/3}}$ $r_t \geq 0{,}05\ d_O$ $e_t \leq 1{,}5\ e_n$ Notes (2) & (7)	$\frac{3\ i_0}{4} + 0{,}25$	

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

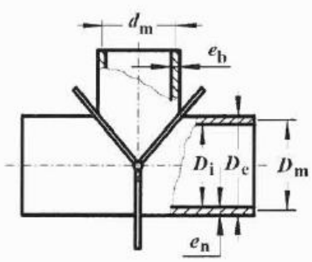
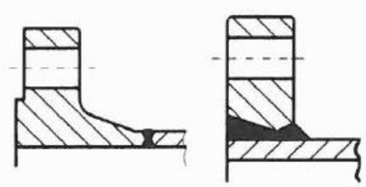
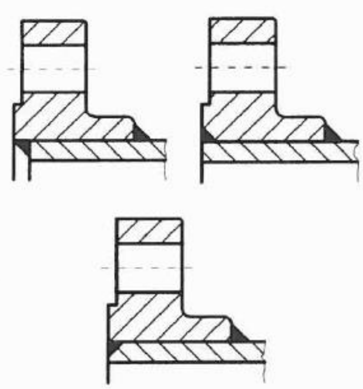
Composant	Caractéristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	Z
13. Triform 	$\frac{2\,e_n}{D_m}$	1	Note (13)	$\frac{0{,}9}{h^{2/3}}$	$\frac{3\,i_0}{4}+0{,}25$	Collecteur $\frac{\pi}{32}\frac{D_o^4-D_i^4}{D_o}$ Dérivation $\frac{\pi}{4}d_m^2\,e_x$ e_x = MIN (e_f ; $i\,e_b$)
14.1. Bride à assembler bout-à-bout 		1	1			
14.2. Bride à emmancher et à souder (soudée des deux côtés) 		1	1,2			

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

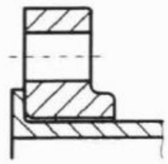
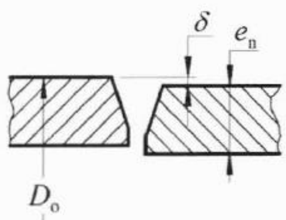
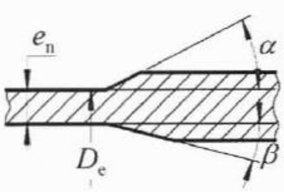
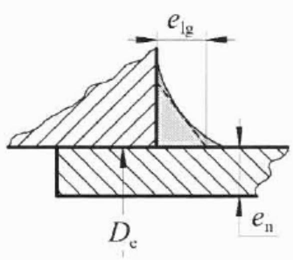
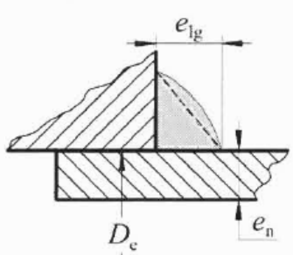
Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_1 dans le plan	Z
14.3. Bride tournantes 		1	1,6			
14.4 Bride à visser Voir Figure C6.3.7-2		1	2,3			
15.1 Soudure bout-à-bout 			1 $e_n \geq 5$ mm et $\delta \leq 0{,}1\ e_n$ Note (15)			$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$
			1,8 $e_n < 5$ mm ou $\delta > 0{,}1\ e_n$ Note (15)			
15.2. Transition d'épaisseur de paroi  $\alpha \leq 30°$ $\beta \leq 15°$			$1{,}3 + 0{,}0036\ D_o / e_n + 3{,}6\ \delta / e_n$ avec un maximum de 1,9 Note (15) sans soudure circonférentielle au niveau de la transition $\delta = 0$			$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	Z
15.3 Composant emmanché-soudé  forme concave avec raccordement régulier au tuyau		1	1,3	$\frac{2{,}1\, e_n}{e_{lg}}$ avec un minimum de 1,3 et un maximum de 2,1		$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$
15.4 Composant emmanché-soudé  forme convexe		1	2,1	$\frac{2{,}1\, e_n}{e_{lg}}$ avec un minimum de 1,3 et un maximum de 2,1		$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$

Notes du Tableau C10.2.6-1.

(1) Le coefficient de flexibilité k s'applique à la flexion dans tous les plans. Le coefficient pour la torsion est égal à 1 dans tous les cas à l'exception du cas 2 (tuyau droit et coude ondulé) pour lequel il est égal à 0,9.

(2) Les coefficients k, i, i_0, i_1 s'appliquent sur toute la longueur effective des coudes et des cintres (ligne épaissie sur les schémas) et à l'intersection des axes pour les tés et les piquages.

(3) Si ces composants sont munis :

- d'une bride à l'une de leurs extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/6}$,
- d'une bride à leurs deux extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/3}$.

(4) Si la pression est susceptible d'apporter une correction d'ovalisation (grand diamètre, petite épaisseur), les coefficients sont divisés par :

- $1+6\left(\dfrac{P}{E}\right)\left(\dfrac{r_m}{e_r}\right)^{7/3}\left(\dfrac{R_c}{r_m}\right)^{1/3}$ pour le coefficient k.

- $1+3{,}25\left(\dfrac{P}{E}\right)\left(\dfrac{r_m}{e_r}\right)^{5/2}\left(\dfrac{R_c}{r_m}\right)^{2/3}$ pour les coefficients i, i_0, i_1.

P étant la pression de service et E le module d'élasticité à 20°C.

(5) L'épaisseur de la paroi de la réduction ne doit pas être inférieure à e_1 sauf au voisinage de l'extrémité de petit diamètre où, toutefois, l'épaisseur de la paroi ne doit pas être inférieure à e_2.

(6) Le coefficient d'intensification de contrainte « hors du plan », pour un piquage dont le rapport des diamètres de la tubulure et du collecteur est supérieur à 0,5, peut être non-conservatif. Par ailleurs, il a été démontré qu'un raccordement régulier par une soudure de forme concave réduit la valeur de ce coefficient. Le choix d'une valeur appropriée pour ce coefficient reste donc de la responsabilité du Concepteur.

(7) Les coefficients d'intensification de contrainte pour les raccordements de tubulures sont basés sur des essais avec au moins deux diamètres de tuyau droit de chaque coté de l'axe de la tubulure. Le cas de tubulures plus proches requiert une attention particulière.

(8) Les pièces forgées utilisées doivent être appropriées aux conditions de service.

(9) Lorsque les limitations portant sur le rayon et l'épaisseur ne sont pas respectées et en l'absence de données fiables la caractéristique de flexibilité doit être prise égale à $\dfrac{2\,e_n}{D_m}$.

(10) Le Concepteur doit vérifier que le dimensionnement en fonction de la pression est au moins équivalent à celui du tuyau droit.

(11) Les coefficients ne s'appliquent qu'aux piquages à axes concourants.

(12) D'autres valeurs peuvent être utilisées sous réserve de justification.

(13) En l'absence de données fiables, la détermination des coefficients est de la responsabilité du Concepteur.

(14) En l'absence de données plus précises, les coefficients d'intensification de contrainte peuvent être pris égaux à 2,5.

(15) Le coefficient s'applique dans le cas où les tolérances de fabrication (voir Partie F) sont respectées. Dans le cas contraire, la détermination des coefficients est de la responsabilité du Concepteur.

(16) Pour des rapports $\dfrac{d_m}{D_m}\le 0{,}5$, le coefficient d'intensification de contrainte peut être déterminé à partir de la formulation ci-dessous :

$$i=\mathrm{MIN}\left[0{,}45\left\{\frac{D_m}{2\,e_n}\right\}^{\frac{2}{3}}\left\{\frac{d_m}{D_m}\right\}^{\frac{1}{2}}\left\{\frac{e_b}{e_n}\right\}F\ ;\ \left(0{,}17\left\{\frac{D_m}{2\,e_n}\right\}^{\frac{2}{3}}+0{,}25\right)\left\{\frac{e_b}{e_n}\right\}F\right]$$

avec :

$F = 1$ pour une soudure meulée arasée

$F = 1{,}6$ dans les autres cas

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from

$$P = \frac{2fze}{D - e}$$

where

P = allowable pressure
f = allowable stress
z = joint factor (input as material property in CAEPIPE)
e = nominal pipe thickness× (1 – mill tolerance/100) – corrosion allowance "c"

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. shouldbe included in corrosion allowance in CAEPIPE)

D=outside diameter

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thicknesse_{equi}

$$e_{equi} = \frac{e}{t_f}$$

Where

$$t_f = \left[\frac{R/D - 0.25}{R/D - 0.50}\right]$$

<u>For closely spaced miter bends</u>, the allowable pressure is calculated from

$$P = \min\left[\left(\frac{2fze}{D_m}.\frac{e}{e + 0.643\tan\theta\sqrt{0.5D_m e}}\right), \left(\frac{2fze}{D_m}.\frac{R - 0.5D_m}{R - 0.25D_m}\right)\right] \text{ with } \theta \le 22.5$$

<u>For widely spaced miter bends</u>, the allowable pressure is calculated from

$$P = \min\left[\left(\frac{2fze}{D_m}.\frac{e}{e + 0.643\tan\theta\sqrt{0.5D_m e}}\right), \left(\frac{2fze}{D_m}.\frac{R - 0.5D_m}{R - 0.25D_m}\right)\right] \text{with } \theta \le 22.5$$

$$P = \left(\frac{2fze}{D_m}.\frac{e}{e + 1.25\tan\theta\sqrt{0.5D_m e}}\right) \text{ with } \theta \le 22.5$$

Where

D_m = mean diameter of pipe = D-t_n
R = effective bend radius of the miter

θ = miter half angle
t_n = nominal thickness

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) iscalculated from

$$\sigma_1 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} \leq f_h$$

Where

P = maximum of CAEPIPE input pressures P1, P2 and P3
D_o = outside diameter
e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance "c"
i = stress intensification factor; the product of 0.75i shall not be less than 1.0
M_A = resulting bending moment due to sustained loads
Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
f_h = hot allowable stress

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently

$$\sigma_2 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kf_h$$

M_B = resultant bending moment due to occasional load
k = 1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE k =1.2 is used for occasional loading.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from

$$\sigma_3 = \frac{iM_C}{Z} + \leq f_a$$

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
f_a = $U(1.25f_C + 0.25f_h)\frac{E_h}{E_c}$
U = cyclic stress range reduction factor as mentioned below

Number of cycle	Stress range reduction factor U
$f_a <= 7000$	1.0
7001 to 140000	0.9
14001 to 220000	0.8
22001 to 0.7	0.7
45001 to 100000	0.6
100001 to 2000000	0.5

f_C = allowable stress at cold temperature
f_C = allowable stress at hot temperature
E_C = elastic modulus at cold temperature
E_h = elastic modulus at hot temperature

$$\sigma_4 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_h + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_5) , due to sustained, thermal and alternating loadings shall satisfy the equation below.

$$\sigma_5 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_C}{3Z} \leq f_{cr}$$

Where

f_{cr} = allowable creep stress value

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte

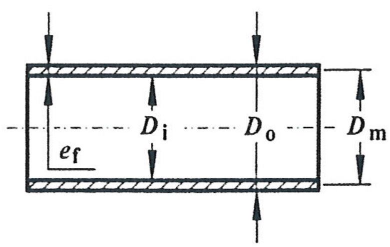
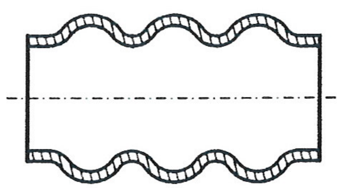
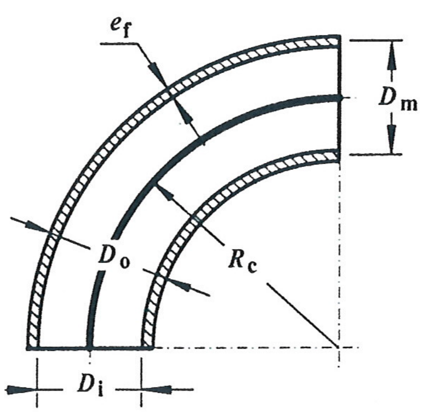
Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	
1. Tuyau droit soudé bout-à-bout 		1	1	1	1	$\frac{\pi}{32}\,\frac{D_e^4 - D_i^4}{D_e}$
2. Tuyau droit ondulé ou coude ondulé 		5	2,5	2,5	2,5	
3. Coude ou cintre soudé bout-à-bout  Note : Pour les intersections tubulure-coude voir § C2.2.7.4.4.	$\frac{4\,e_f\,R_c}{D_m^2}$	$\frac{1{,}65}{h}$	$\frac{0{,}9}{h^{2/3}}$ Notes (2) & (3)	$\frac{0{,}75}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0{,}9}{h^{2/3}}$	$\frac{\pi}{32}\,\frac{D_e^4 - D_i^4}{D_e}$

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

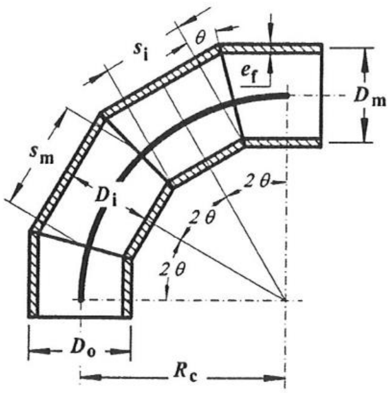
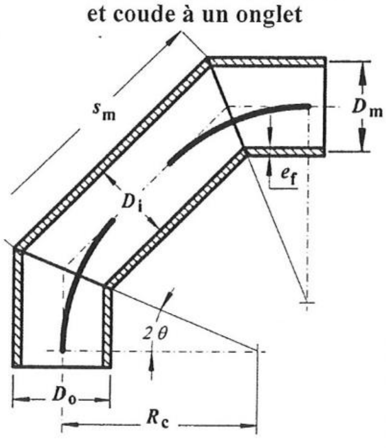
Composant	Caractéristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	
4.1 Coude à sections rapprochées ou à sections multiples  $s_m \le \frac{D_m}{2}(1+\tan\theta)$ $R_c = \frac{s_m \cot\theta}{2}$	$\frac{4\,R_c\,e_f}{D_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ $s_i \ge 6\,e_f$ $\theta \le 22,5°$ Notes (2) & (3)	$\frac{0,9}{h^{2/3}}$ Notes (2),(3) & (4)	$\frac{0,9}{h^{2/3}}$	$\frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$
4.2 Coude à sections espacées et coude à un onglet  $s_m > \frac{D_m}{2}(1+\tan\theta)$ $R_c = \frac{D_m(1+\cot\theta)}{4}$	$\frac{4\,R_c\,e_f}{D_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ $\theta \le 22,5°$ Note (2)	$\frac{0,9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0,9}{h^{2/3}}$	$\frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

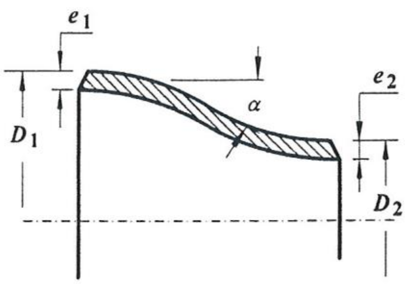
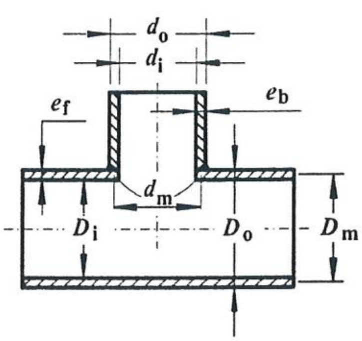
Composant	Caracté-ristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte i	i_0 hors du plan	i_i dans le plan	Module d'inertie
5.1 Réduction forgée 		1		$0{,}5 + \frac{\alpha}{100}\left(\frac{D_2}{e_2}\right)^{1/2}$ MAX = 2,0 (α en °) $\alpha \leq 60°$ $d_1/e_1 \leq 100$ $d_2/e_2 \leq 100$ Note (5)		
5.2 Réduction chaudronnée voir figure C2.2.4				Note (14)		
6. Té reconstitué non renforcé avec tubulure posée ou pénétrante 	$\frac{2\,e_f}{D_m}$	1	$\frac{0{,}9}{h^{2/3}}$ Notes (2) & (12)	$\frac{0{,}9}{h^{2/3}\left(\sin\alpha\right)^{3/2}}$ α = angle d'inclinaison de la tubulure par rapport au collecteur	$\frac{3\,i_0}{4} + 0{,}25$	Collecteur $\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$ Dérivation $\frac{\pi}{4} d_m^2\ e_x$ e_x = MIN (e_f ; $i\,e_b$)
				Notes (2), (6), (7) & (11)		

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

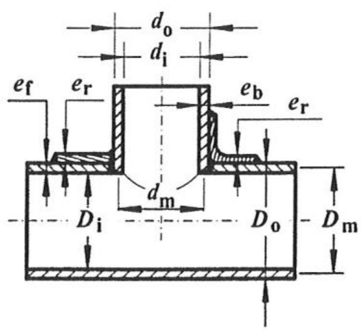
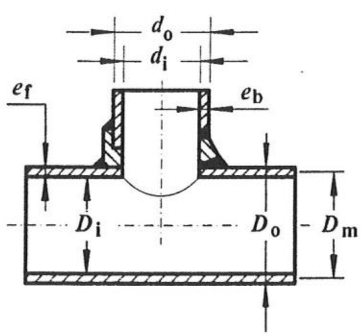
Composant	Caracté-ristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte i	i_0 hors du plan	i_i dans le plan	Module d'inertie
7. Té reconstitué avec tubulure posée ou pénétrante et renforcé par anneau ou selle de renfort  avec anneau renfort / avec selle de renfort	si $e_r \le 1,5\ e_f$ $\frac{2\left(e_f + 0,5\ e_r\right)^{5/2}}{e_f^{\ 3/2}\ D_m}$ si $e_r > 1,5\ e_f$ $8\ \frac{e_r}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ Notes (2) & (12)	$\frac{0,9}{h^{2/3}\left(\sin\alpha\right)^{3/2}}$ α = angle d'inclinaison de la tubulure par rapport au collecteur Notes (2), (6), (7) & (11)	$\frac{3\ i_0}{4} + 0,25$	Collecteur $\frac{\pi}{32}\ \frac{D_e^4 - D_i^4}{D_e}$ Dérivation $\frac{\pi}{4}\ d_m^2\ e_x$ e_x =MIN (e_f ; $i\ e_b$)
8. Piquage avec pièces forgées  Type manchon forgé / Type weldolets etc.	$6,6\ \frac{e_f}{D_m}$	1 Type manchon forgé 1 Type weldolets etc.		2,1 $\frac{0,9}{h^{2/3}}$ Notes (2), (6), (8) & (10)	2,1 $\frac{3\ i_0}{4} + 0,25$	

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

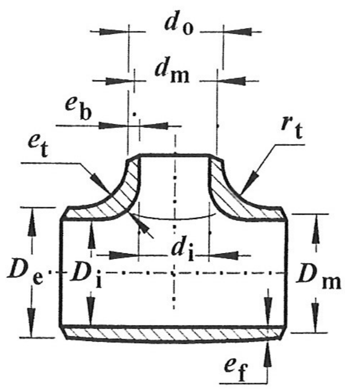
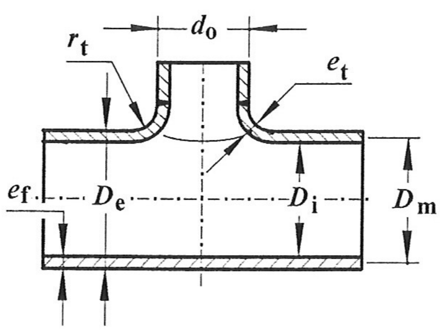
Composant	Caracté-ristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte i	 i_0 hors du plan	 i_i dans le plan	Module d'inertie
11. Té forgé 	$\frac{8,8\ e_f}{D_m}$	1	$\frac{0,9}{h^{2/3}}$	$\frac{0,9}{h^{2/3}}$ $e_t \geq 1,5\ e_f$ Notes (2), (7), (8), (9) & (11)	$\frac{3\ i_0}{4} + 0,25$	Collecteur $\frac{\pi}{32}\ \frac{D_e^4 - D_i^4}{D_e}$ Dérivation $\frac{\pi}{4}\ d_m^2\ e_x$ e_x = MIN (e_f ; $i\ e_b$)
12. Té à souder extrudé 	$\left(1+\frac{2\ r_t}{D_m}\right)\frac{2\ e_f}{D_m}$	1	Note (13)	$\frac{0,9}{h^{2/3}}$ $r_t \geq 0,05\ d_o$ $e_t \leq 1,5\ e_f$ Notes (2) & (7)	$\frac{3\ i_0}{4} + 0,25$	

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

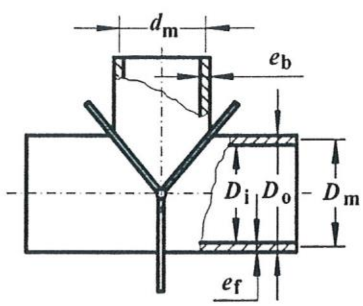
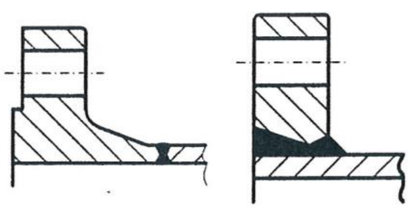
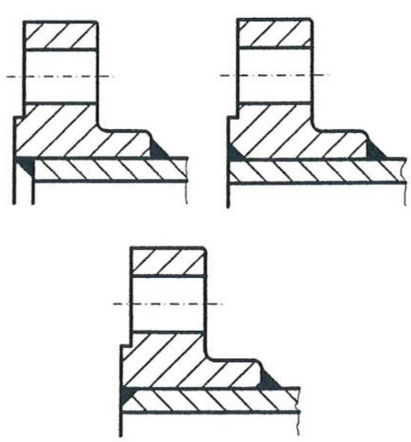
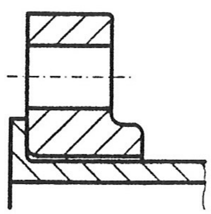
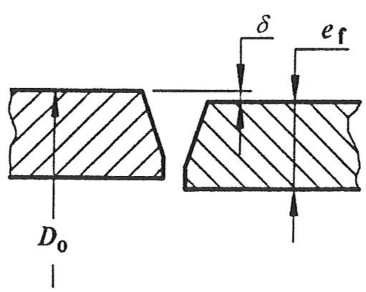
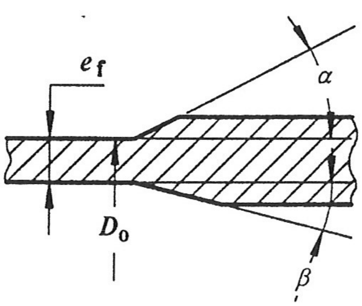
Composant	Caracté-ristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte i	i_0 hors du plan	i_i dans le plan	Module d'inertie
13. Triform 	$\frac{2\ e_f}{D_m}$	1	Note (13)	$\frac{0,9}{h^{2/3}}$	$\frac{3\ i_0}{4} + 0,25$	Collecteur $\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$ Dérivation $\frac{\pi}{4} d_m^2\ e_x$ $e_x = \text{MIN}\ (e_f\ ;\ i\ e_b)$
14.1 Bride à assembler bout-à-bout 		1	1			
14.2 Bride à emmancher et à souder (soudée des deux côtés) 		1	1,2			

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

<table>
<tr><th rowspan="2">Composant</th><th rowspan="2">Caracté-ristique de flexibilité

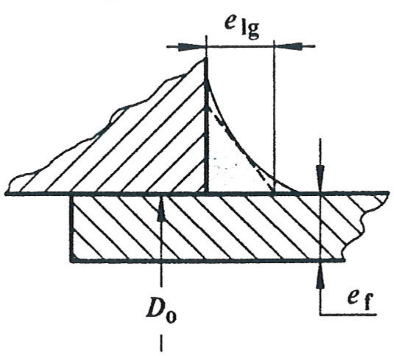
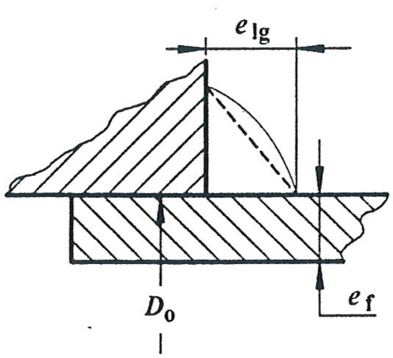
h</th><th rowspan="2">Coefficient de flexibilité

k
Note (1)</th><th colspan="3">Coefficients d'intensification de contrainte</th><th rowspan="2">Module d'inertie</th></tr>
<tr><th>i</th><th>i_0
hors du plan</th><th>i_i
dans le plan</th></tr>
<tr><td>14.3 Bride tournantes
</td><td></td><td>1</td><td colspan="3">1,6</td><td></td></tr>
<tr><td>14.4 Bride à visser
Voir figure C2.2.8.3.7-2</td><td></td><td>1</td><td colspan="3">2,3</td><td></td></tr>
<tr><td rowspan="2">15.1 Soudure bout-à-bout

</td><td rowspan="2"></td><td rowspan="2"></td><td colspan="3">1
$e_n \geq 5$ mm
et $\delta \leq 0,1\ e_f$
Note (15)</td><td rowspan="2">$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$</td></tr>
<tr><td colspan="3">1,8
$e_n < 5$ mm ou
$\delta > 0,1\ e_f$
Note (15)</td></tr>
<tr><td>15.2 Transition d'épaisseur de paroi


$\alpha \leq 30°$ $\beta \leq 15°$</td><td></td><td></td><td colspan="3">$1,3 + 0,0036\ D_0 / e_f + 3,6\ \delta / e_f$
avec un maximum de 1,9
Note (15)

sans soudure circonférentielle au niveau de la transition $\delta = 0$</td><td>$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$</td></tr>
</table>

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

Composant	Caracté-ristique de flexibilité	Coefficient de flexibilité	Coefficients d'intensification de contrainte			Module d'inertie
	h	k Note (1)	i	i_0 hors du plan	i_i dans le plan	
15.3 Composant emmanché-soudé  forme concave avec raccordement régulier au tuyau		1	1,3	$\frac{2,1\ e_f}{e_{lg}}$ avec un minimum de 1,3 et un maximum de 2,1		$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$
15.4 Composant emmanché-soudé  forme convexe		1	2,1	$\frac{2,1\ e_f}{e_{lg}}$ avec un minimum de 1,3 et un maximum de 2,1		$\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$

Notes du tableau C3.2.6-1

(1) Le coefficient de flexibilité k s'applique à la flexion dans tous les plans. Le coefficient pour la torsion est égal à 1 dans tous les cas à l'exception du cas 2 (tuyau droit et coude ondulé) pour lequel il est égal à 0,9.

(2) Les coefficients k, i, i_0, i_1 s'appliquent sur toute la longueur effective des coudes et des cintres (ligne épaissie sur les schémas) et à l'intersection des axes pour les tés et les piquages.

(3) Si ces composants sont munis :

- d'une bride à l'une de leurs extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/6}$,
- d'une bride à leurs deux extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/3}$.

(4) Si la pression est susceptible d'apporter une correction d'ovalisation (grand diamètre, petite épaisseur), les coefficients sont divisés par :

- $1+6\left(\frac{P}{E}\right)\left(\frac{r_m}{e_r}\right)^{7/3}\left(\frac{R_c}{r_m}\right)^{1/3}$ pour le coefficient k.
- $1+3{,}25\left(\frac{P}{E}\right)\left(\frac{r_m}{e_r}\right)^{5/2}\left(\frac{R_c}{r_m}\right)^{2/3}$ pour les coefficients i, i_0, i_1.

P étant la pression de service et E le module d'élasticité à 20 °C.

(5) L'épaisseur de la paroi de la réduction ne doit pas être inférieure à e_1 sauf au voisinage de l'extrémité de petit diamètre où, toutefois, l'épaisseur de la paroi ne doit pas être inférieure à e_2.

(6) Le coefficient d'intensification de contrainte « hors du plan », pour un piquage dont le rapport des diamètres de la tubulure et du collecteur est supérieur à 0,5, peut être non-conservatif. Par ailleurs, il a été démontré qu'un raccordement régulier par une soudure de forme concave réduit la valeur de ce coefficient. Le choix d'une valeur appropriée pour ce coefficient reste donc de la responsabilité du Concepteur.

(7) Les coefficients d'intensification de contrainte pour les raccordements de tubulures sont basés sur des essais avec au moins deux diamètres de tuyau droit de chaque coté de l'axe de la tubulure. Le cas de tubulures plus proches requiert une attention particulière.

(8) Les pièces forgées utilisées doivent être appropriées aux conditions de service.

(9) Lorsque les limitations portant sur le rayon et l'épaisseur ne sont pas respectées et en l'absence de données fiables la caractéristique de flexibilité doit être prise égale à $\frac{2\,e_f}{D_m}$.

(10) Le Concepteur doit vérifier que le dimensionnement en fonction de la pression est au moins équivalent à celui du tuyau droit.

(11) Les coefficients ne s'appliquent qu'aux piquages à axes concourants.

(12) D'autres valeurs peuvent être utilisées sous réserve de justification.

(13) En l'absence de données fiables, la détermination des coefficients est de la responsabilité du Concepteur.

(14) En l'absence de données plus précises, les coefficients d'intensification de contrainte peuvent être pris égaux à 2,5.

(15) Le coefficient s'applique dans le cas où les tolérances de fabrication (voir partie F) sont respectées. Dans le cas contraire, la détermination des coefficients est de la responsabilité du Concepteur.

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from

$$S_L = \frac{P(D-t)}{4t} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum pressure

D = outside diameter

t = nominal wall thickness

i = stress intensification factor. The product $0.75i$, shall not be less than 1.0

M_A = resultant bending moment due to sustained loads $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus, for reduced outlets, effective section modulus

S_h = hot allowable stress: smaller of:
0.67 yield stress at temperature
0.44 tensile strength at 20º C
0.67 rupture stress (after 100,000 hours at temperature)

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasionalloads (S_O),such as earthquake or wind. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from

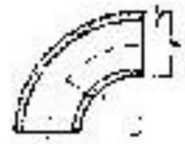
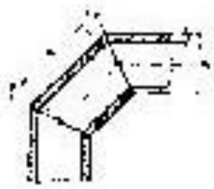
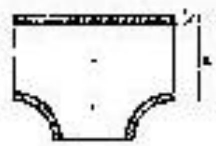
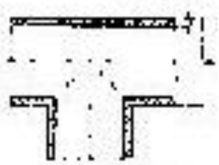
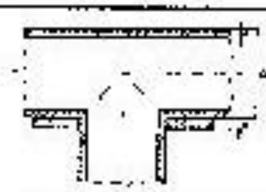
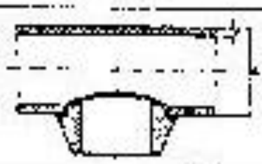
$$S_E = \frac{iM_C}{Z} \leq S_A$$

where

M_C = resultant moment due to thermal expansion

S_A = smaller of:
C_f (0.8 yield strength at 20º C + 0.13 hot yield strength)
C_f (0.8 yield strength at 20º C + 0.2 x 0.67 rupture stress)

C_f = stress range reduction factor

	leidingelement piping component			h	k	i
	gladde bocht met m (≤ 2) flenzen pipe bend or elbow with m (≤ 2) flanged ends			$\frac{4dR}{(D_a-d)^2}$	$1{,}65h^{\frac{m-6}{6}}$	$0{,}9h^{\frac{m-4}{6}}$
	korte segmentbocht met m (≤ 2) flenzen closely spaced mitre bend with m (≤ 2) flanged ends $r < \frac{D_a-d}{2}(1+\tan\varphi)$			$\frac{2dr}{(D_a-d)^2}\lvert\cot\varphi\rvert$	$1{,}52h^{\frac{m-5}{6}}$	$0{,}9h^{\frac{m-4}{6}}$
	lange segmentbocht widely spaced mitre bend $r \geq \frac{D_a-d}{2}(1+\tan\varphi)$			$\frac{d}{D_a-d}(1+\cot\varphi)$	$1{,}52h^{-\frac{5}{6}}$	$0{,}9h^{-\frac{2}{3}}$
T-stukken en aftakkingen Tees and branches	gesmeed of geperst forged or pressed			$\frac{8{,}8d}{D_a-d}$	1	$0{,}9h^{-\frac{2}{3}}$
	opgebouwd, onversterkt fabricated, unreinforced			$\frac{2d}{D_a-d}$		
	opgebouwd met ringversterking fabricated, with pad or saddle reinforcement	$d_r \leq 1{,}5d$		$\frac{2(d+0{,}5d_r)^{2{,}5}}{(D_a-d)\,d^{1{,}5}}$		
		$d_r > 1{,}5d$		$\frac{8{,}1d}{D_a-d}$		
	opgebouwd, versterkt fabricated, reinforced			$\frac{8{,}8d}{D_a-d}$		
Pijpverbindingen Pipe connections	stompe las butt weld		–	–	1	1
	schroefverbinding screwed connection		–	–		2,3
	blokflens met twee hoeklassen double welded slip-on flange		–	–		1,3

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 6.3.

$$p = \frac{2\sigma_{tn} z_L s_{eff}}{D_y m - s_{eff}}$$

where

p = allowable pressure
σ_{tn} = allowable stress
z_L = joint efficiency of longitudinal weld (input as material property)
s_{eff} = nominal pipe thickness × (1 – mill tolerance/100) – corrosion allowance
D_y = outside diameter
D_i = inside diameter $= D_y - s_{eff}$
m = pressure coefficient
= 1.0 for $D_y/D_i < 1.6$
= $0.25(D_y/D_i) + 0.6$ for $1.6 \leq D_y/D_i \leq 2.0$

Sustained Stress

Stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 9.37.

$$S_L = \frac{p_{max} D_y}{4 s_{eff} z_C} + \frac{0.75 k_1 M_A}{W_y} \leq \sigma_{tn2}$$

where

p_{max} = maximum pressure
z_C = joint efficiency of circumferential weld (input as material property)
k_1 = stress intensification factor. The product $0.75k_1$ shall not be less than 1.0
M_A = resultant bending moment due to sustained loads
W_y = section modulus, for reduced outlets, effective section modulus
σ_{tn2} = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of the stress due to sustained loads (S_L) and the stress (S_O) due to occasional loads such as earthquake or wind from Equation 9.38. Wind and earthquake are not considered concurrently.

$$S_{LO} = \frac{p_{max} D_y}{4 s_{eff} z_C} + \frac{0.75 k_1 (M_A + M_B)}{W_y} \leq 1.2\sigma_{tn2}$$

where

M_B = resultant bending moment due to occasional loads

Expansion Stress

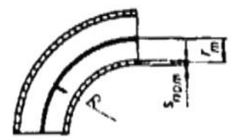
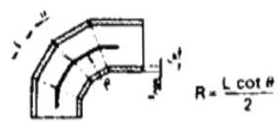
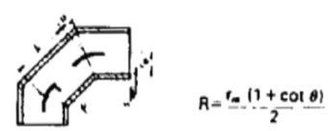
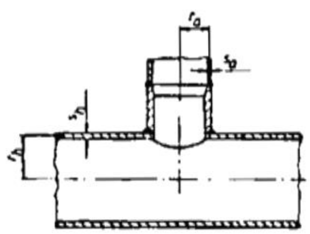
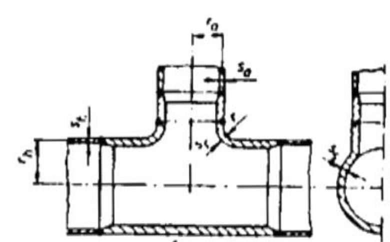
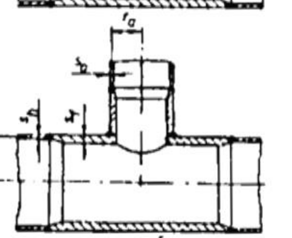
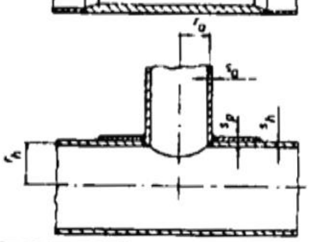
The stress (S_E) due to thermal expansion is calculated from Equation 9.39.

$$S_E = \frac{k_1 M_C}{W_y} \leq S_r$$

where
M_C = resultant bending moment due to thermal expansion
S_r = $f(1.17\sigma_1 + 0.17\sigma_2)$ from Equation 9.43
f = stress range reduction factor taken from Table 9.1
σ_1 = smaller of σ_{tn1} and $0.267R_m$
σ_2 = smaller of σ_{tn2} and $0.367R_m$
σ_{tn1} = allowable stress at cold condition
σ_{tn2} = allowable stress at hot condition
R_m = tensile strength at room temperature
At moderate temperatures (up to 370º C) for carbon steel, low alloy steel and chromium steel (specified as CS material type) and up to 425º C for austenitic stainless steel (specified as AS material type), the limits $0.267R_m$ and $0.367R_m$ are disregarded and S_r is selected as smaller of $S_r'$and S_r'',

where
S_r' = $1.17\sigma_{tn1} + 0.20\sigma_{tn2}$
S_r'' = $290f - \sigma_{tn2}$

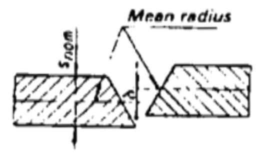
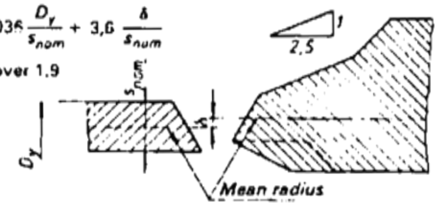
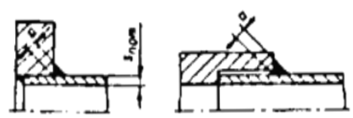
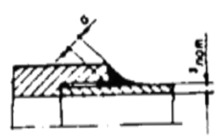
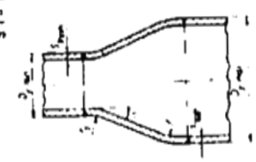
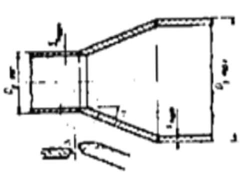
Table 9:2 k and k_1

Item	Type of fitting	h	k	k_1	Figure
1	Bend, see notes 1 and 2	$\frac{s_{nom} \cdot R}{r_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$	
2	Mitre bend of segment length L smaller than r_m (1 + tan θ); see notes 1 and 2	$\frac{L \cdot s_{nom} \cdot \cot \theta}{2 r_m^2}$	$\frac{1,5}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$	
3	Mitre bend of segment length L not less than r_m (1 + tan θ) or inclined circumferential welds; see notes 1 and 3	$\frac{s_{nom}}{2 r_m}(1 + \cot \theta)$	1	$\frac{0,9}{h^{2/3}}$	
4	Branch without local reinforcement of the main pipe; see note 1	$\frac{s_h}{r_h}$	1	$\frac{0,9}{h^{2/3}}$	
5	Raised edges on main pipe or branch radiused at joint; see note 1	$\left(\frac{s_e}{s_h}\right)^{3/2} \cdot \frac{s_e \cdot R_e}{r_h^2}$	1	$\frac{0,9}{h^{2/3}}$	
6	Branch on locally thickened main pipe; see note 1				
	$L < \frac{d_i}{2} + 1,8\sqrt{D_y \cdot s_l}$	$\frac{\left(\frac{s_h}{2} + \frac{s_l}{2}\right)^{5/2}}{r_h \cdot s_h^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	
	$L \geq \frac{d_i}{2} + 1,8\sqrt{D_y \cdot s_l}$	$\frac{s_l^{5/2}}{r_h \cdot s_h^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	
7	Branch with plate reinforcement; see notes 1 and 4	$\frac{\left(s_h + \frac{s_p}{2}\right)^{5/2}}{r_h \cdot s_h^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	

Symbols (items 4–7)

r = fillet radius
r_a = mean radius of branch $\left(= \frac{d_y - s_a}{2}\right)$
R_e = effective radius = $r + r_a$
r_h = mean radius of main pipe $\left(= \frac{D_y - s_h}{2}\right)$
s_a = nominal wall thickness of branch
s_h = nominal wall thickness of main pipe
s_e = effective wall thickness = $0,5(s_r + s_t)$
s_r = wall thickness in fillet (see item 5)
s_t = wall thickness of main pipe side at branch (see item 5)
s_l = wall thickness of locally thickened main pipe
s_p = thickness of plate reinforcement

Table 9:2 (cont.)

Item	Type of fitting	h	k	k_1	Figure
8	Butt weld $s_{nom} > 4{,}5$ mm and $\delta/s_{nom} \leq 0{,}1$ $s_{nom} \leq 4{,}5$ mm or $\delta/s_{nom} > 0{,}1$		1 1	1,0 1,8 (If the weld is ground flush inside and out, k_1 may be set = 1,0)	
9	Butt weld between dissimilar thicknesses according to Section 11.2.2		1	$1{,}3 + 0{,}0036\,\frac{D_y}{s_{nom}} + 3{,}6\,\frac{\delta}{s_{nom}}$ but not over 1,9	
10	Fillet weld (spigot type)		1	2,1	 Flange $a \geq 1{,}2\,s_{nom}$ Pipe joint $a \geq 1{,}05\,s_{nom}$
11	Concave fillet weld (spigot type) with even transition to the pipe (no undercut allowed)		1	1,3	 $a \geq 1{,}05\,s_{nom}$
12	Conical reducer with defined knuckles r and r_1, complying with Section 6.5.2.3; see notes 1 and 5		1	$0{,}5 + 0{,}01 \cdot \alpha \sqrt{\frac{D_{y\,min}}{s_{1\,nom}}}$ but not over 2,0	
13	Conical reducer without knuckles; see notes 1 and 5 $s_{1\,nom} > 4{,}5$ mm and $\delta/s_{1\,nom} \leq 0{,}1$ $s_{1\,nom} \leq 4{,}5$ mm or $\delta/s_{1\,nom} > 0{,}1$		1	$0{,}9 + 0{,}017 \cdot \alpha \sqrt{\frac{D_{y\,min}}{s_{1\,nom}}}$ $1{,}25 + 0{,}023 \cdot \alpha \sqrt{\frac{D_{y\,min}}{s_{1\,nom}}}$ but not less than 1,8	
14	Thread joint or connection to threaded flange		1	2,3	

Symbols (items 12–13)

$D_{y\,min}$, $D_{y\,max}$, α: see Section 6.5
$s_{1\,nom}$ = nominal wall thickness of the smaller pipe
s_{nom} = nominal wall thickness of the larger pipe
δ = difference in mean radius across a weld

Allowable Pressure

The allowable pressure is calculated from 5.3.2.1.

$$P = 2StFLJT/D$$

where
P = allowable pressure
S = specified minimum yield strength
t = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance
F = design factor = 0.8 for steel pipe (from 5.2.3)
L = location factor (from Table 5.1)
J = joint factor (from Table 5.2), input as material property
T = temperature derating factor for steel pipe (from Table 5.3)
D = outside diameter

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) and wind loads, is calculated from (5.6.3.5)

$$S_L = \frac{PD}{4t} + i\frac{M}{Z} \leq SFLJT$$

where
P = maximum pressure
D = outside diameter
t = minimum wall thickness
i = stress intensification factor
M = resultant bending moment due to sustained loads
Z = corroded section modulus
S = specified minimum yield strength
F = design factor
L = location factor
J = joint factor
T = temperature derating factor

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained and wind loads (S_L) and stress due to occasional loads (S_O), such as earthquake. The allowable stress for occasional stress is not given in the code, therefore it is conservatively taken the same as the sustained stress allowable.

$$S_{LO} = S_L + i\frac{M}{Z} \leq SFLJT$$

where

M = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from (5.6.3.3).

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where
S_b = resultant bending stress $= iM_b/Z$
S_t = torsional stress $= M_t/2Z$
M_b = resultant bending moment due to expansion loads
M_t = torsional moment due to expansion loads
Z = un-corroded section modulus

Table 5.5
Flexibility and Stress Intensification Factors

Description	Flexibility Factor *k*	Stress Intens. Factor *i*
Buttwelded joint, reducer, or welding neck flange	1	1.0
Double-welded slip-on or socket welding flange	1	1.2
Fillet welded joint, or single-welded socket welding flange	1	1.3
Lap joint flange (with CSA Standard CAN3-Z245.12) (lap joint stub)	1	1.6
Screwed pipe joint, or screwed flange	1	2.3
Corrugated pipe, straight or curved, or creased bend**	5	2.5

Description	Flexibility Factor *k**	Stress Intens. Factor *i**	Flexibility Characteristic *h*	See sketch
Welding elbow, or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{tR}{r^2}$	A
Mitre bend with close spacing†‡ $s < r(1 + \tan\alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\alpha}{2} \cdot \frac{ts}{r^2}$	B
Mitre bend with wide spacing ‡§ $s \geq r(1 + \tan\alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\alpha}{2} \frac{t}{r}$	C
Welding tee per CSA Standard CAN3-Z245.11	1	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{t}{r}$	D
Reinforced fabricated tee, with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2\,T)^{5/2}}{t^{3/2} r}$	E
Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	F

**The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system, and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for curved and mitre elbows, and to the intersection point for tees.*

Where flanges are attached to one or both ends, the values of k and i in the Table shall be multiplied by the following factors:

One end flanged: $(h)^{1/6}$

Both ends flanged: $(h)^{1/3}$

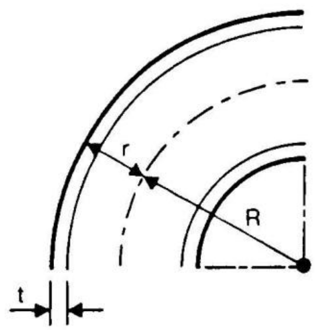
‡Subject to the limitations of Clause 5.4.2.2.2(d).

§Also includes single-mitre joint.

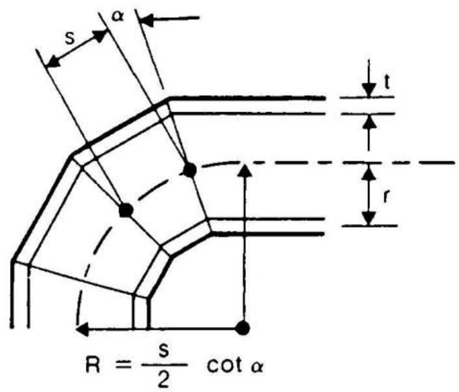
**Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Note: *Designers are cautioned that specific cases may require more comprehensive analysis than that specified in Clause 5.6.*

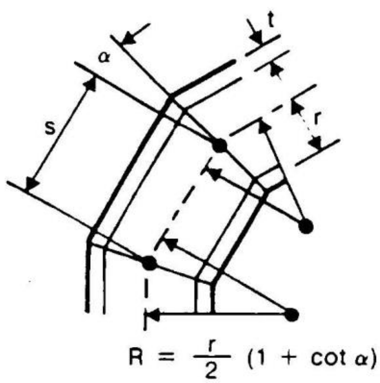
Table 5.5 (Concluded)



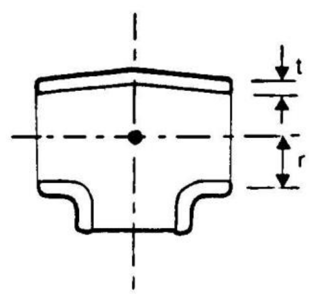
Sketch A



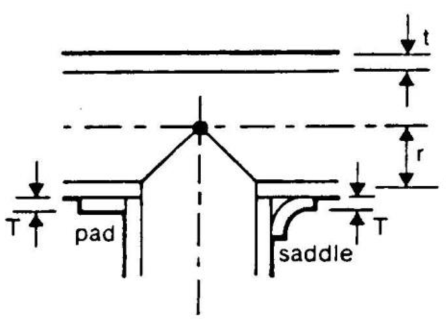
Sketch B



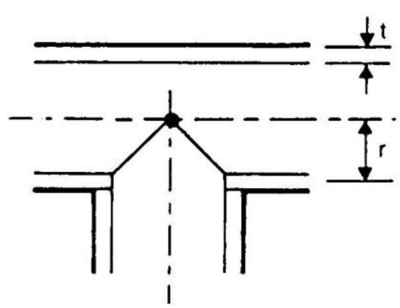
Sketch C



Sketch D



Sketch E



Sketch F

Allowable Pressure

The allowable pressure is calculated from 5.4.2.1.

$$P = 2StFLJT/D$$

where
P = allowable pressure
S = specified minimum yield strength
t = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance
F = design factor = 0.8 for steel pipe (from 5.2.3)
L = location factor (from Table 5.1)
J = joint factor (from Table 5.2), input as material property
T = temperature derating factor for steel pipe (from Table 5.3)
D = outside diameter

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) and wind loads, is calculated from (5.19.3.5)

$$S_L = \frac{PD}{4t} + i\frac{M}{Z} \leq SFLJT$$

where
P = maximum pressure
D = outside diameter
t = minimum wall thickness
i = stress intensification factor
M = resultant bending moment due to sustained loads
Z = corroded section modulus
S = specified minimum yield strength
F = design factor
L = location factor
J = joint factor
T = temperature derating factor

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained and wind loads (S_L) and stress due to occasional loads (S_O), such as earthquake. The allowable stress for occasional stress is not given in the code, therefore it is conservatively taken the same as the sustained stress allowable.

$$S_{LO} = S_L + i\frac{M}{Z} \leq SFLJT$$

where
M = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from (5.6.3.3).

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where

S_b = resultant bending stress $= iM_b/Z$
S_t = torsional stress $= M_t/2Z$
M_b = resultant bending moment due to expansion loads
M_t = torsional moment due to expansion loads
Z = un-corroded section modulus

Table 5.8
Flexibility and Stress Intensification Factors

Description	Flex-ibility Factor *k*	Stress Intens. Factor *i*
Buttwelded joint, reducer, or welding neck flange	1	1.0
Double-welded slip-on or socket welding flange	1	1.2
Fillet welded joint, or single-welded socket welding flange	1	1.3
Lap joint flange (with ANSI B16.9 lap joint stub)	1	1.6
Screwed pipe joint, or screwed flange	1	2.3
Corrugated pipe, straight or curved, or creased bend**	5	2.5

Description	Flex-ibility Factor *k**	Stress Intens. Factor *i**	Flexibility Character-istic *h*	See sketch
Welding elbow, or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{tR}{r^2}$	A
Mitre bend with close spacing†‡ $s < r(1 + \tan\alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\alpha}{2} \cdot \frac{ts}{r^2}$	B
Mitre bend with wide spacing ‡§ $s \geq r(1 + \tan\alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\alpha}{2} \frac{t}{r}$	C
Welding tee per CSA Standard **CAN/CSA-Z245.11**	1	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{t}{r}$	D
Reinforced fabricated tee, with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2\,T)^{5/2}}{t^{3/2} r}$	E
Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	F

**The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system, and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for curved and mitre elbows, and to the intersection point for tees.*

†Where flanges are attached to one or both ends, the values of k and i in the Table shall be multiplied by the following factors:

One end flanged: $(h)^{1/6}$

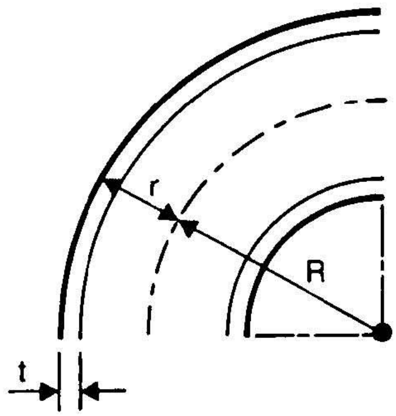
Both ends flanged: $(h)^{1/3}$

‡Subject to the limitations of Clause 7.2.3(e).

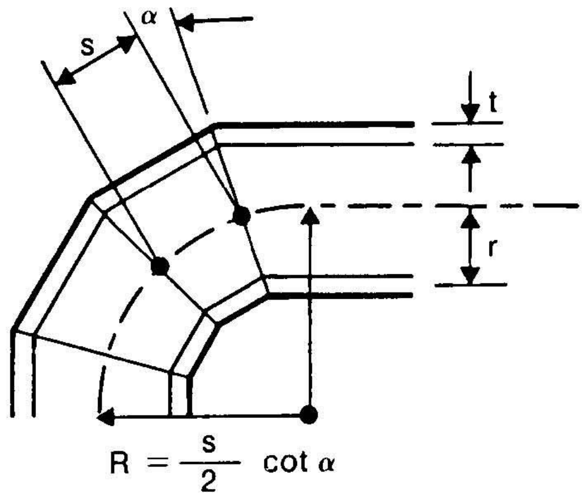
§Also includes single-mitre joint.

***Factors shown apply to bending. Flexibility factor for torsion equals 0.9.*

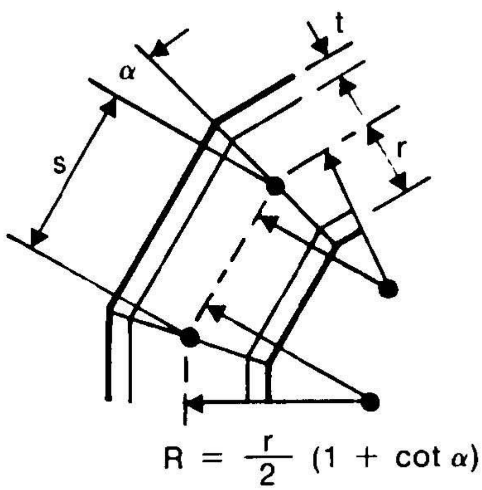
Note: *Designers are cautioned that specific cases may require more comprehensive analysis than that specified in Clause 5.19.*



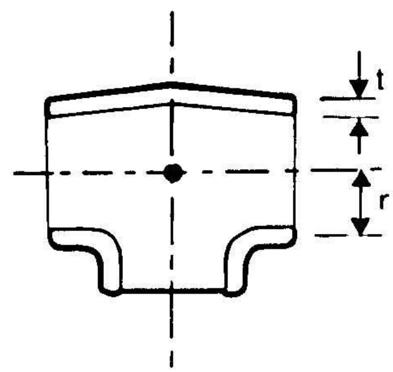
Sketch A



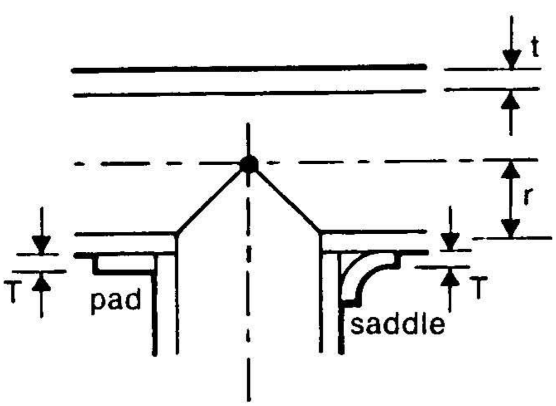
Sketch B



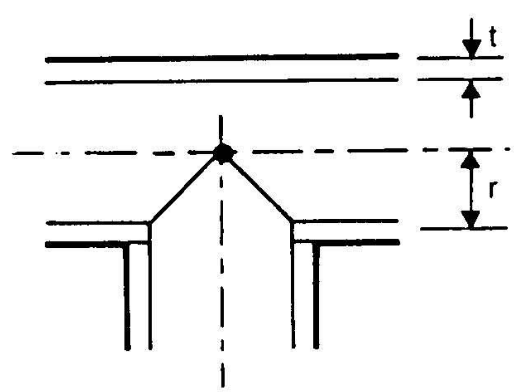
Sketch C



Sketch D



Sketch E



Sketch F

Allowable Pressure

For straight pipe, the allowable pressure for a given wall thickness shall be determined by the following formula from Clause 4.3.5.1.

$$P = FLJT\left(\frac{2St}{D}\right)$$

where

P = allowable pressure

S = specified minimum yield strength, input as material property in CAEPIPE

t = minimum wall thickness = nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance (see Note below)

F = design factor = 0.8 as per Clause 4.3.6.

L = location factor (from Table 4.2), input into CAEPIPE analysis option

J = joint factor (from Table 4.3), input as material property in CAEPIPE

T = temperature factor for steel pipe (from Table 4.4), determined based on Design Temperature input into CAEPIPE

D = outside diameter

Note:

Corrosion allowance input into CAEPIPE should include corrosion/erosion allowance and allowance for grooving and threading.

Sustained + Occasional Stress (Unrestrained Piping = Un-buried Piping)

The sum of longitudinal pressure stress and the total bending stress due to sustained force (pressure, weight and other sustained mechanical loads) and occasional loads (such as wind, seismic, etc.) shall be limited in accordance with the following formula from Clause 4.8.5.

$$0.5S_h + s_B \leq SFLT$$

where

S_h = hoop stress due to pressure P, as computed using formula given in Clause 4.6.5 = $\frac{PD}{2t}$

S_B = absolute value of beam bending stresses resulting from sustained and occasional loads = $\frac{iM_B}{Z_C}$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter of pipe

t = minimum wall thickness = nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance (see Note above for corrosion allowance)

i = stress intensification factor (from Table 4.8)

M_B = resultant bending moment due to sustained and occasional loads

Z_C = <u>corroded</u> section modulus computed using corroded wall thickness = Nominal wall thickness – corrosion allowance, in which mill tolerance is not deducted.

S = specified minimum yield strength

F = design factor = 0.8 as per Clause 4.3.6

L = location factor (from Table 4.2)
T = temperature factor for steel pipe (from Table 4.4) determined based on Maximum Temperature input into CAEPIPE (T1 through T10)

Expansion Stress (Unrestrained Piping = Un-buried Piping)

The thermal expansion stress range (S_E) for those portions of pipeline systems shall be limited in accordance with the formulae given in Clauses 4.8.3 and 4.8.4.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where
S_b = resultant bending stress= iM_b/Z
S_t = torsional stress = $M_t/(2Z)$
M_b = resultant bending moment due to expansion loads
M_t = torsional moment due to expansion loads
Z = un-corroded section modulus
i = stress intensification factor (from Table 4.8)
S = specified minimum yield strength
T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot}.

T_{hot} = maximum(T_{opr}, T_{ref}) (see Note 3 below)

Combined Stress (Restrained Piping = Buried Piping)

For those portions of restrained pipelines, the combined stress shall be limited in accordance with the formula given in Clause 4.7.2.1.

$$S_h - S_L + s_B \leq ST$$

where
S_h = hoop stress due to pressure P, as determined using formula given in Clause 4.6.5 = $\frac{PD}{2t}$
S_L = longitudinal compressive stress as determined using the formula given in Clause 4.7.1
= $S_L = \vartheta S_h - E_c\alpha(T_{opr} - T_{ref})$ (see Notes below)
S_B = absolute value of beam bending stresses resulting from sustained and occasional loads = $\frac{iM_B}{Z_C}$
P = maximum of CAEPIPE input pressures P1 through P10
D = outside diameter of pipe
t = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance (see Note above)
i = stress intensification factor (from Table 4.8)
M_B = resultant bending moment due to sustained and occasional loads
Z_C = corroded section modulus computed using corroded wall thickness = Nominal wall thickness – corrosion allowance, in which mill tolerance is not deducted.

ϑ = Poisson's ratio, input as material property in CAEPIPE
T_{opr} = operating temperature under consideration. See Note 2 below.
T_{ref} = ambient temperature at the time of restraint = Reference temperature in CAEPIPE
E_c = modulus of elasticity of steel at T_{ref}
α = coefficient of thermal expansion at T_{opr} defined above
S = specified minimum yield strength
T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot}.

T_{hot} = maximum(T_{opr}, T_{ref}) (see Note 3 below)

Note:

1. Evaluation as per Clause 4.7.2.1 (listed above) for Restrained Piping shall be performed in CAEPIPE only when the value of S_L computed as listed above is negative (compressive).

2. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE calculates longitudinal stress (S_L) due to

   Thermal expansion range from T_{ref} to T1 as

   $E_c\alpha\left(T_{opr} - T_{ref}\right) = E_c\alpha_{T1}\left(T_1 - T_{ref}\right)$

   Thermal expansion range from T_{ref} to T2 as

   $E_c\alpha\left(T_{opr} - T_{ref}\right) = E_c\alpha_{T2}\left(T_2 - T_{ref}\right)$

   Thermal expansion range from T1 to T2 as

   $E_c\alpha(T_n - T_m) = E_c\alpha_n\left(T_n - T_{ref}\right) - E_c\alpha_m\left(T_m - T_{ref}\right)$, where n = 1 and m = 2

3. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE determines Temperature factor (T) as given below.

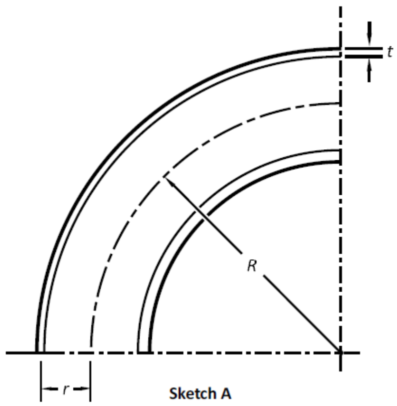
   Thermal expansion range from T_{ref} to T_1 as maximum(T_1, T_{ref})

   Thermal expansion range from T_{ref} to T_2 as maximum(T_2, T_{ref})

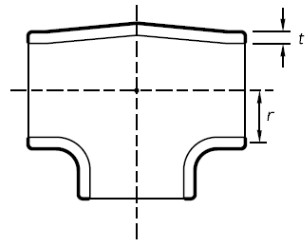
   Thermal expansion range from $\boldsymbol{T_1}$ to $\boldsymbol{T_2}$ as maximum($\boldsymbol{T_1}$, $\boldsymbol{T_2}$)

Table 4.8
Flexibility and stress intensification factors
(See Clauses 4.8.7 and 11.14.2.)

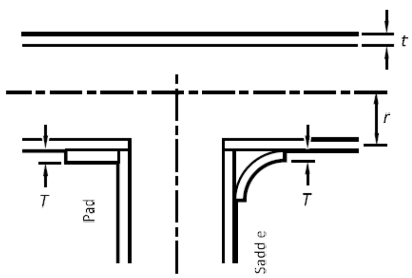
There is a commentary available for this Table.



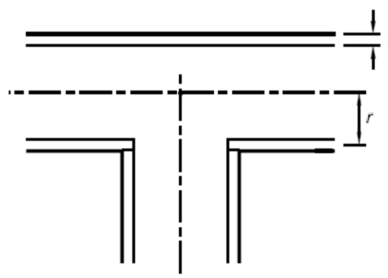
Sketch A



Sketch B



Sketch C



Sketch D

(Continued)

Table 4.8 (Concluded)

Description	Flexibility factor, κ*	Stress intensification factor, *i**
Buttwelded joint, reducer, or welding neck flange	1	1.0
Double-welded slip-on or socket welding flange	1	1.2
Fillet-welded joint or single-welded socket welding flange	1	1.3
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Screwed pipe joint or screwed flange	1	2.3
Corrugated pipe, straight or curved, or creased bend‡	5	2.5

Description	Flexibility factor, κ*	Stress intensification factor, *i**	Flexibility characteristic, *h*	See sketch
Welding elbow or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{tR}{r^2}$	A
Welding tee per CSA Z245.11	1	$\frac{0.9}{h^{2/3}}$	$4.4\frac{t}{r}$	B
Reinforced fabricated tee with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t+1/2T)^{\frac{5}{2}}}{t^{3/2}r}$	C
Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	D

* *The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for elbows, and to the intersection point for tees.*

† *Where flanges are attached to one or both ends, the values of κ and i in this Table shall be multiplied by the following factors:*

a) one end flanged: $(h)^{1/6}$

b) both ends flanged: $(h)^{1/3}$

‡ *Factors shown apply to bending. Flexibility factor for torsion equals 0.9.*

Note: *Designers are cautioned that more comprehensive analysis than that specified in Clauses 4.6 to 4.10 can be necessary for specific cases.*

Allowable Pressure

For straight pipe, the allowable pressure for a given wall thickness shall be determined by the following formula from Clause 4.3.5.1.

$$P = FLJT\left(\frac{2St}{D}\right)$$

where
P = allowable pressure
S = specified minimum yield strength, input as material property in CAEPIPE
t = minimum wall thickness = nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance (see Note below)
F = design factor = 0.8 as per Clause 4.3.6.
L = location factor (from Table 4.2), input into CAEPIPE analysis option
J = joint factor (from Table 4.3), input as material property in CAEPIPE
T = temperature factor for steel pipe (from Table 4.4), determined based on Design Temperature input into CAEPIPE
D = outside diameter

Note:

Corrosion allowance input into CAEPIPE should include corrosion/erosion allowance and allowance for grooving and threading.

Sustained + Occasional Stress (Unrestrained Piping = Un-buried Piping)

The sum of longitudinal pressure stress and the total bending stress due to sustained force (pressure, weight and other sustained mechanical loads) and occasional loads (such as wind, seismic, etc.) shall be limited in accordance with the following formula from Clause 4.8.5.

$$0.5S_h + s_B \leq SFLT$$

where
S_h = hoop stress due to pressure P, as computed using formula given in Clause 4.6.5 = $\frac{PD}{2t}$
S_B = absolute value of beam bending stresses resulting from sustained and occasional loads = $\frac{iM_B}{Z_C}$
P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter of pipe
t = minimum wall thickness = nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance (see Note above for corrosion allowance)
i = stress intensification factor (from Table 4.8)
M_B = resultant bending moment due to sustained and occasional loads
Z_C = corroded section modulus computed using corroded wall thickness = Nominal wall thickness – corrosion allowance, in which mill tolerance is not deducted.
S = specified minimum yield strength

F = design factor = 0.8 as per Clause 4.3.6
L = location factor (from Table 4.2)
T = temperature factor for steel pipe (from Table 4.4) determined based on Maximum Temperature input into CAEPIPE (T1 through T10)

Expansion Stress (Unrestrained Piping = Un-buried Piping)

The thermal expansion stress range (S_E) for those portions of pipeline systems shall be limited in accordance with the formulae given in Clauses 4.8.3 and 4.8.4.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \le 0.72ST$$

where
S_b = resultant bending stress$= iM_b/Z$
S_t = torsional stress $= M_t/(2Z)$
M_b = resultant bending moment due to expansion loads
M_t = torsional moment due to expansion loads
Z = un-corroded section modulus
i = stress intensification factor (from Table 4.8)
S = specified minimum yield strength
T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot}.

T_{hot} = maximum(T_{opr}, T_{ref}) (see Note 3 below)

Combined Stress (Restrained Piping = Buried Piping)

For those portions of restrained pipelines, the combined stress shall be limited in accordance with the formula given in Clause 4.7.2.1.

$$S_h - S_L + s_B \le ST$$

where
S_h = hoop stress due to pressure P, as determined using formula given in Clause 4.6.5 = $\frac{PD}{2t}$
S_L = longitudinal compressive stress as determined using the formula given in Clause 4.7.1
= $S_L = \vartheta S_h - E_c\alpha(T_{opr} - T_{ref})$ (see Notes below)
S_B = absolute value of beam bending stresses resulting from sustained and occasional loads = $\frac{iM_B}{Z_C}$
P = maximum of CAEPIPE input pressures P1 through P10
D = outside diameter of pipe
t = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance (see Note above)
i = stress intensification factor (from Table 4.8)
M_B = resultant bending moment due to sustained and occasional loads

Z_C = corroded section modulus computed using corroded wall thickness = Nominal wall thickness – corrosion allowance, in which mill tolerance is not deducted.
ϑ = Poisson's ratio, input as material property in CAEPIPE
T_{opr} = operating temperature under consideration. See Note 2 below.
T_{ref} = ambient temperature at the time of restraint = Reference temperature in CAEPIPE
E_c = modulus of elasticity of steel at T_{ref}
α = coefficient of thermal expansion at T_{opr} defined above
S = specified minimum yield strength
T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot}.

T_{hot} = maximum(T_{opr}, T_{ref}) (see Note 3 below)

Note:

1. Evaluation as per Clause 4.7.2.1 (listed above) for Restrained Piping shall be performed in CAEPIPE only when the value of S_L computed as listed above is negative (compressive).

2. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE calculates longitudinal stress (S_L) due to

   Thermal expansion range from T_{ref} to T1 as

   $$E_c\alpha\left(T_{opr} - T_{ref}\right) = E_c\alpha_{T1}\left(T_1 - T_{ref}\right)$$

   Thermal expansion range from T_{ref} to T2 as

   $$E_c\alpha\left(T_{opr} - T_{ref}\right) = E_c\alpha_{T2}\left(T_2 - T_{ref}\right)$$

   Thermal expansion range from T1 to T2 as

   $$E_c\alpha(T_n - T_m) = E_c\alpha_n\left(T_n - T_{ref}\right) - E_c\alpha_m\left(T_m - T_{ref}\right),$$ where n = 1 and m = 2

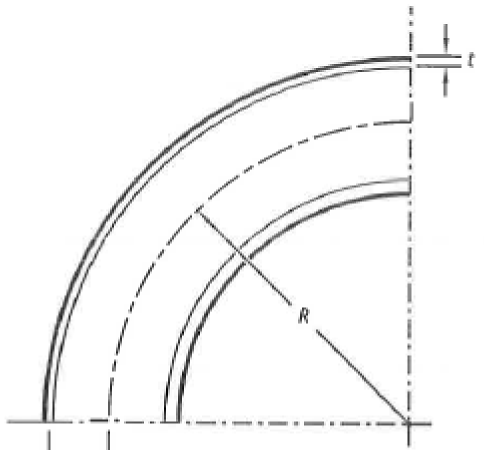
3. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE determines Temperature factor (T) as given below.

   Thermal expansion range from T_{ref} to T_1 as maximum(T_1, T_{ref})

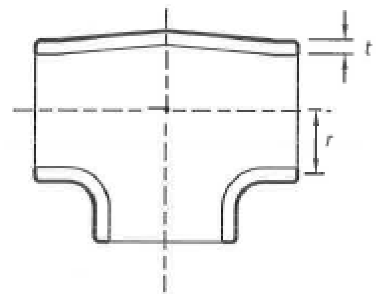
   Thermal expansion range from T_{ref} to T_2 as maximum(T_2, T_{ref})

Thermal expansion range from T_1 to T_2 as maximum(T_1, T_2)

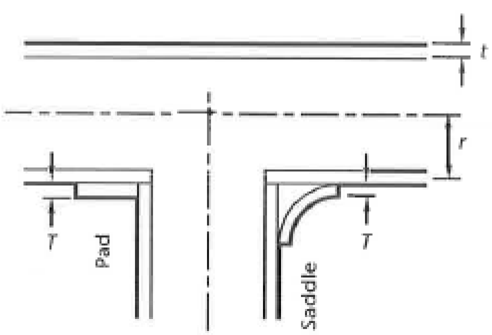
Table 4.8
Flexibility and stress intensification factors
(See Clauses 4.8.7, 11.14.2, and C.5.1.4.)



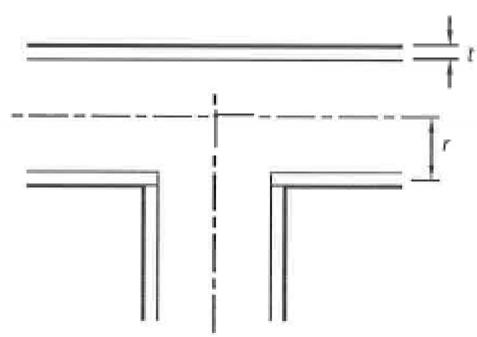
Sketch A



Sketch B



Sketch C



Sketch D

(Continued)

Table 4.8 (Concluded)

Description	Flexibility factor, κ*	Stress intensification factor, i*
Buttwelded joint, reducer, or welding neck flange	1	1.0
Double-welded slip-on or socket welding flange	1	1.2
Fillet-welded joint or single-welded socket welding flange	1	1.3
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Screwed pipe joint or screwed flange	1	2.3
Corrugated pipe, straight or curved, or creased bend‡	5	2.5

Description	Flexibility factor, κ*	Stress intensification factor, i*	Flexibility characteristic, h	See sketch
Welding elbow or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{tR}{r^2}$	A
Welding tee per CSA Z245.11	1	$\frac{0.9}{h^{2/3}}$	$4.4\frac{t}{r}$	B
Reinforced fabricated tee with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2T)^{\frac{5}{2}}}{t^{3/2}r}$	C
Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	D

* *The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for elbows, and to the intersection point for tees.*

† *Where flanges are attached to one or both ends, the values of κ and i in this Table shall be multiplied by the following factors:*

a) *one end flanged: $(h)^{1/6}$*

b) *both ends flanged: $(h)^{1/3}$*

‡ *Factors shown apply to bending. Flexibility factor for torsion equals 0.9.*

Note: *Designers are cautioned that more comprehensive analysis than that specified in Clauses 4.6 to 4.10 can be necessary for specific cases.*

Fiber Reinforced Plastic Pipe Stress

Hoop stress: $S_H = \frac{PD}{2t_m}$

Axial stress: $S_A = \frac{PD}{4t_m} + \frac{F}{A}$

Bending stress: $S_B = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$

Torsional stress: $S_T = \frac{M_t}{2Z}$

Longitudinal maximum = Axial + Bending = $S_A + S_B$

Longitudinal Minimum = Axial – Bending = $S_A - S_B$

where

P = pressure
D = outside diameter
t_m = minimum thickness
= nominal thickness x (1 – mill tolerance/100) – corrosion allowance
i_i = in-plane stress intensification factor
i_o = out of plane stress intensification factor
M_i = in plane bending moment
M_o = out of plane bending moment
M_t = torque
Z = section modulus
F = axial force
A = cross-section area

Von Mises Stress and Maximum & Minimum Principal Stresses

Hoop stress: $S_H = \frac{PD}{2t_m}$

Axial stress: $S_A = \frac{PD}{4t} + \frac{F}{A}$

Bending stress: $S_B = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$

Torsional stress: $S_T = \frac{M_t}{2Z}$

(a) <u>At one Extreme Surface of Pipe</u>

$T1 = \frac{S_H - S_A - S_B}{2}$

$U1 = \sqrt{T1^2 + (S_T)^2}$

Sigma 1 $= \sigma_1 = \frac{S_H + S_A + S_B}{2} + U1$

Sigma 2 $= \sigma_2 = \frac{S_H + S_A + S_B}{2} - U1$

VonMises_t $= \sqrt{(\sigma_1)^2 - \sigma_1\sigma_2 + (\sigma_2)^2}$

Max_t $= \sigma_1$

Min_t $= \sigma_2$

(b) <u>At the other Extreme Surface of Pipe</u>

$T2 = \frac{S_H - S_A + S_B}{2}$

$U2 = \sqrt{T2^2 + (S_T)^2}$

Sigma 1 $= \sigma_1 = \frac{S_H + S_A - S_B}{2} + U2$

Sigma 2 $= \sigma_2 = \frac{S_H + S_A - S_B}{2} - U2$

VonMises_b $= \sqrt{(\sigma_1)^2 - \sigma_1\sigma_2 + (\sigma_2)^2}$

Max_b $= \sigma_1$

Min_b $= \sigma_2$

(c) <u>For the entire Pipe Cross-section at a Node</u>

VonMises Stress = Max(VonMises_t, VonMises_b)

Maximum Principal Stress = Max(Max_t, Max_b)

Minimum Principal Stress = Min(Min_t, Min_b)

where
P = pressure
D = outside diameter
t = nominal thickness
t_m = minimum thickness = t x (1 – mill tolerance/100) – corrosion allowance
i_i = in-plane stress intensification factor
i_o = out-of-plane stress intensification factor
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torque
Z = section modulus
F = axial force
A = cross-section area

Stress Intensification Factors (SIFs)

CAEPIPE computes Stress Intensification Factors (SIFs) for "None" code as per SIF equations provided in ASME B31.3 as given below.

For "Piping code = None" and a non-FRP material, the in-plane and out-of-plane Stress Intensification Factors (SIF) for a 90° bend/elbow are taken to be the same as those computed using Appendix D of ASME B31.3 (appended below for reference).

For a bend with bend angle less than 90°, the in-plane and out-of-plane SIFsarecomputed using the procedure given in ASME/BPVC Section III, Division1, Case N-319-2 "Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping."

For better clarity, when piping code = None, the SIF for a bend of other than 90 deg is as follows:

The SIF for curved pipe of arc lengths between 0 and 180 deg can be estimated by multiplying the SIF for 90 deg bend as given by ASME B31.3 code by a scalar multiplier. This scalar multiplier is arrived at by taking the ratio of the involved Bending stress index C(2z) values as given below.

Scalar multiplier = [C(2z) value for the required angle bend / C(2z) value for 90 deg bend] , where the C(2z) values are taken from ASME/BPVC Section III, Division 1, Code Case N-319-2 document titled "Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping", which are listed below.

C(2z) = 1.95/h^(2/3) for bend angles of 90 deg or greater

C(2z) = 1.75/h^(0.56) for a bend angle of 45 deg

C(2z) = 1.0 for a bend angle of 0 deg (straight pipe)

For other bend angles, the C(2z) values can be interpolated between the above C(2z) values.

As an example, a 45 deg bend SIF could be reasonably estimated to be {SIF for B31 90 deg bend} x [C(2z) for a 45 deg bend / C(2z) for a 90 deg bend]. You may note that the Scalar multiplier is 1.0 for bend angles greater than 90 deg.

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

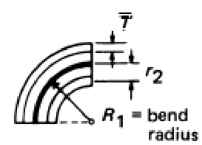
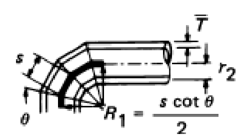
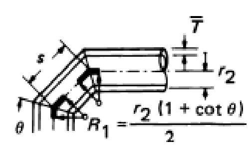
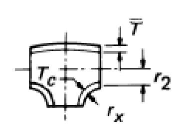
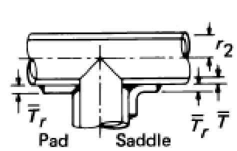
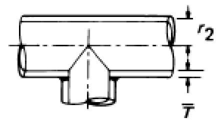
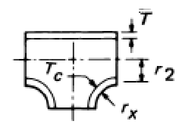
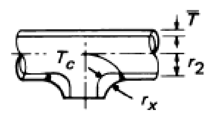
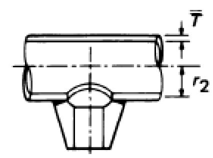
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2 (1 + \tan\theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan\theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1 \frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5} r_2}$	

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$, $T_c < 1.5\ \bar{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1+\frac{r_x}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\bar{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

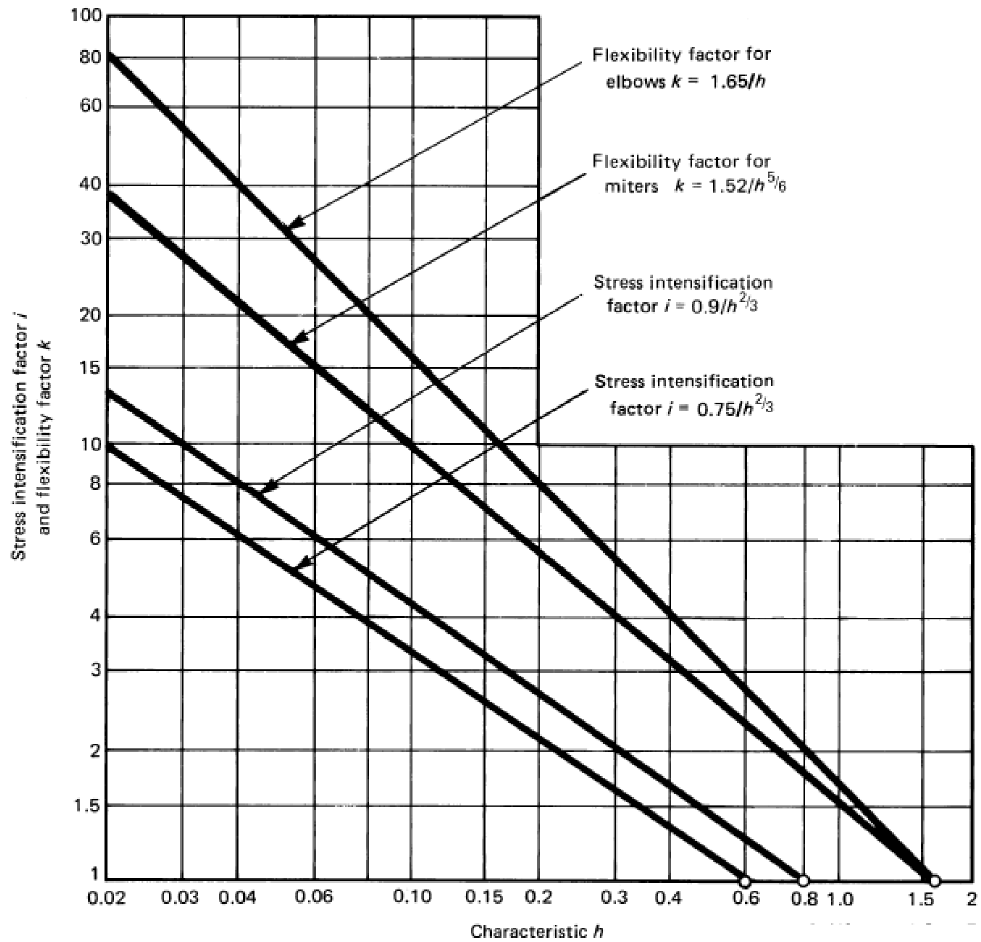


Chart A

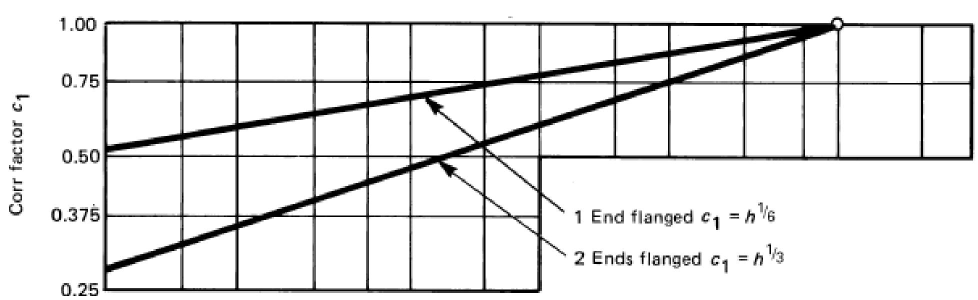


Chart B

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd) (14)

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\bar{T} \leq 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\bar{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\bar{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1, which can be read directly from Chart B, entering with the computed h.

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\bar{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\bar{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5\bar{T}$, a flexibility characteristic of $4.4\,\bar{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\bar{T}_r$ is $> 1\frac{1}{2}\,\bar{T}$, use $h = 4\,\bar{T}/r_2$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

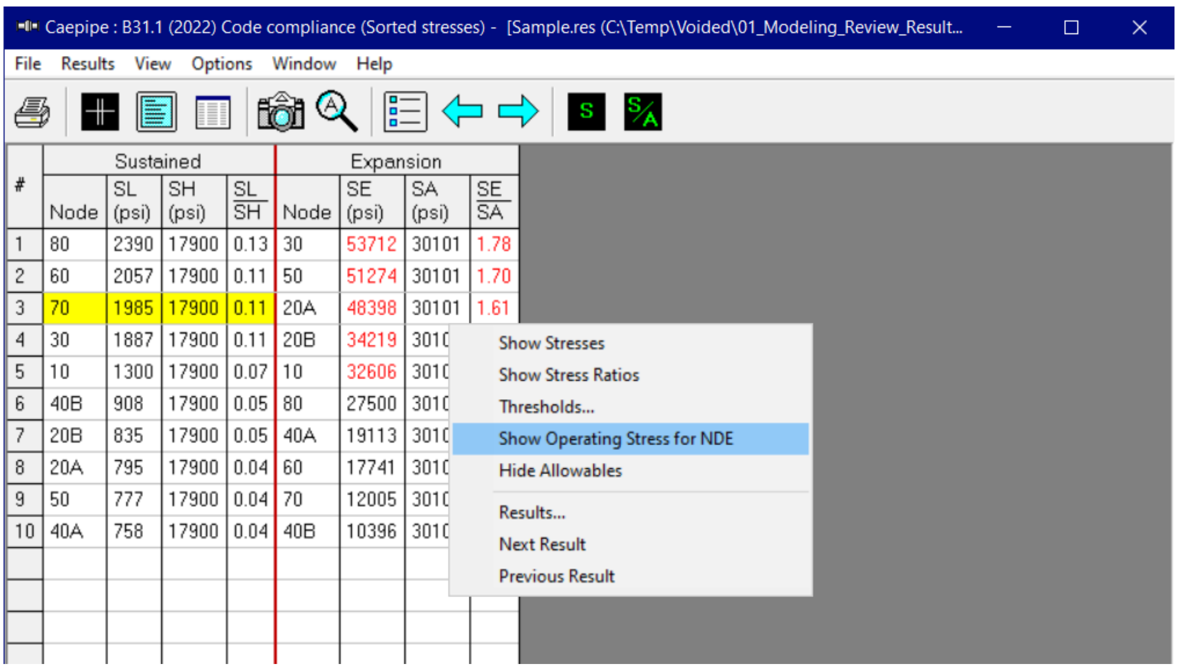
(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

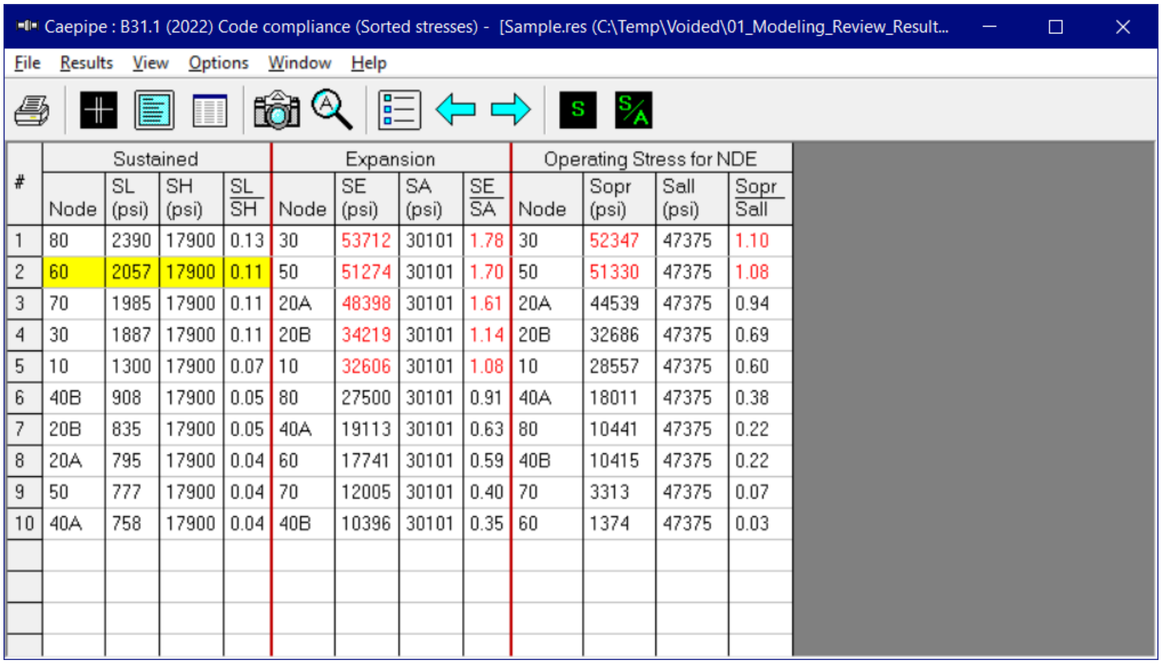
This function is available to users who wish to inspect or examine high stress areas (Non-Destructive Evaluation, NDE) where piping has high "operating stresses" or examine stress areas that are higher than 35% of the allowable stress for Impact Testing as per para. 523.2.2 (f)(4) of ASME B31.5 (2017) code or examine stress ratios for Impact Test Exemption as per para . 323.2.2 (b)(3) of ASME B31.3 (2022) code.

While piping codes do not consider the operating condition (W+P+T) as a required load case for code compliance, you may, however, evaluate this load case the same way as you would do for other code compliance cases such as Sustained (W+P) and Expansion (T). CAEPIPE will show columns displaying Operating Stress (S_{opr}) and Allowable stress (S_{all}) alongside the code required stresses even though the *Operating Stress is not a code requirement.*

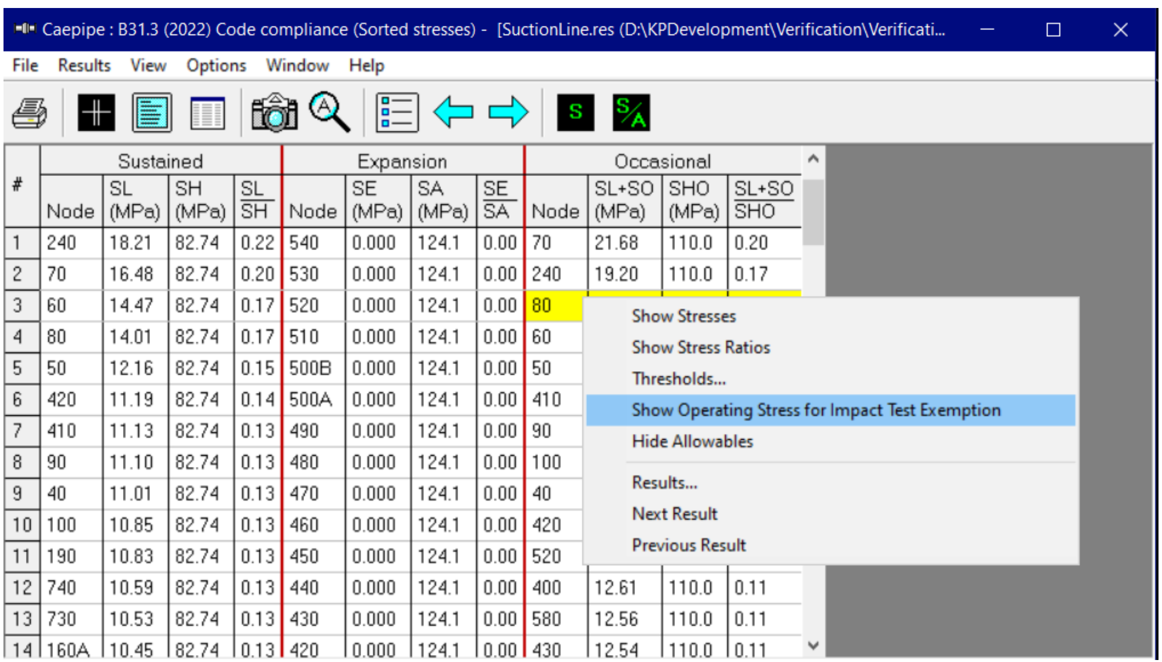
To display these columns, you will have to turn them on first:(mouse right click) > Show Operating Stress for NDE for all codes excepting ASME B31.5 and ASME B31.3. For ASME B31.5 Code, this option will change as "Show Operating Stress for Impact Test". Similarly, for ASME B31.3 Code, this option will change as "Show Operating Stress for Impact Test Exemption".



The allowable stress for NDE is NOT specified nor recommended by piping codes but, as mentioned above, may aid in identifying regions of high combined stress in the piping system, which may warrant a closer examination in engineering judgment.

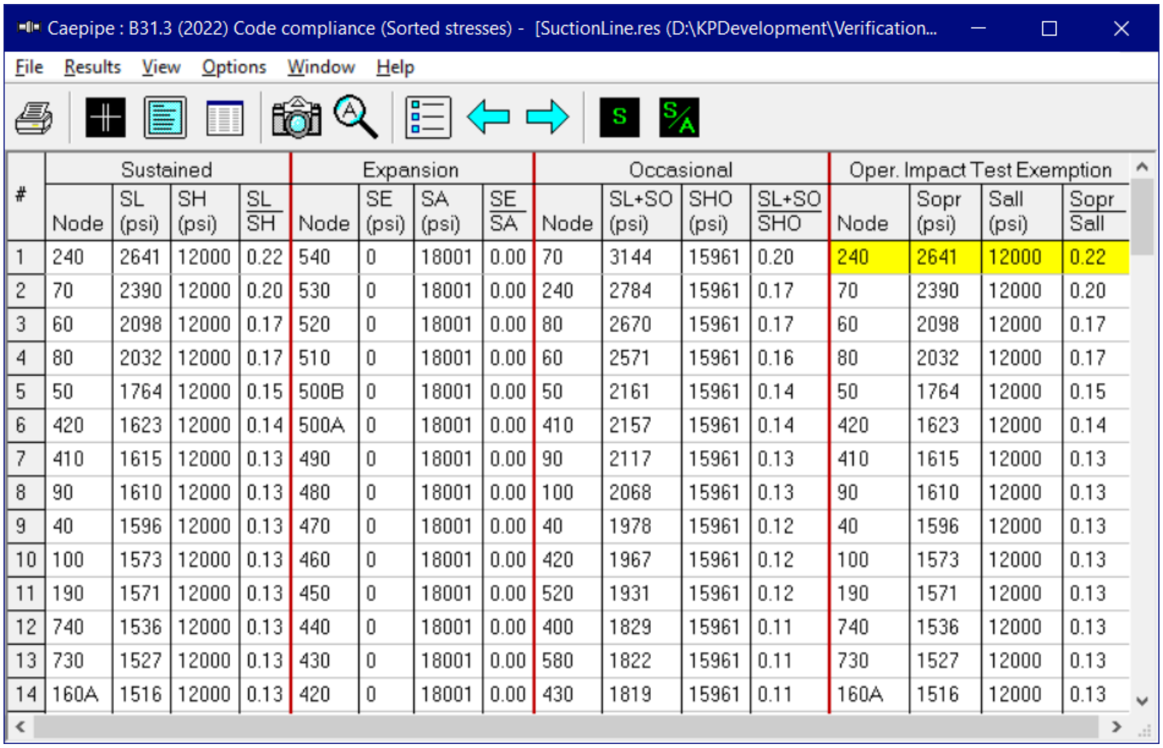


#	Sustained				Expansion				Operating Stress for NDE			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA	Node	Sopr (psi)	Sall (psi)	Sopr/Sall
1	80	2390	17900	0.13	30	53712	30101	1.78	30	52347	47375	1.10
2	60	2057	17900	0.11	50	51274	30101	1.70	50	51330	47375	1.08
3	70	1985	17900	0.11	20A	48398	30101	1.61	20A	44539	47375	0.94
4	30	1887	17900	0.11	20B	34219	30101	1.14	20B	32686	47375	0.69
5	10	1300	17900	0.07	10	32606	30101	1.08	10	28557	47375	0.60
6	40B	908	17900	0.05	80	27500	30101	0.91	40A	18011	47375	0.38
7	20B	835	17900	0.05	40A	19113	30101	0.63	80	10441	47375	0.22
8	20A	795	17900	0.04	60	17741	30101	0.59	40B	10415	47375	0.22
9	50	777	17900	0.04	70	12005	30101	0.40	70	3313	47375	0.07
10	40A	758	17900	0.04	40B	10396	30101	0.35	60	1374	47375	0.03

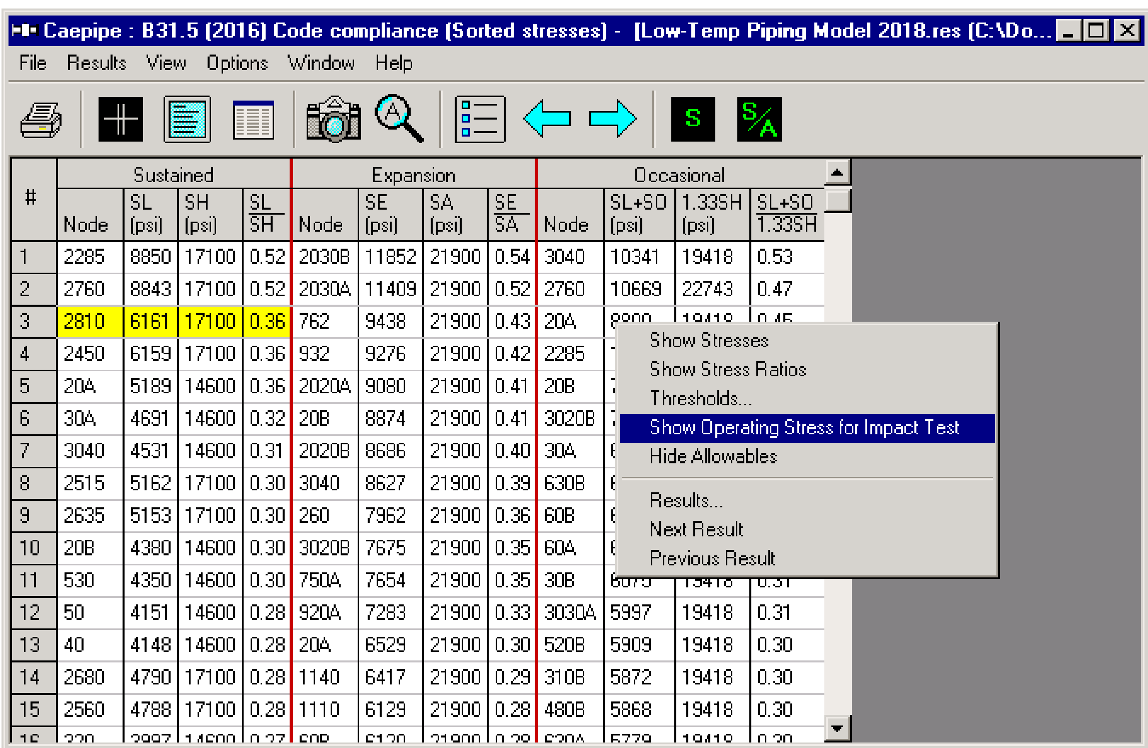


#	Sustained				Expansion				Occasional			
	Node	SL (MPa)	SH (MPa)	SL/SH	Node	SE (MPa)	SA (MPa)	SE/SA	Node	SL+SO (MPa)	SHO (MPa)	SL+SO/SHO
1	240	18.21	82.74	0.22	540	0.000	124.1	0.00	70	21.68	110.0	0.20
2	70	16.48	82.74	0.20	530	0.000	124.1	0.00	240	19.20	110.0	0.17
3	60	14.47	82.74	0.17	520	0.000	124.1	0.00	80			
4	80	14.01	82.74	0.17	510	0.000	124.1	0.00	60			
5	50	12.16	82.74	0.15	500B	0.000	124.1	0.00	50			
6	420	11.19	82.74	0.14	500A	0.000	124.1	0.00	410			
7	410	11.13	82.74	0.13	490	0.000	124.1	0.00	90			
8	90	11.10	82.74	0.13	480	0.000	124.1	0.00	100			
9	40	11.01	82.74	0.13	470	0.000	124.1	0.00	40			
10	100	10.85	82.74	0.13	460	0.000	124.1	0.00	420			
11	190	10.83	82.74	0.13	450	0.000	124.1	0.00	520			
12	740	10.59	82.74	0.13	440	0.000	124.1	0.00	400	12.61	110.0	0.11
13	730	10.53	82.74	0.13	430	0.000	124.1	0.00	580	12.56	110.0	0.11
14	160A	10.45	82.74	0.13	420	0.000	124.1	0.00	430	12.54	110.0	0.11

Operating Stress for NDE / Impact Test / Impact Test Exemption

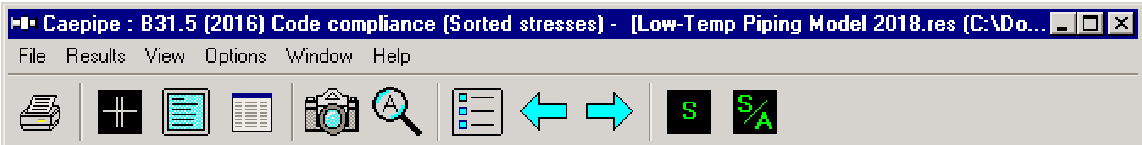


#	Sustained Node	SL (psi)	SH (psi)	SL/SH	Expansion Node	SE (psi)	SA (psi)	SE/SA	Occasional Node	SL+SO (psi)	SHO (psi)	SL+SO/SHO	Oper. Impact Test Exemption Node	Sopr (psi)	Sall (psi)	Sopr/Sall
1	240	2641	12000	0.22	540	0	18001	0.00	70	3144	15961	0.20	240	2641	12000	0.22
2	70	2390	12000	0.20	530	0	18001	0.00	240	2784	15961	0.17	70	2390	12000	0.20
3	60	2098	12000	0.17	520	0	18001	0.00	80	2670	15961	0.17	60	2098	12000	0.17
4	80	2032	12000	0.17	510	0	18001	0.00	60	2571	15961	0.16	80	2032	12000	0.17
5	50	1764	12000	0.15	500B	0	18001	0.00	50	2161	15961	0.14	50	1764	12000	0.15
6	420	1623	12000	0.14	500A	0	18001	0.00	410	2157	15961	0.14	420	1623	12000	0.14
7	410	1615	12000	0.13	490	0	18001	0.00	90	2117	15961	0.13	410	1615	12000	0.13
8	90	1610	12000	0.13	480	0	18001	0.00	100	2068	15961	0.13	90	1610	12000	0.13
9	40	1596	12000	0.13	470	0	18001	0.00	40	1978	15961	0.12	40	1596	12000	0.13
10	100	1573	12000	0.13	460	0	18001	0.00	420	1967	15961	0.12	100	1573	12000	0.13
11	190	1571	12000	0.13	450	0	18001	0.00	520	1931	15961	0.12	190	1571	12000	0.13
12	740	1536	12000	0.13	440	0	18001	0.00	400	1829	15961	0.11	740	1536	12000	0.13
13	730	1527	12000	0.13	430	0	18001	0.00	580	1822	15961	0.11	730	1527	12000	0.13
14	160A	1516	12000	0.13	420	0	18001	0.00	430	1819	15961	0.11	160A	1516	12000	0.13



#	Sustained Node	SL (psi)	SH (psi)	SL/SH	Expansion Node	SE (psi)	SA (psi)	SE/SA	Occasional Node	SL+SO (psi)	1.33SH (psi)	SL+SO/1.33SH
1	2285	8850	17100	0.52	2030B	11852	21900	0.54	3040	10341	19418	0.53
2	2760	8843	17100	0.52	2030A	11409	21900	0.52	2760	10669	22743	0.47
3	2810	6161	17100	0.36	762	9438	21900	0.43	20A	[illegible]	[illegible]	[illegible]
4	2450	6159	17100	0.36	932	9276	21900	0.42	2285	[illegible]	[illegible]	[illegible]
5	20A	5189	14600	0.36	2020A	9080	21900	0.41	20B	[illegible]	[illegible]	[illegible]
6	30A	4691	14600	0.32	20B	8874	21900	0.41	3020B	[illegible]	[illegible]	[illegible]
7	3040	4531	14600	0.31	2020B	8686	21900	0.40	30A	[illegible]	[illegible]	[illegible]
8	2515	5162	17100	0.30	3040	8627	21900	0.39	630B	[illegible]	[illegible]	[illegible]
9	2635	5153	17100	0.30	260	7962	21900	0.36	60B	[illegible]	[illegible]	[illegible]
10	20B	4380	14600	0.30	3020B	7675	21900	0.35	60A	[illegible]	[illegible]	[illegible]
11	530	4350	14600	0.30	750A	7654	21900	0.35	30B	[illegible]	[illegible]	[illegible]
12	50	4151	14600	0.28	920A	7283	21900	0.33	3030A	5997	19418	0.31
13	40	4148	14600	0.28	20A	6529	21900	0.30	520B	5909	19418	0.30
14	2680	4790	17100	0.28	1140	6417	21900	0.29	310B	5872	19418	0.30
15	2560	4788	17100	0.28	1110	6129	21900	0.28	480B	5868	19418	0.30
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Operating Stress for NDE / Impact Test / Impact Test Exemption



#	Sustained				Expansion				Occasional				Oper. Stress for Impact Test			
	Node	SL (psi)	SH (psi)	SL / SH	Node	SE (psi)	SA (psi)	SE / SA	Node	SL+SO (psi)	1.33SH (psi)	SL+SO / 1.33SH	Node	Sopr (psi)	Sall (psi)	Sopr / Sall
1	2285	8850	17100	0.52	2030B	11852	21900	0.54	3040	10341	19418	0.53	2030B	13389	5110	2.62
2	2760	8843	17100	0.52	2030A	11409	21900	0.52	2760	10669	22743	0.47	2030A	12913	5110	2.53
3	2810	6161	17100	0.36	762	9438	21900	0.43	20A	8800	19418	0.45	20B	12489	5110	2.44
4	2450	6159	17100	0.36	932	9276	21900	0.42	2285	10086	22743	0.44	762	10916	5110	2.14
5	20A	5189	14600	0.36	2020A	9080	21900	0.41	20B	7164	19418	0.37	932	10753	5110	2.10
6	30A	4691	14600	0.32	20B	8874	21900	0.41	3020B	7131	19418	0.37	2020A	10249	5110	2.01
7	3040	4531	14600	0.31	2020B	8686	21900	0.40	30A	6984	19418	0.36	3020B	10204	5110	2.00
8	2515	5162	17100	0.30	3040	8627	21900	0.39	630B	6491	19418	0.33	260	10135	5110	1.98
9	2635	5153	17100	0.30	260	7962	21900	0.36	60B	6379	19418	0.33	60B	9927	5110	1.94
10	20B	4380	14600	0.30	3020B	7675	21900	0.35	60A	6283	19418	0.32	750A	9717	5110	1.90
11	530	4350	14600	0.30	750A	7654	21900	0.35	30B	6075	19418	0.31	20A	9659	5110	1.89
12	50	4151	14600	0.28	920A	7283	21900	0.33	3030A	5997	19418	0.31	2020B	9583	5110	1.88
13	40	4148	14600	0.28	20A	6529	21900	0.30	520B	5909	19418	0.30	1140	9458	5110	1.85
14	2680	4790	17100	0.28	1140	6417	21900	0.29	310B	5872	19418	0.30	920A	9338	5110	1.83
15	2560	4788	17100	0.28	1110	6129	21900	0.28	480B	5868	19418	0.30	30B	8620	5110	1.69
16	320	3997	14600	0.27	60B	6120	21900	0.28	630A	5779	19418	0.30	30A	8501	5110	1.66

Thickness and Section Modulus used in Weight, Pressure and Stress Calculations for ANSI B31.x Codes

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
ASME B31.1					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus
ASME B31.3					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness - Corrosion allowance	-	Nominal Thickness – Corrosion allowance
Section Modulus used	-	-	*Corroded* Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	*Corroded* Section Modulus; For Branch, effective section modulus
ASME B31.4					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch effective section modulus
ASME B31.5					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness – Corrosion allowance	-	Nominal Thickness – Corrosion allowance

Thickness and Section Modulus used in Weight, Pressure and Stress Calculations for ANSI B31.x Codes

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
Section Modulus used	-	-	Corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Corroded Section Modulus; For Branch, effective section modulus
ASME B31.8 and ASME B31.12 PL					
Pipe Thickness used	Nominal Thk.	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus
ASME B31.9					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus
ASME B31.12					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus

Note:

1. Corrosion allowance includes thickness required for threading, grooving, erosion, corrosion etc.
2. Un-corroded section modulus = section modulus calculated using the nominal thickness.

3. Corroded section modulus = section modulus calculated using the “corroded thickness”. Corroded thickness = nominal thickness – corrosion allowance

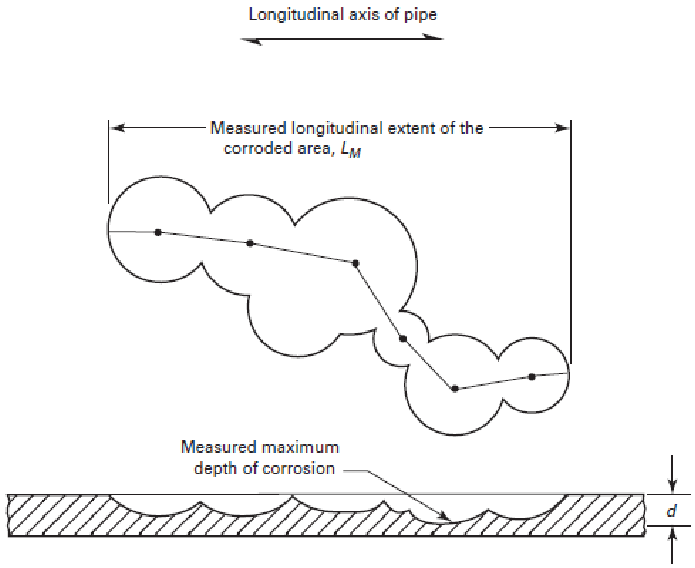
4. Effective section modulus = section modulus calculated using effective branch thickness, which is lesser of $i_i t_b$ or t_h

where, t_b = branch nominal thickness, t_h = header nominal thickness, i_i = in-plane SIF at branch

Remaining Strength

of

Corroded Pipelines



Method 1: B31G Original Method (0.67dL)

Failure Stress (SF) of Corroded Pipeline is computed as per Section 2.2 (a) titled "Level 1 Evaluation" as detailed below.

For Z <= 20

$$S_F = S_{flow}\left[\frac{1-\frac{2}{3}\left(\frac{d}{t}\right)}{1-\frac{2}{3}\left(\frac{d}{tM}\right)}\right]$$

For Z > 20

$$S_F = S_{flow}\left(1-\frac{d}{t}\right)$$

$$P_F = \frac{2S_F t}{D}$$

$$L_{all} = 1.12. B\sqrt{D.t}$$

$$B = \sqrt{\left(\frac{\frac{d}{t}}{1.1\frac{d}{t}-0.15}\right)^2 - 1}$$

where

S_F= failure stress

S_{flow} = flow stress = 1.1 SMYS

SMYS = Minimum Metal Yield Strength at Reference Temperature

d = measured maximum depth of corrosion

t = pipe wall thickness

M = bulging magnification factor = $\sqrt{1 + 0.8Z}$

Z = $\frac{L^2}{Dt}$

L = length of metal loss

D = pipe outside diameter

P_F= failure pressure

P_{FS}= safe pressure = P_F/Safety Factor; where Safety factor is input by the user

L_{all} = Maximum Allowable Defect Length

Method 2: B31G Modified Method (0.85dL)

Failure Stress (SF) of Corroded Pipeline is computed as per Section 2.2 (b) titled "Level 1 Evaluation" as detailed below.

For Z <= 50

M = $\sqrt{1 + 0.6275Z - 0.003375Z^2}$

For Z > 50

M = $0.032Z + 3.3$

$$S_F = S_{flow}\left[\frac{1 - 0.85\left(\frac{d}{t}\right)}{1 - 0.85\left(\frac{d}{tM}\right)}\right]$$

$$P_F = \frac{2S_F t}{D}$$

$$L_{all} = 1.12.B\sqrt{D.t}$$

$$B = \sqrt{\left(\frac{\frac{d}{t}}{1.1\frac{d}{t} - 0.15}\right)^2 - 1}$$

where

S_F= failure stress

S_{flow} = flow stress = SMYS + 10000 psi (69 MPa)

SMYS = Minimum Metal Yield Strength at Reference Temperature

d = measured maximum depth of corrosion

t = pipe wall thickness

M = bulging magnification factor

Z = $\frac{L^2}{Dt}$

L = length of metal loss

D = pipe outside diameter

P_F= failure pressure

P_{FS}= safe pressure = P_F/Safety Factor; where Safety factor is input by the user

L_{all} = Maximum Allowable Defect Length

Method 3: Exact Trapezoid

Failure Stress (SF) of Corroded Pipeline is computed as per Section 2.3 titled "Level 2 Evaluation" as detailed below. In this method, corroded area 'A' is numerically computed using the trapezoid method

$$S_F = S_{flow}\left(\frac{1-\frac{A}{A_o}}{1-\frac{A}{A_o M}}\right)$$

$$P_F = \frac{2S_F t}{D}$$

$$L_{all} = 1.12.B\sqrt{D.t}$$

$$B = \sqrt{\left(\frac{\frac{d}{t}}{1.1\frac{d}{t}-0.15}\right)^2 - 1}$$

For Z <= 50

M = $\sqrt{1+0.6275Z-0.003375Z^2}$

For Z > 50

M = $0.032Z+3.3$

where

S_F= failure stress

S_{flow} = flow stress = SMYS + 10000 psi (69 MPa)

SMYS = Minimum Metal Yield Strength at Reference Temperature

M = bulging magnification factor

Z = $\frac{L^2}{Dt}$

L = length of metal loss

A = corroded area numerically computed using the trapezoid method

A_o = L.t

D = pipe outside diameter

t = pipe wall thickness

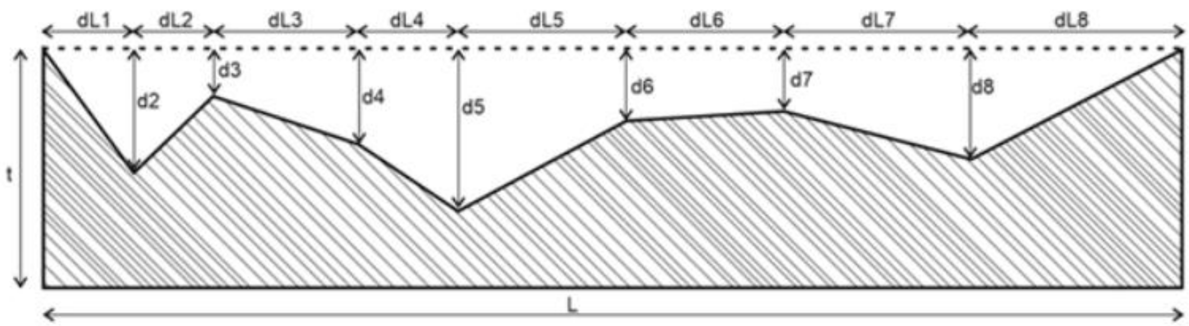
P_F= failure pressure

P_{FS}= safe pressure = P_F/Safety Factor; where Safety factor is input by the user

d/t = A/Ao

Method 4: Equivalent Area

Failure Stress (SF) of Corroded Pipeline is computed as per Section 2.3 as detailed below. In this method, corroded area 'A' is numerically computed using the Equivalent Area method



For Z_e <= 50

M = $\sqrt{1 + 0.6275Z_e - 0.003375{Z_e}^2}$

For Z_e > 50

M = $0.032Z_e + 3.3$

$$S_F = S_{flow}\left(\frac{1 - \frac{A}{A_o}}{1 - \frac{A}{A_o M}}\right)$$

$$P_F = \frac{2S_F t}{D}$$

$$L_{all} = 1.12.B\sqrt{D.t}$$

$$B = \sqrt{\left(\frac{\frac{A}{A_o}}{1.1\frac{A}{A_o} - 0.15}\right)^2 - 1}$$

where

S_F= failure stress

S_{flow} = flow stress = SMYS + 10000 psi (69 MPa)

SMYS = Minimum Metal Yield Strength at Reference Temperature

M = bulging magnification factor

L_e = equivalent flaw length =L. $\frac{\left(\frac{d1+d2+d3+\cdots\ldots+dn}{n}\right)}{d}$

d1, d2,…dn = measured depth of corrosion at node 1, 2, …n

L = length of metal loss

d = measured maximum depth of corrosion

$Z_e = \frac{{L_e}^2}{Dt}$

D = pipe outside diameter

t = pipe wall thickness

A = corroded area = $\boldsymbol{L}.\left(\frac{d1+d2+d3+\cdots\ldots+dn}{n}\right)$

A_o = L.t

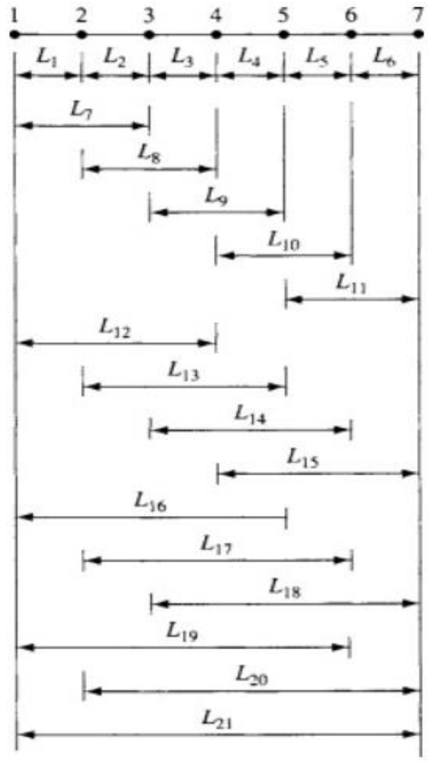
P_F= failure pressure

P_{FS}= safe pressure = P_F/Safety Factor; where Safety factor is input by the user

Method 5: Effective Area Method

Failure Stress (SF) of Corroded Pipeline is computed as per Section 2.3 titled "Level 2 Evaluation" as detailed below.

In the effective area method, each pit is assessed with a combination of other corroded regions in an iterative procedure. The numbers of calculations performed are n!/2(n-2)!, where *n* = number of pits. For example, if one takes seven (7) pit readings, the program will make 21 iterations as shown below.



$$S_F = min\left[S_{flow}\left(\frac{1-\frac{A_i}{A_{oi}}}{1-\frac{A_i}{A_{oi}M_i}}\right)\right]$$

$$P_F = \frac{2S_F t}{D}$$

$$L_{all} = min\left(1.12.B_i\sqrt{D.t}\right)$$

$$B_i = \sqrt{\left(\frac{\frac{A_i}{A_{oi}}}{1.1\frac{A_i}{A_{oi}}-0.15}\right)^2 - 1}$$

For Z_i <= 50

$M_i = \sqrt{1 + 0.6275Z_i - 0.003375Z_i^2}$

For Z_i > 50

$M_i = 0.032Zi + 3.3$

where

S_F= failure stress

S_{flow} = flow stress = SMYS + 10000 psi (69 MPa)

SMYS = Minimum Metal Yield Strength at Reference Temperature

M = bulging magnification factor

$Z_i = \frac{Li^2}{Dt}$

L_i = length of possible failure area #i

A_i = possible failure area #i. Area A_i numerically calculated using the trapezoid method

$A_{oi} = L_i.t$

D = pipe outside diameter

t = pipe wall thickness

P_F= failure pressure

P_{FS}= safe pressure = P_F/Safety Factor; where Safety factor is input by the user

Fatigue Evaluation

Simplified Fatigue Evaluation

Given below are the equations that are used in computing the total number of "equivalent reference displacement stress range cycles (N)" for Simplified Fatigue Evaluation.

$$N = N_E + \sum(q_i^5 . N_i) \ for \ i = 1,2,\ldots,n \qquad \text{Eq. 1}$$

$$N = N_E + \sum(q_i^3 . N_i) \ for \ i = 1,2,\ldots,n \qquad \text{Eq. 2}$$

$$N = N_E + \sum(q_i . N_i) \ for \ i = 1,2,\ldots,n \qquad \text{Eq. 3}$$

where

N_E = number of cycles of the reference displacement stress range, S_E

N_i = number of cycles associated with the displacement stress range, S_i

$q_i = S_i/S_E$

S_E = reference displacement stress range, psi (kPa) = Maximum stress range computed among the displacement stress ranges selected by the user for Simplified Fatigue Evaluation.

S_i = maximum computed stress range for the i^{th} displacement stress range.

Table given below lists the specific equation used in computing total number of "equivalent reference displacement stress range cycles (N)", for different piping codes.

Once the "equivalent reference displacement stress range cycles (N)" is computed, then CAEPIPE uses this "N" to compute the Stress Range Reduction Factor (f or U) as per the piping code selected for analysis.

Sl. No.	Piping Code and Description	Equation Number
1	ASME B31.1 (2022) - Power Piping	Eq. 1
2	ASME B31.1 (1967) - Power Piping	Eq. 1
3	ASME B31.1 (1973) - Power Piping	Eq. 1
4	ASME B31.1 (1977) - Power Piping	Eq. 1
5	ASME B31.1 (1980) - Power Piping	Eq. 1
6	ASME B31.3 (2022) - Process Piping	Eq. 2
7	ASME B31.4 (2022) - Pipeline Transportation Systems for Liquids and Slurries	Eq. 1
8	ASME B31.5 (2022) - Refrigeration Piping and Heat Transfer Components	Eq. 1
9	ASME B31.8 (2022) - Gas Transmission and Distribution Piping Systems	Eq. 1
10	ASME B31.9 (2020) - Building Services Piping	Eq. 1
11	ASME B31.12 IP (2019) - Hydrogen Piping ASME B31.12 IP (2023) – Hydrogen Piping	Eq. 3 Eq. 2
12	ASME B31.12 PL (2019) - Hydrogen Pipelines ASME B31.12 PL (2023) – Hydrogen Pipelines	Eq. 3 Eq. 2
13	ASME NM.1 (2022) - Thermoplastic Piping Systems	Not Applicable
14	ASME NM.2 (2022) - Glass-Fiber-Reinforced Thermosetting-Resin Piping Systems (GRP/FRP)	Not Applicable
15	ASME Class 2 (1980) - ASME Section III, Subsection NC - Class 2	Eq. 1
16	ASME Class 2 (1986) - ASME Section III, Subsection NC - Class 2	Eq. 1
17	ASME Class 2 (1992) - ASME Section III, Subsection NC - Class 2	Eq. 1
18	ASME Class 2 (2015) - ASME Section III, Subsection NC - Class 2	Eq. 1
19	ASME Class 2 (2017) ASME Section III, Subsection NC - Class 2	Eq. 1

Sl. No.	Piping Code and Description	Equation Number
20	ASME Class 2 (2021) - ASME Section III, Subsection NC - Class 2	Eq. 1
21	ASME Class 2 (2023) - ASME Section III, Subsection NC - Class 2	Eq. 1
22	ASME Class 3 (2017) - ASME Section III, Subsection ND - Class 3	Eq. 1
23	ASME Class 3 (2021) - ASME Section III, Subsection ND - Class 3	Eq. 1
24	ASME Class 3 (2023) - ASME Section III, Subsection ND - Class 3	Eq. 1
25	ISO 14692-3 (2017) - Petroleum and Natural Gas Industries - Glass Reinforced Plastics (GRP/FRP) Piping	Not Applicable
26	EN 13480 (2020) - Metallic industrial piping	Eq. 1
27	EN 13941 (2019) - District heating pipes	Not Applicable
28	BS 806 (1986) - Construction of Ferrous Piping Installations for and in Connection with Land Boilers (British)	Not Applicable
29	DNV-ST-F101 – Submarine pipeline systems	Not Applicable
30	IGEM (2012) - Institution of Gas Engineers and Managers (IGEM) IGE/TD/12 Edition 2 (UK)	Not Applicable
31	Norwegian (1983) - Process design	Eq. 1
32	Norwegian (1990) - Process design	Eq. 1
33	RCC-M (1985) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Eq. 1
34	RCC-M (2018) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Eq. 1
35	RCC-M (2020) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Eq. 1
36	RCC-M (2022) - Design and Construction Rules for Mechanical Components of PWR Nuclear Islands (French)	Eq. 1
37	CODETI (2013) - CODE DE CONSTRUCTION DES TUYAUTERIES INDUSTRIELLES (French)	Eq. 1
38	Stoomwezen (1989) - Dutch Power piping code	Eq. 1
39	Swedish (1978) – Swedish piping code	Eq. 1
40	Z183 (1990) - Oil Pipeline Systems (Canadian)	Eq. 1
41	Z184 (1992) - Gas Pipeline Systems (Canadian)	Eq. 1
42	Z662 (2019) - Oil & Gas Pipeline Systems (Canadian)	Eq. 1
43	NONE (for AWWA M11 applications, and for applications in aircraft, aerospace & defence industries)	Not Applicable

Detailed Fatigue Evaluation

Detailed Fatigue Evaluation is performed as per Miner's Rule which is based on Cumulative Damage Theory.

Miner's Rule is based on the concept that fatigue damage accumulates over time and that failure occurs when the accumulated damage reaches a critical value, typically set to 1. The rule is expressed mathematically as:

$$D = \sum \frac{n_i}{N_i}$$

where, D = Total cumulative damage, n_i = Actual number of cycles at alternating stress level i, N_i = Number of cycles to Failure at stress level i (from the S-N curve).

When the total damage D equals or exceeds 1.0, then the fatigue evaluation is considered to have failed.

Example Calculation

Assume a piping system experiences the following cyclic loading conditions:

- **Expansion (T1):** Alternating Stress amplitude of 15000 psi, with 5000 cycles.
- **Expansion (T2):** Alternating Stress amplitude of 30000 psi, with 2000 cycles.

The alternating stress amplitudes listed above are one-half of the stress range values (=SE/2.0) at a particular Node for Expansion (T1) and Expansion (T2) cases respectively.

From the sample S-N curve given below,

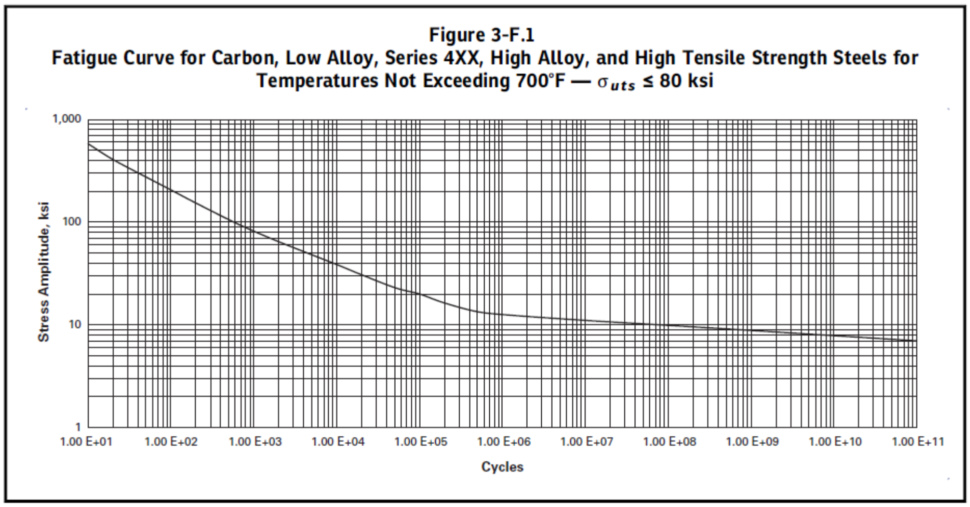


Figure 3-F.1
Fatigue Curve for Carbon, Low Alloy, Series 4XX, High Alloy, and High Tensile Strength Steels for Temperatures Not Exceeding 700°F — $\sigma_{uts} \le 80$ ksi

- **At Alternating Stress 15000 psi:** N1 (Number of cycles to failure) = 1E+6 cycles.
- **At Alternating Stress 30000 psi:** N2 (Number of cycles to failure) = 1E+4 cycles.

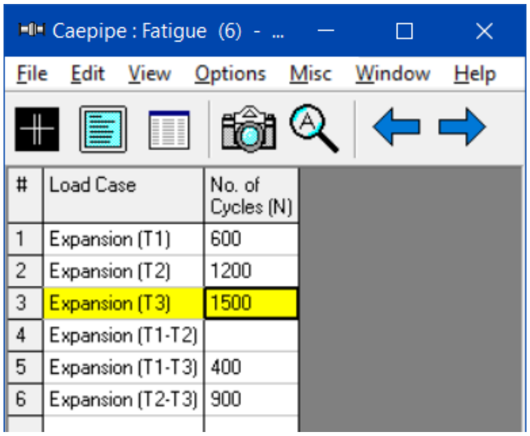
Calculate damage:

- **Damage at 15000 psi:** n1/N1 = 5000/1E+6 = 0.005
- **Damage at 30000 psi:** n2/N2 = 2000/1E+4 = 0.200
- **Total Cumulative Damage:** D = 0.005 + 0.2 = 0.205

Since D < 1.0, the component meets the Fatigue requirement for the given cyclic loading conditions, though it will have consumed 20.5% of its total allowable fatigue life.

Actual Number of Cycles to be Input for Simplified and Detailed Fatigue Analysis:

In CAEPIPE, the actual number of cycles associated with each selected expansion load case can be entered as shown below. When Simplified or Detailed Fatigue Analysis is enabled, CAEPIPE utilizes this table (containing the actual number of cycles for the selected load cases) to perform both Simplified and Detailed Fatigue Analysis. Please note, as stated above, when any of the load cases is not to be included in the Fatigue Evaluation, then leave the 'Number of Cycles (N)' field for that load case BLANK as shown below.



When Simplified Fatigue Analysis is turned ON, CAEPIPE uses the above table for calculating the "equivalent reference displacement stress range cycles (N)", which then is used to compute the stress range reduction factor ('f' or 'U') as detailed in the section titled 'Simplified Fatigue Evaluation' in the CAEPIPE Code Compliance Manual.

Similarly, when the Detailed Fatigue Analysis is turned ON, CAEPIPE uses the above table to compute the "Cumulative Damage (D)" as outlined in the section titled 'Detailed Fatigue Evaluation' in the CAEPIPE Code Compliance Manual.

For better clarity, refer to the example given below for inputting the Fatigue Cycle table:

Consider a piping system that operates at three different temperature levels, each with a corresponding number of cycles over its service life and with the reference temperature of 70^0F.

20 cycles of $T_1 = Expansion\ (T_1) = T_1 - T_{ref} = 270^0F - 70^0F = 200^0F$

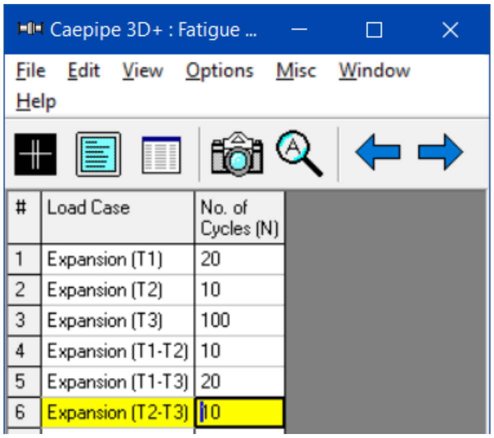
10 cycles of $T_2 = Expansion\ (T_2) = T_2 - T_{ref} = -80^0F - 70^0F = -150^0F$

100 cycles of $T_3 = Expansion\ (T_3) = T_3 - T_{ref} = -30^0F - 70^0F = -100^0F$

With reference to the above temperature ranges, the number of cycles that can be entered in CAEPIPE for each load case are as follows.

- For Expansion (T_1), the number of cycles=20
- For Expansion (T_2), the number of cycles=10
- For Expansion (T_3), the number of cycles=100
- For Expansion $(T_1 - T_2)$, the number of cycles = Min(T_1, T_2) = Min(20,10) = 10
- For Expansion $(T_1 - T_3)$, the number of cycles = Min(T_1, T_3) = Min(20,100) = 20
- For Expansion $(T_2 - T_3)$, the number of cycles = Min(T_2, T_3) = Min(10,100) = 10

Accordingly, the Fatigue Cycle table in CAEPIPE is to be input as shown below.



The above approach to input the number of cycles is conservative as the sum of the Number of Cycles input is greater than the sum of actual number of cycles (i.e., [170 = 20+10+100+10+20+10] > [130 = 20+10+100]). There may be alternate ways to input the number of cycles, such as “combining” or "lumping" the ranges of variations to produce the maximum effect as stated in Clause NB-3553 ‘Fatigue Usage’ of ASME Section III, Subsection NB (2021).

Rotating Equipment Qualification

API 610 (11th Edition, 2010) / ISO 13709:2009 for Pumps

The allowable nozzle forces and moments for pumps are taken from Table 4 of the eleventh edition of API Standard 610 / ISO 13709.

Table 4 — Nozzle loadings

	SI units								
	Nominal size of flange (DN)								
	⩽ 50	80	100	150	200	250	300	350	400
	Forces (N)								
Each top nozzle									
F_X	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Y	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_Z	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Each side nozzle									
F_X	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Y	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_Z	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Each end nozzle									
F_X	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_Y	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Z	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
	Moments (N·m)								
Each nozzle									
M_X	460	950	1 330	2 300	3 530	5 020	6 100	6 370	7 320
M_Y	230	470	680	1 180	1 760	2 440	2 980	3 120	3 660
M_Z	350	720	1 000	1 760	2 580	3 800	4 610	4 750	5 420
M_R	620	1 280	1 800	3 130	4 710	6 750	8 210	8 540	9 820

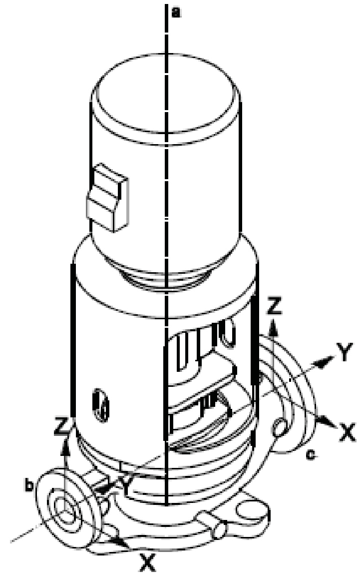
Table 4 — Nozzle loadings (*continued*)

	US Customary units								
	Nominal size of flange (NPS)								
	⩽ 2	**3**	**4**	**6**	**8**	**10**	**12**	**14**	**16**
	Forces (lbf)								
Each top nozzle									
F_X	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Y	130	200	260	460	700	1 000	1 200	1 300	1 500
F_Z	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Each side nozzle									
F_X	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Y	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_Z	130	200	260	460	700	1 000	1 200	1 300	1 500
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Each end nozzle									
F_X	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_Y	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Z	130	200	260	460	700	1 000	1 200	1 300	1 500
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
	Moments (ft·lbf)								
Each nozzle									
M_X	340	700	980	1 700	2 600	3 700	4 500	4 700	5 400
M_Y	170	350	500	870	1 300	1 800	2 200	2 300	2 700
M_Z	260	530	740	1 300	1 900	2 800	3 400	3 500	4 000
M_R	460	950	1 330	2 310	3 500	5 000	6 100	6 300	7 200

NOTE 1 See Figures 20 through 24 for orientation of nozzle loads (X, Y and Z).

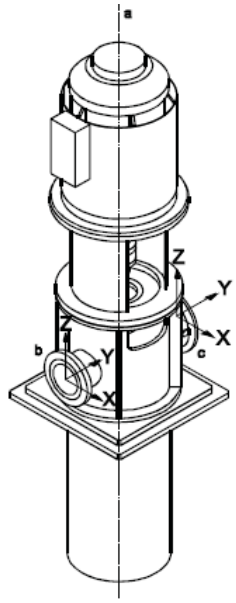
NOTE 2 Each value shown above indicates range from minus that value to plus that value; for example 160 indicates a range from −160 to +160.

The coordinate systems and nozzle orientations for various pump configurations are shown next.



[a] Shaft centreline.
[b] Discharge.
[c] Suction.

Figure 21 — Coordinate system for the forces and moments in Table 5 — Vertical in-line pumps

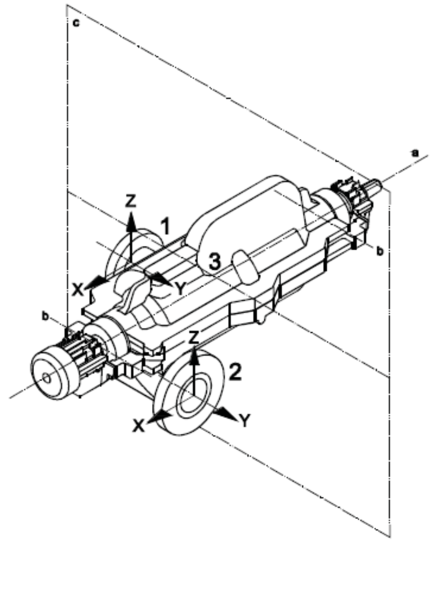


a Shaft centreline.

b Discharge.

c Suction.

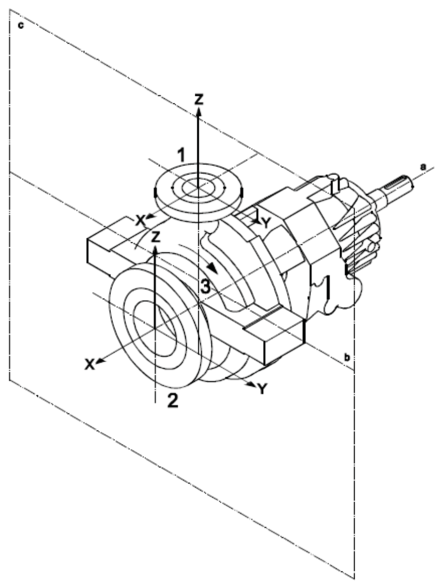
Figure 22 — Coordinate system for the forces and moments in Table 5 — Vertically suspended, double-casing pumps



Key

1 discharge nozzle
2 suction nozzle
3 centre of pump
a Shaft centreline.
b Pedestal centreline.
c Vertical plane.

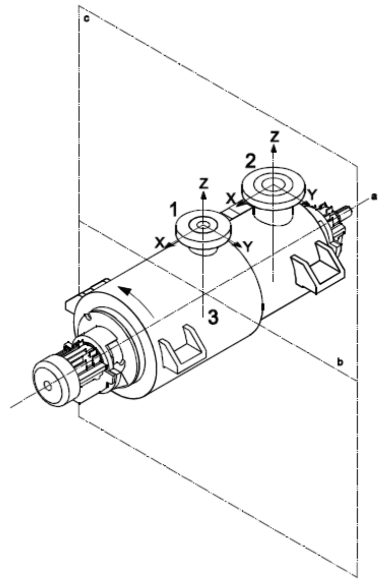
Figure 23 — Coordinate system for the forces and moments in Table 5 — Horizontal pumps with side suction and side discharge nozzles



Key

1 discharge nozzle
2 suction nozzle
3 centre of pump
a Shaft centreline.
b Pedestal centreline.
c Vertical plane.

Figure 24 — Coordinate system for the forces and moments in Table 5 — Horizontal pumps with end suction and top discharge nozzles



Key

1 discharge nozzle
2 suction nozzle
3 centre of pump
a Shaft centreline.
b Pedestal centreline.
c Vertical plane.

Figure 25 — Coordinate system for the forces and moments in Table 5 — Horizontal pumps with top nozzles

Criteria for Piping Design

The criteria for piping design are taken from Appendix F of the API 610.

F.1 Horizontal pumps

F.1.1 Acceptable piping configurations should not cause excessive misalignment between the pump and driver. Piping configurations that produce component nozzle loads lying within the ranges specified in Table 5 limit casing distortion to one-half the pump vendor's design criterion (see 6.3.3) and ensure pump shaft displacement of less than 250 μm (0,010 in).

F.1.2 Piping configurations that produce loads outside the ranges specified in Table 5 are also acceptable without consultation with the pump vendor if the conditions specified in F.1.2 a) through F.1.2 c) as follows are satisfied. Satisfying these conditions ensures that any pump casing distortion is within the vendor's design criteria (see 6.3.3) and that the displacement of the pump shaft is less than 380 μm (0,015 in).

a) The individual component forces and moments acting on each pump nozzle flange shall not exceed the range specified in Table 5 (T4) by a factor of more than 2.

b) The resultant applied force (F_{RSA}, F_{RDA}) and the resultant applied moment (M_{RSA}, M_{RDA}) acting on each pump-nozzle flange shall satisfy the appropriate interaction equations as given in Equations (F.1) and (F.2):

$$[F_{RSA}/(1,5 \times F_{RST4})] + [M_{RSA}/(1,5 \times M_{RST4})] < 2 \qquad (F.1)$$

$$[F_{RDA}/(1,5 \times F_{RDT4})] + [M_{RDA}/(1,5 \times M_{RDT4})] < 2 \qquad (F.2)$$

c) The applied component forces and moments acting on each pump nozzle flange shall be translated to the centre of the pump. The magnitude of the resultant applied force, F_{RCA}, the resultant applied moment, M_{RCA}, and the applied moment shall be limited by Equations (F.3) to (F.5). (The sign convention shown in Figures 21 through 25 and the right-hand rule should be used in evaluating these equations.)

$$F_{RCA} < 1,5(F_{RST4} + F_{RDT4}) \qquad (F.3)$$

$$|M_{YCA}| < 2,0(M_{YST4} + M_{YDT4}) \qquad (F.4)$$

$$M_{RCA} < 1,5(M_{RST4} + M_{RDT4}) \qquad (F.5)$$

where

$$F_{RCA} = [(F_{XCA})^2 + (F_{YCA})^2 + (F_{ZCA})^2]^{0,5}$$

where

$$F_{XCA} = F_{XSA} + F_{XDA}$$

$$F_{YCA} = F_{YSA} + F_{YDA}$$

$$F_{ZCA} = F_{ZSA} + F_{ZDA}$$

$$M_{RCA} = [(M_{XCA})^2 + (M_{YCA})^2 + (M_{ZCA})^2]^{0,5}$$

where

$$M_{XCA} = M_{XSA} + M_{XDA} - [(F_{YSA})(zS) + (F_{YDA})(zD) - (F_{ZSA})(yS) - (F_{ZDA})(yD)]/1\,000$$

$$M_{YCA} = M_{YSA} + M_{YDA} + [(F_{XSA})(zS) + (F_{XDA})(zD) - (F_{ZSA})(xS) - (F_{ZDA})(xD)]/1\,000$$

$$M_{ZCA} = M_{ZSA} + M_{ZDA} - [(F_{XSA})(yS) + (F_{XDA})(yD) - (F_{YSA})(xS) - (F_{YDA})(xD)]/1\,000$$

In USC units, the constant 1 000 shall be changed to 12. This constant is the conversion factor to change millimetres to metres or inches to feet.

F.1.3 Piping configurations that produce loads greater than those allowed in F.1.2 shall be approved by the purchaser and the vendor.

NOTE In order to evaluate the actual machine distortion (at ambient conditions), the piping alignment checks required in API RP 686, Chapter 6, should be performed. API RP 686 allows only a small fraction of the permitted distortion resulting from use of the values from this annex.

F.2 Vertical in-line pumps

Vertical in-line pumps that are supported only by the attached piping may be subjected to component piping loads that are more than double the values shown in Table 4 if these loads do not cause a principal stress greater than 41 N/mm^2 (5 950 psi) in either nozzle. For calculation purposes, the section properties of the pump nozzles shall be based on Schedule 40 pipe whose nominal size is equal to that of the appropriate pump nozzle. Equation (F.6), Equation (F.7), and Equation (F.8) can be used to evaluate principal stress, longitudinal stress and shear stress, respectively, in the nozzles.

For SI units, the following equations apply:

$$\sigma_p = (\sigma/2) + (\sigma^2/4 + \tau^2)^{0,5} < 41 \quad \text{(F.6)}$$

$$\sigma_l = [1,27 \times F_Y / (D_o^2 - D_i^2)] + [10\,200 \times D_o (M_X^2 + M_Z^2)^{0,5}] / (D_o^4 - D_i^4) \quad \text{(F.7)}$$

$$\tau = [1,27 \times (F_X^2 + F_Z^2)^{0,5}] / (D_o^2 - D_i^2) + [5\,100 \times D_o (|M_Y|)] / (D_o^4 - D_i^4) \quad \text{(F.8)}$$

For USC units, the following equations apply:

$$\sigma_p = (\sigma/2) + (\sigma^2/4 + \tau^2)^{0,5} < 5\,950 \quad \text{(F.9)}$$

$$\sigma_l = [1,27 \times F_Y / (D_o^2 - D_i^2)] + [122 \times D_o (M_X^2 + M_Z^2)^{0,5}] / (D_o^4 - D_i^4) \quad \text{(F.10)}$$

$$\tau = [1,27 \times (F_X^2 + F_Z^2)^{0,5}] / (D_o^2 - D_i^2) + [61 \times D_o (|M_Y|)] / (D_o^4 - D_i^4) \quad \text{(F.11)}$$

where

σ_p is the principal stress, expressed in MPa (lbf/in^2);

σ_l is the longitudinal stress, expressed in MPa (lbf/in^2);

τ is the shear stress, expressed in MPa (lbf/in^2);

F_X is the applied force on the X axis;

F_Y is the applied force on the Y axis;

F_Z is the applied force on the Z axis;

M_X is the applied moment on the X axis;

M_Y is the applied moment on the Y axis;

M_Z is the applied moment on the Z axis;

D_i, D_o are the inner and outer diameters of the nozzles, expressed in millimetres (inches).

F_X, F_Y, F_Z, M_X, M_Y, and M_Z represent the applied loads acting on the suction or discharge nozzles; thus, subscripts S_A and D_A have been omitted to simplify the equations. The sign of F_Y is positive if the load puts the nozzle in tension; the sign is negative if the load puts the nozzle in compression. One should refer to Figure 20 and the applied nozzle loads to determine whether the nozzle is in tension or compression. The absolute value of M_Y should be used in Equations (F.8) to (F.11).

F.3 Nomenclature

The following definitions apply to the sample problems in F.4

where

C	is the centre of the pump. For pump types OH2 and BB2 with two support pedestals, the centre is defined by the intersection of the pump shaft centreline and a vertical plane passing through the centre of the two pedestals (see Figure 23 and Figure 24). For pump types BB1, BB3, BB4 and BB5 with four support pedestals, the centre is defined by the intersection of the pump shaft centreline and a vertical plane passing midway between the four pedestals (see Figure 22);
D	is the discharge nozzle;
D_i	is the inside diameter of Schedule 40 pipe whose nominal size is equal to that of the pump nozzle in question, expressed in millimetres (inches);
D_o	is the outside diameter of Schedule 40 pipe whose nominal size is equal to that of the pump nozzle in question, expressed in millimetres (inches);
F	is the force, expressed in newtons (pounds force);
F_R	is the resultant force. (F_{RSA} and F_{RDA} are calculated by the square root of the sum of the squares method using the applied component forces acting on the nozzle flange. F_{RST4} and F_{RDT4} are extracted from Table 4, using the appropriate nozzle size);
M	is the moment, expressed in newton metres (foot-pounds force);
M_R	is the resultant moment. (M_{RSA} and M_{RDA} are calculated by the square root of the squares method using the applied component moments acting on the nozzle flange. M_{RST4} and M_{RDT4} are extracted from Table 4 using the appropriate nozzle size);
σ_p	is the principal stress, expressed in megapascals (pounds force per square inch);
σ_l	is the longitudinal stress, expressed in newtons per square millimetre (pounds per square inch);
τ	is the shear stress, expressed in newtons per square millimetre (pounds per square inch);
S	is the suction nozzle;
x, y, z	are the location coordinates of the nozzle flanges with respect to the centre of the pump, expressed in millimetres (inches);
X, Y, Z	are the directions of the load (see Figures 20 to 24);
Subscript A	is an applied load;
Subscript T4	is a load extracted from Table 4.

Verification of API 610 Pump Compliance

Implementation of API 610 Pump Compliance in CAEPIPE is verified using the sample provided in API Standard 610, 11th Edition and presented in this section.

F.4.3 Example 1B — USC units

F.4.3.1 Problem

For an overhung end-suction process pump (OH2), the nozzle sizes and location coordinates are as given in Table F.4. The applied nozzle loadings are as given in Table F.5. The problem is to determine whether the conditions specified in F.1.2 a), F.1.2 b), and F.1.2 c) are satisfied.

Table F.4 — Nozzle sizes and location coordinates for Example 1B

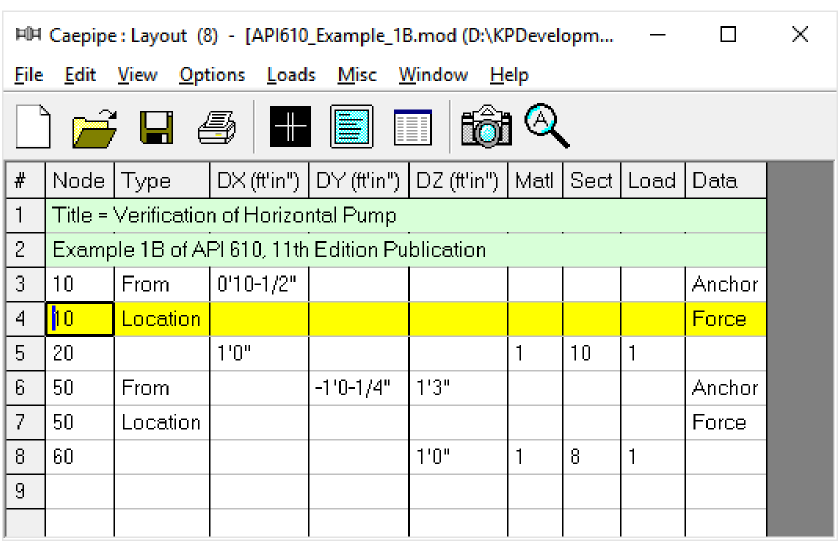
Dimensions in inches

Nozzle	Size	*x*	*y*	*z*
Suction	10	+10,50	0	0
Discharge	8	0	−12,25	+15

Table F.5 — Applied nozzle loadings for Example 1B

Force	Value lbf	Moment	Value ft·lbf
—	—	Suction	—
F_{XSA}	+2 900	M_{XSA}	−1 000
F_{YSA}	0	M_{YSA}	−3 700[a]
F_{ZSA}	−1 990	M_{ZSA}	−5 500
—	—	Discharge	—
F_{XDA}	+1 600	M_{XDA}	+500
F_{YDA}	−100	M_{YDA}	−2 500
F_{ZDA}	+1 950	M_{ZDA}	−3 600
[a] See F.4.1.2.1.			

CAEPIPE model corresponding to the above API Publication sample



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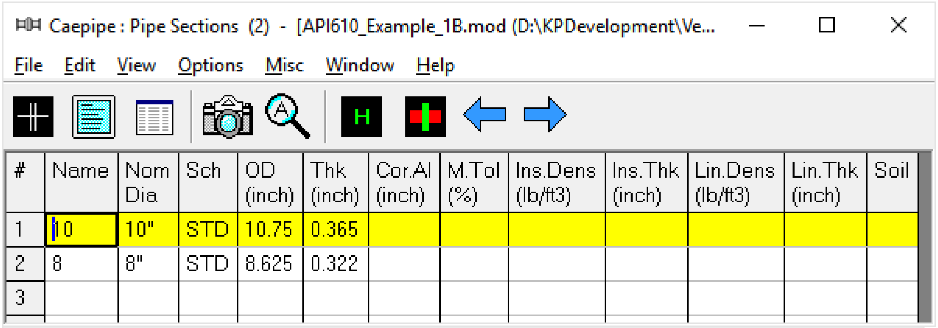
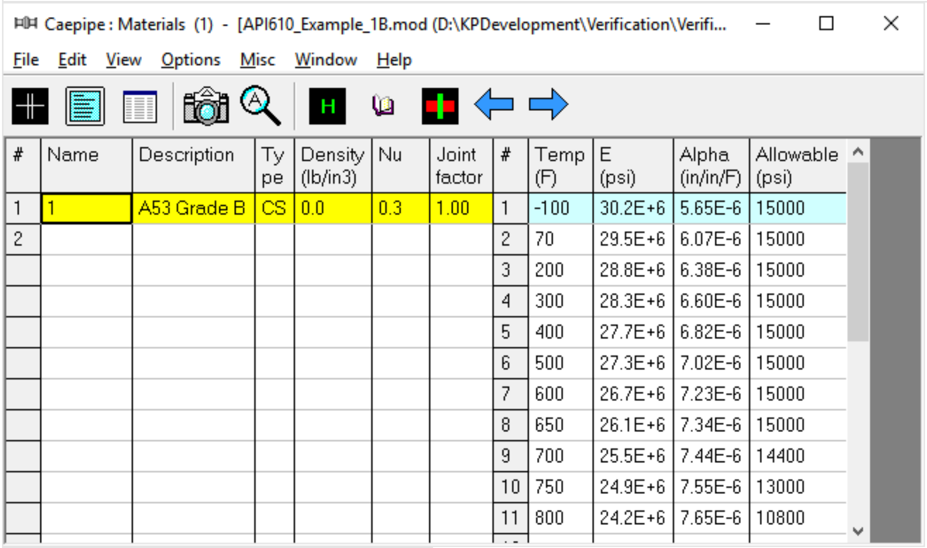
#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title = Verification of Horizontal Pump								
2	Example 1B of API 610, 11th Edition Publication								
3	10	From	0'10-1/2"						Anchor
4	10	Location							Force
5	20		1'0"			1	10	1	
6	50	From		-1'0-1/4"	1'3"				Anchor
7	50	Location							Force
8	60				1'0"	1	8	1	
9									

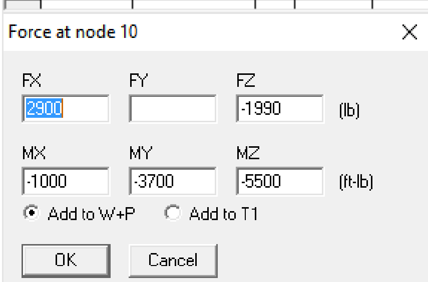


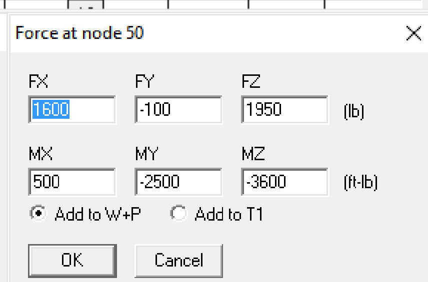
#	Name	Nom Dia	Sch	OD (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Thk (inch)	Lin.Dens (lb/ft3)	Lin.Thk (inch)	Soil
1	10	10"	STD	10.75	0.365							
2	8	8"	STD	8.625	0.322							
3												

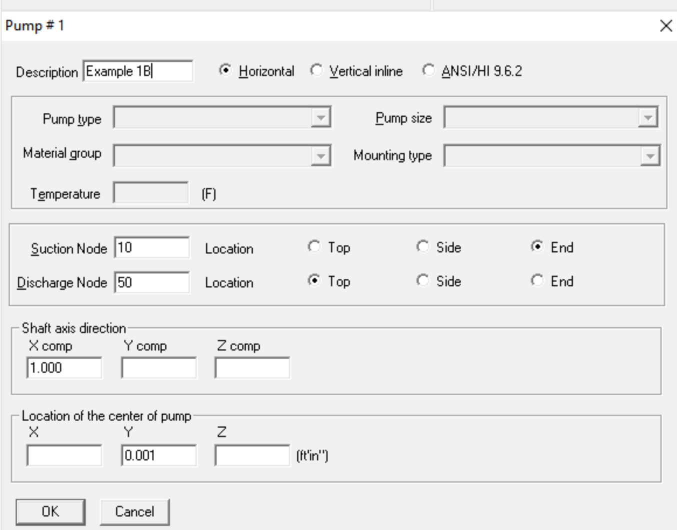


#	Name	Description	Type	Density (lb/in3)	Nu	Joint factor
1	1	A53 Grade B	CS	0.0	0.3	1.00
2						

#	Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
1	-100	30.2E+6	5.65E-6	15000
2	70	29.5E+6	6.07E-6	15000
3	200	28.8E+6	6.38E-6	15000
4	300	28.3E+6	6.60E-6	15000
5	400	27.7E+6	6.82E-6	15000
6	500	27.3E+6	7.02E-6	15000
7	600	26.7E+6	7.23E-6	15000
8	650	26.1E+6	7.34E-6	15000
9	700	25.5E+6	7.44E-6	14400
10	750	24.9E+6	7.55E-6	13000
11	800	24.2E+6	7.65E-6	10800







Results from API 610, 11th Edition

F.4.3.2 Solution

F.4.3.2.1 A check of condition of F.1.2 a) is as follows:

For the 10 in end suction nozzle:

$|F_{XSA}/F_{XST4}| = |+2\ 900/1\ 500| = 1{,}93 < 2{,}00$

$|F_{YSA}/F_{YST4}| = |0/1\ 200| = 0 < 2{,}00$

$|F_{ZSA}/F_{ZST4}| = |-1\ 990/1\ 000| = 1{,}99 < 2{,}00$

$|M_{XSA}/M_{XST4}| = |-1\ 000/3\ 700| = 0{,}27 < 2{,}00$

$|M_{YSA}/M_{YST4}| = |-3\ 700/1\ 800| = 2{,}06 > 2{,}00$

$|M_{ZSA}/M_{ZST4}| = |-5\ 500/2\ 800| = 1{,}96 < 2{,}00$

For the 8 in top discharge nozzle:

$|F_{XDA}/F_{XDT}| = |+1\ 600/850| = 1{,}88 < 2{,}00$

$|F_{YDA}/F_{YDT}| = |-100/700| = 0{,}14 < 2{,}00$

$|F_{ZDA}/F_{ZDT4}| = |+1\ 950/1\ 100| = 1{,}77 < 2{,}00$

$|M_{XDA}/M_{XDT4}| = |+500/2\ 600| = 0{,}19 < 2{,}00$

$|M_{YDA}/M_{YDT4}| = |-2\ 500/1\ 300| = 1{,}93 < 2{,}00$

$|M_{ZDA}/M_{ZDT4}| = |-3\ 600/1\ 900| = 1{,}89 < 2{,}00$

F.4.3.2.2 A check of condition F.1.2 b) is as follows:

For the suction nozzle, F_{RSA} and M_{RSA} are determined using the square root of the sum of the squares method:

$$F_{RSA} = [(F_{XSA})^2 + (F_{YSA})^2 + (F_{ZSA})^2]^{0,5} = [(+2\ 900)^2 + (0)^2 + (-1\ 990)^2]^{0,5} = 3\ 517$$

$$M_{RSA} = [(M_{XSA})^2 + (M_{YSA})^2 + (M_{ZSA})^2]^{0,5} = [(-1\ 000)^2 + (-3\ 599)^2 + (-5\ 500)^2]^{0,5} = 6\ 649$$

Referring to Equation (F.1),

$$F_{RSA}/(1{,}5 \times F_{RST4}) + M_{RSA}/(1{,}5 \times M_{RST4}) < 2$$

$$3\ 517/(1{,}5 \times 2\ 200) + 6\ 649/(1{,}5 \times 5\ 000) < 2$$

$$1{,}95 < 2$$

For the discharge nozzle, F_{RDA} and M_{RDA} are determined by the same method used to find F_{RSA} and M_{RSA}:

$$F_{RDA} = [(F_{XDA})^2 + (F_{YDA})^2 + (F_{ZDA})^2]^{0,5} = [(+1\ 600)^2 + (-100)^2 + (+1\ 950)^2]^{0,5} = 2\ 524$$

$$M_{RDA} = [(M_{XDA})^2 + (M_{YDA})^2 + (M_{ZDA})^2]^{0,5} = [(+500)^2 + (-2\ 500)^2 + (-3\ 600)^2]^{0,5} = 4\ 411$$

Referring to Equation (**F**.2),

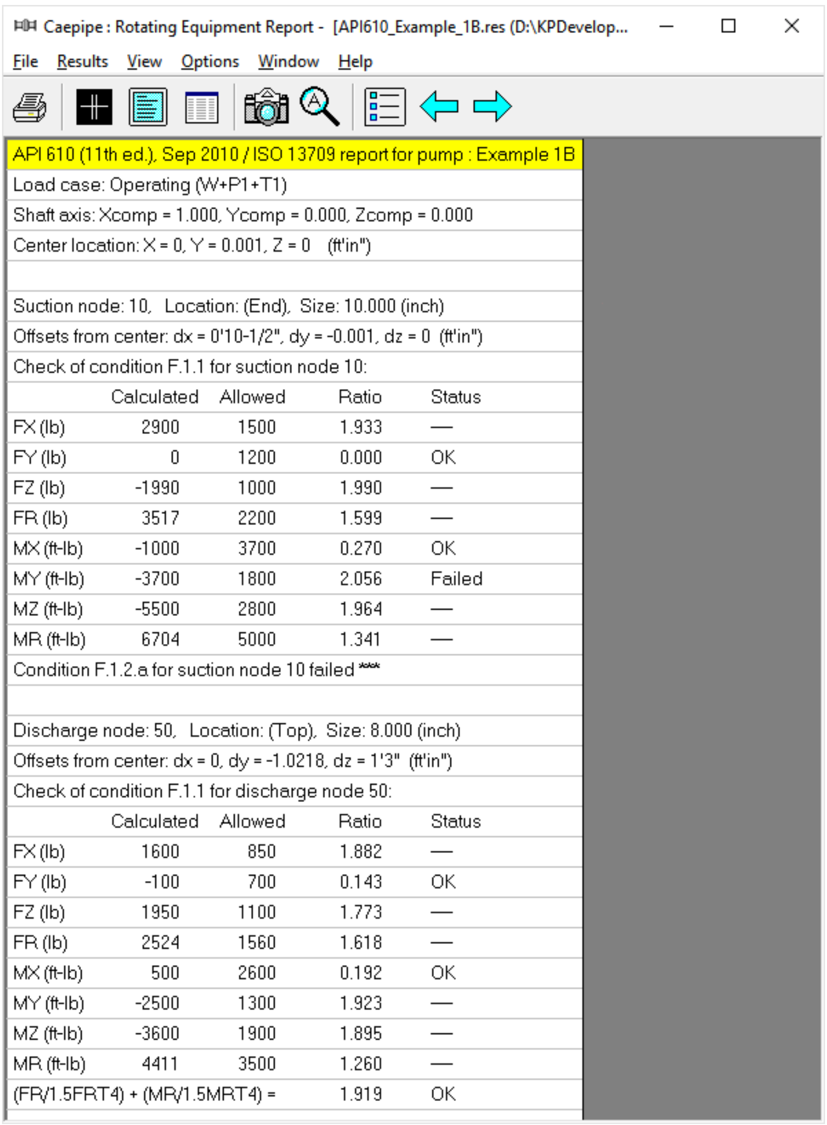
$$F_{RDA}/(1,5 \times F_{RDT4}) + M_{RDA}/(1,5 \times M_{RDT4}) < 2$$

$$2\ 524/(1,5 \times 1\ 560) + 4\ 411/(1,5 \times 3\ 500) < 2$$

$$1,92 < 2$$

The loads acting on each nozzle satisfy the appropriate interaction equation, so the condition specified in **F**.1.2 b) is satisfied.

Results from CAEPIPE Rotating Equipment Report



API 610 (11th ed.), Sep 2010 / ISO 13709 report for pump : Example 1B				
Load case: Operating (W+P1+T1)				
Shaft axis: Xcomp = 1.000, Ycomp = 0.000, Zcomp = 0.000				
Center location: X = 0, Y = 0.001, Z = 0 (ft'in")				
Suction node: 10, Location: (End), Size: 10.000 (inch)				
Offsets from center: dx = 0'10-1/2", dy = -0.001, dz = 0 (ft'in")				
Check of condition F.1.1 for suction node 10:				
	Calculated	Allowed	Ratio	Status
FX (lb)	2900	1500	1.933	—
FY (lb)	0	1200	0.000	OK
FZ (lb)	-1990	1000	1.990	—
FR (lb)	3517	2200	1.599	—
MX (ft-lb)	-1000	3700	0.270	OK
MY (ft-lb)	-3700	1800	2.056	Failed
MZ (ft-lb)	-5500	2800	1.964	—
MR (ft-lb)	6704	5000	1.341	—
Condition F.1.2.a for suction node 10 failed ***				
Discharge node: 50, Location: (Top), Size: 8.000 (inch)				
Offsets from center: dx = 0, dy = -1.0218, dz = 1'3" (ft'in")				
Check of condition F.1.1 for discharge node 50:				
	Calculated	Allowed	Ratio	Status
FX (lb)	1600	850	1.882	—
FY (lb)	-100	700	0.143	OK
FZ (lb)	1950	1100	1.773	—
FR (lb)	2524	1560	1.618	—
MX (ft-lb)	500	2600	0.192	OK
MY (ft-lb)	-2500	1300	1.923	—
MZ (ft-lb)	-3600	1900	1.895	—
MR (ft-lb)	4411	3500	1.260	—
(FR/1.5FRT4) + (MR/1.5MRT4) =			1.919	OK

Coordinate System for ASME B73.1, B73.3 and B73.5M horizontal end suction pumps

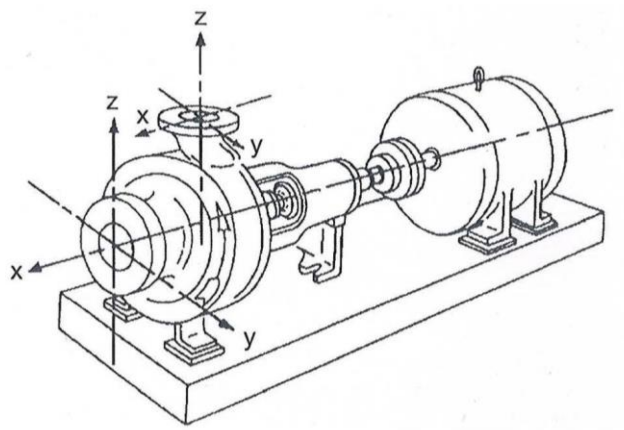


Figure 1 – Coordinate system for ASME B73.1, B73.3 and B73.5M horizontal end suction pumps

A1.0 Definitions (refer to Figure above)

F_{xs} = applied force on X-axis on suction nozzle, to be assessed using equation sets 1-5

F_{ys} = applied force on Y-axis on suction nozzle, to be assessed using equation sets 1-5

F_{zs} = applied force on Z-axis on suction nozzle, to be assessed using equation sets 1-5

M_{xs} = applied moment about X-axis on suction nozzle, to be assessed using equation sets 1-5

M_{ys} = applied moment about Y-axis on suction nozzle, to be assessed using equation sets 1-5

M_{zs} = applied moment about Z-axis on suction nozzle, to be assessed using equation sets 1-5

F_{xd} = applied force on X-axis on discharge nozzle, to be assessed using equation sets 1-5

F_{yd} = applied force on Y-axis on discharge nozzle, to be assessed using equation sets 1-5

F_{zd} = applied force on Z-axis on discharge nozzle, to be assessed using equation sets 1-5

M_{xd} = applied moment about X-axis on discharge nozzle, to be assessed using equation sets 1-5

M_{yd} = applied moment about Y-axis on discharge nozzle, to be assessed using equation sets 1-5

M_{zd} = applied moment about Z-axis on discharge nozzle, to be assessed using equation sets 1-5

$F_{xs\ max}$ = maximum value of force on X-axis on suction nozzle, to be used with equation sets 1-5

$F_{ys\ max}$ = maximum value of force on Y-axis on suction nozzle, to be used with equation sets 1-5

$F_{zs\ max}$ = maximum value of force on Z-axis on suction nozzle, to be used with equation sets 1-5

$M_{xs\ max}$ = maximum value of moment about X-axis on suction nozzle, to be used with equation sets 1-5

$M_{ys\ max}$ = maximum value of moment about Y-axis on suction nozzle, to be used with equation sets 1-5

$M_{zs\ max}$ = maximum value of moment about Z-axis on suction nozzle, to be used with equation sets 1-5

$F_{xd\ max}$ = maximum value of force on X-axis on discharge nozzle, to be used with equation sets 1-5

$F_{yd\ max}$ = maximum value of force on Y-axis on discharge nozzle, to be used with equation sets 1-5

$F_{zd\ max}$ = maximum value of force on Z-axis on discharge nozzle, to be used with equation sets 1-5

$M_{xd\ max}$ = maximum value of moment about X-axis on discharge nozzle, to be used with equation sets 1-5

$M_{yd\ max}$ = maximum value of moment about Y-axis on discharge nozzle, to be used with equation sets 1-5

$M_{zd\ max}$ = maximum value of moment about Z-axis on discharge nozzle, to be used with equation sets 1-5

Group 1 is defined as ASME B73.1, B73.3 and B73.5M sizes AA and AB. Two/four-pole, 60 cycle speed and up to 20/10 hp, respectively.

Group 2 is defined as ASME B73.1, B73.3 and B73.5M sizes A05, A10, A20, A30, A40, A50, A60, A70 and A80. Two/four-pole, 60-cycle speed and up to 130/65 hp, respectively.

Group 3 is defined as ASME B73.1, B73.3 and B73.5M sizes A90, A100, A110 and A120. Four/six-pole, 60-cycle speed and up to 220/146 hp, respectively.

A1.1 ASME B73.1 pump assessment of applied nozzle loads

Loads given in Tables B through E are applicable for ASME B73.1 pumps constructed of ASTM A351/A351M – Grade CF8M (Type 316SS) operated between 20 and 1000 F and mounted on a grouted metal baseplate with anchor bolts.

For an individual force or moment, pumps must be capable of satisfactory operation when subjected to loads shown in Table B while meeting the criteria of equation set 1 provided in Table A below.

For a combination of more than one force and/or moment, pumps must be capable of satisfactory operation when subjected to the loads in Tables C through E while meeting the criteria of equation sets 2 – 5 of Table A given below. When combining loads, the absolute value of any individual load must not exceed the value given in Table B.

Adjustment of the tabulated maximum forces and moments are performed if any of the following occur.

a. Temperature is above 100^0 F.

b. The pump material construction is not ASTM A351/A351M – Grade CF8M.

c. The base is not a fully grouted metal baseplate with anchor bolts.

Table A – Equation sets 1 through 5 (using the maximum forces and moments of the referenced tables, applied loads shall satisfy the criteria defined by these equations)

Set	Equation	Reference	Remarks
1	$\left\|\frac{F_{XS}}{F_{XSmax}}\right\| \leq 1.0, \left\|\frac{F_{YS}}{F_{YSmax}}\right\| \leq 1.0, \left\|\frac{F_{ZS}}{F_{ZSmax}}\right\| \leq 1.0, \left\|\frac{M_{XS}}{M_{XSmax}}\right\| \leq 1.0, \left\|\frac{M_{YS}}{M_{YSmax}}\right\| \leq 1.0, \left\|\frac{M_{ZS}}{M_{ZSmax}}\right\| \leq 1.0$ $\left\|\frac{F_{Xd}}{F_{Xdmax}}\right\| \leq 1.0, \left\|\frac{F_{Yd}}{F_{Ydmax}}\right\| \leq 1.0, \left\|\frac{F_{Zd}}{F_{Zdmax}}\right\| \leq 1.0, \left\|\frac{M_{Xd}}{M_{Xdmax}}\right\| \leq 1.0, \left\|\frac{M_{Yd}}{M_{Ydmax}}\right\| \leq 1.0, \left\|\frac{M_{Zd}}{M_{Zdmax}}\right\| \leq 1.0$	Table B	Individual loading
2	$\frac{1}{2} x \left[\left\|\frac{F_{XS}}{F_{XSmax}}\right\| + \left\|\frac{F_{YS}}{F_{YSmax}}\right\| + \left\|\frac{F_{ZS}}{F_{ZSmax}}\right\| + \left\|\frac{M_{XS}}{M_{XSmax}}\right\| + \left\|\frac{M_{YS}}{M_{YSmax}}\right\| + \left\|\frac{M_{ZS}}{M_{ZSmax}}\right\| + \left\|\frac{F_{Xd}}{F_{XSmax}}\right\| + \left\|\frac{F_{Yd}}{F_{YSmax}}\right\| + \left\|\frac{F_{Zd}}{F_{ZSmax}}\right\| + \left\|\frac{M_{Xd}}{M_{Xdmax}}\right\| + \left\|\frac{M_{Yd}}{M_{Ydmax}}\right\| + \left\|\frac{M_{Zd}}{M_{Zdmax}}\right\| \right] \leq 1.0$	Table C	Nozzle stress, hold-down bolt stress, pumps slippage
3	$-1.0 \leq a = \frac{F_{YS}}{F_{YS\,max}} + \frac{M_{XS}}{M_{XS\,max}} + \frac{M_{YS}}{M_{YS\,max}} + \frac{M_{ZS}}{M_{ZS\,max}} + \frac{F_{Yd}}{F_{Yd\,max}} + \frac{M_{Xd}}{M_{Xd\,max}} + \frac{M_{Yd}}{M_{Yd\,max}} + \frac{M_{Zd}}{M_{Zd\,max}} \leq 1.0$	Table D	y-axis movement
4	$-1.0 \leq b = \frac{F_{XS}}{F_{XS\,max}} + \frac{F_{ZS}}{F_{ZS\,max}} + \frac{M_{XS}}{M_{XS\,max}} + \frac{M_{YS}}{M_{YS\,max}} + \frac{M_{ZS}}{M_{ZS\,max}} + \frac{F_{Xd}}{F_{Xd\,max}} + \frac{F_{Yd}}{F_{Yd\,max}} + \frac{F_{Zd}}{F_{Zd\,max}} + \frac{M_{Xd}}{M_{Xd\,max}} + \frac{M_{Yd}}{M_{Yd\,max}} + \frac{M_{Zd}}{M_{Zd\,max}} \leq 1.0$	Table E	z-axis movement
5	$\sqrt{a^2 + b^2 \leq 1.0}$	Equation sets 3 and 4	Combined axis movement

Table B – Maximum forces and moments for use with equation set 1 to assess applied loads

ASME B73 Designation	Pump Size	Suction						Discharge					
		Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
		$F_{xs\ max}$	$F_{ys\ max}$	$F_{zs\ max}$	$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$	$F_{xd\ max}$	$F_{yd\ max}$	$F_{zd\ max}$	$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
AA	1.5 × 1 × 6	1050	750	750	720	170	170	800	1350	3000	410	410	410
AB	3 × 1.5 × 6	1050	1240	1250	900	490	490	800	1350	3000	500	550	510
A10	3 × 2 × 6	1050	1050	1050	900	220	220	800	1350	3000	500	1000	510
AA	1.5 × 1 × 8	1050	1210	1210	720	190	190	800	1350	3000	360	360	360
---	3 × 1.5 × 8[a]	1050	1240	1250	900	490	490	800	1350	3000	440	440	440
A50	3 × 1.5 × 8	2700	1350	1500	1300	370	370	1400	1350	3250	460	460	460
A60	3 × 2 × 8	2700	1350	1500	1300	600	600	1400	1350	3250	660	660	660
A70	4 × 3 × 8	2700	1350	1500	1300	350	350	1400	1350	3250	1200	1460	690
A05	2 × 1 × 10	2340	960	960	1270	220	220	1400	1350	3250	660	660	660
A50	3 × 1.5 × 10	2700	1350	1500	1300	420	420	1400	1350	3250	370	370	370
A60	3 × 2 × 10	2700	1350	1480	1300	310	310	1400	1350	3250	560	560	560
A70	4 × 3 × 10	2300	1350	1500	1300	310	310	1400	1350	3250	1200	1460	690
A80	6 × 4 × 10	2700	1350	1500	1300	1100	1100	1400	1350	3250	1200	1500	690
A20	3 × 1.5 × 13	2700	1350	1500	1300	670	670	1400	1350	3250	530	530	530
A30	3 × 2 × 13	1920	1230	1230	1300	350	350	1400	1350	3250	1200	1270	690
A40	4 × 3 × 13	2700	1350	1500	1300	400	400	1400	1350	3250	1200	1500	690
A80	6 × 4 × 13	2700	1350	1500	1300	1300	1100	1400	1350	3250	1200	1500	690
A90	8 × 6 × 13	3500	3180	2000	1500	1170	1170	1500	3000	3500	1250	2840	2840
A100	10 × 8 × 13	3500	3180	2000	1500	2000	2150	1500	3000	3500	1250	2840	2840
A110	8 × 6 × 15	3500	3180	2000	1500	1480	1480	1500	3000	3500	1250	2840	2840
A120	10 × 8 × 15	3500	3180	2000	1500	1130	1130	1500	3000	3500	1250	2840	2840

Table C- Maximum forces and moments for use with equation set 2 to assess applied loads

		Suction						Discharge					
		Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
ASME B73 Designation	Pump Size	$F_{xs\ max}$	$F_{ys\ max}$	$F_{zs\ max}$	$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$	$F_{xd\ max}$	$F_{yd\ max}$	$F_{zd\ max}$	$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
AA	1.5 × 1 × 6	2020	750	750	1830	170	170	2020	1350	6240	410	410	410
AB	3 × 1.5 × 6	2020	1240	2110	2290	490	490	2020	1350	6240	550	550	510
A10	3 × 2 × 6	2020	1050	1050	2290	220	220	2020	1350	6240	1030	1030	510
AA	1.5 × 1 × 8	2020	1210	1210	1830	190	190	2020	1350	6240	360	360	360
—	3 × 1.5 × 8[a]	2020	1240	1640	2290	490	490	2020	1350	6240	440	440	440
A50	3 × 1.5 × 8	2700	1350	1820	3730	370	370	2020	1350	6240	460	460	460
A60	3 × 2 × 8	2700	1350	2490	3730	600	600	1970	1350	6240	660	660	660
A70	4 × 3 × 8	2700	1350	1840	3730	350	350	2020	1350	6240	1460	1460	690
A05	2 × 1 × 10	2340	960	960	3640	220	220	2020	1350	6240	660	660	660
A50	3 × 1.5 × 10	2700	1350	1910	3730	420	420	1940	1350	6240	370	370	370
A60	3 × 2 × 10	2700	1350	1480	3730	310	310	2020	1350	6240	560	560	560
A70	4 × 3 × 10	2300	1350	1640	3730	310	310	2020	1350	6240	1460	1460	690
A80	6 × 4 × 10	2700	1350	6240	3730	1100	1100	2020	1350	6240	3100	3100	690
A20	3 × 1.5 × 13	2700	1350	3060	3730	670	670	2020	1350	6240	530	530	530
A30	3 × 2 × 13	1920	1230	1230	3730	350	350	2020	1350	6240	1460	1460	690
A40	4 × 3 × 13	2700	1350	2390	3730	400	400	2020	1350	6240	1730	1730	690
A80	6 × 4 × 13	2700	1350	6240	3730	4980	1100	2020	1350	6240	2150	2150	690
A90	8 × 6 × 13	6360	3180	5080	8970	1170	1170	6360	3180	13,460	6780	3850	2840
A100	10 × 8 × 13	6360	3180	13,460	8970	2450	2150	6360	3180	13,460	8970	7220	2840
A110	8 × 6 × 15	6360	3180	6680	8970	1480	1480	6360	3180	13,460	6560	3720	2840
A120	10 × 8 × 15	6360	3180	5130	8970	1130	1130	6360	3180	13,460	8970	9060	2840

Table D – Maximum forces and moments for use with equation set 3 to assess applied loads

	Suction						Discharge					
	Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
Pump Group		$F_{ys\ max}$		$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$		$F_{yd\ max}$		$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
Group 1		–2000		900	1200	1250		1500		–500	1500	1250
Group 2		–3500		1300	1300	3000		2500		–1200	1500	3000
Group 3		–5000		1500	2000	4000		3000		–1250	5000	4000

Table E – Maximum forces and moments for use with equation set 4 to assess applied loads

Pump Group	Suction						Discharge					
	Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
	$F_{xs\ max}$		$F_{zs\ max}$	$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$	$F_{xd\ max}$	$F_{yd\ max}$	$F_{zd\ max}$	$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
Group 1	1050		–1250	1500	1200	–2500	800	2000	–3000	–1500	1000	–2500
Group 2	3500		–1500	1500	1300	–3500	1400	2500	–3250	–1500	2150	–3500
Group 3	3500		–2000	1500	4100	–4000	1500	4000	–3500	–1500	5000	–4000

A1.2 Nozzle loads and adjustment factors

The loads in the tables are multiplied by adjustment factors when applicable. The lowest correction factor is applied when more than one adjustment factor is involved. For instance, if the pump is an ASME B73.5 pump (90% reduction factor) mounted on a fully grouted nonmetallic baseplate (80% reduction factor), then the reduction factor for Tables B through E is 80%

A1.2.1 Alternate pump mounting

For alternate mounting conditions, the pump must be mounted on a base that can, as a minimum, withstand the applied nozzle loads combined with normal operating loads.

A1.2.1.1 Still-mounted metal baseplate

100% of the values in Table C and 90% of values in Table D and Table E are used. If after adjusting the value for a particular load in Tables D and E, the absolute value of any adjusted value is lower than the corresponding load in Table B, then the lower value is substituted into Table B.

A1.2.1.2 Ungrouted metal baseplate that is anchored down

100% of the values in Table C and 80% of the values in Tables D and E are used. If after adjusting the value for a particular load in Tables D and E, the absolute value of any adjusted value is lower than the corresponding load in Table B, then the lower value is substituted into Table B.

A1.2.1.3 Grouted nonmetal baseplate with anchor bolts

80% of the values in Tables B through E are used.

A1.2.1.4 Ungrouted nonmetal baseplate that is anchored down

70% of the values in Tables B through E are used.

A1.2.2 Temperature and material adjustment factors for ASME B73.1 and ASME B73.3 pumps

A1.2.2.1 Adjustment factors

For temperatures above 100^0 F and/or the use of a material other than ASTM A351/351M – Grade CF8M, the loads in Table C are reduced by multiplying the proper adjustment factor from Table A1.2.2b.

If after adjusting the value for a particular load in Table C, any adjusted value is lower than the corresponding load in Table B, then the lower value is substituted in Table B.

Material group numbers used in Table A1.2.2b are defined in Table A1.2.2.a

Table A1.2.2a – List of material specifications as used in Table B

Material Groups		Castings	
Material Group No.	Nominal Designation	Spec. No.	Grade(s)
1.0	Ductile Iron	A395	---
1.1	Carbon Steel	A216	WCB
2.1	Type 304	A744	CF-8
2.2	Type 316	A744	CF-8M
2.3	Type 304L Type 316L	A744	CF-3 CF-3M
2.4	Type 321	---	---
2.8	CD-4MCu CD-4MCu	A744 A890	CD-4MCu CD-4MCu Grade 1A, 1B
3.1	Alloy 20	A744	CN-7M
3.2	Nickel	A494	CZ-100
3.4	Monel	A744	M-35-1 M-30C M-35-2
3.5	Inconel 600 Inconel 625 Inconel 825	A744 A744 A744	CY-40 CW-6MC Cu-5MCuC
3.7	Hastelloy B	A494	N-12MV N-7M
3.8	Hastelloy C	A494	CW-6M CW-2M CW-12MW CX-2MW

Table A1.2.2b – ASME B73.1 metallic pump temperature and material adjustment values used on Table C values

	Material Group No.:												
	1.0	1.1	2.1	2.2	2.3	2.4	2.8	3.1	3.2	3.4	3.5	3.7	3.8
			Austenitic Steels					Nickel and Nickel Alloys					
Temp, °F	Ductile Iron	Carbon Steel	Type 304	Type 316	Type 304L Type 316L	Type 321	CD-4M Cu	Alloy 20	Nickel	Monel	Inconel	Hast. B	Hast. C
–20 to 100	0.89	1.00	1.00	1.00	0.83	1.00	1.00	0.83	0.50	0.83	1.00	1.00	1.00
200	0.83	0.94	0.83	0.86	0.70	0.98	1.00	0.77	0.50	0.74	0.93	1.00	1.00
300	0.78	0.91	0.74	0.78	0.63	0.83	1.00	0.73	0.50	0.69	0.89	1.00	1.00
400	0.73	0.88	0.65	0.72	0.58	0.69	0.98	0.67	0.50	0.67	0.85	0.98	0.98
500	0.69	0.83	0.60	0.67	0.53	0.64	0.92	0.65	0.50	0.66	0.83	0.92	0.92
600	0.65	0.76	0.58	0.63	0.50	0.60	0.84	0.63	0.50	0.66	0.80	0.84	0.84
650	0.63	0.74	0.57	0.62	0.49	0.60	0.82	0.63	---	0.66	0.78	0.82	0.82
700	---	0.74	0.56	0.60	0.48	0.58	0.79	0.62	---	0.66	0.77	0.79	0.79

Coordinate System for ASME B73.2 vertical in-line pumps

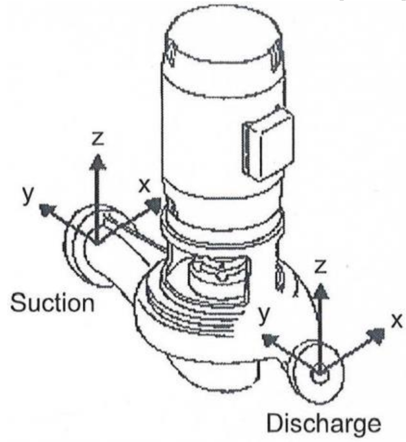


Figure 2 – Coordinate system for ASME B73.2 vertical in-line pumps

A2.0 Definitions (refer to Figure above)

F_{xs} = applied force on X-axis on suction nozzle, to be assessed using equation set 6
F_{ys} = applied force on Y-axis on suction nozzle, to be assessed using equation set 6
F_{zs} = applied force on Z-axis on suction nozzle, to be assessed using equation set 6
M_{xs} = applied moment about X-axis on suction nozzle, to be assessed using equation set 6
M_{ys} = applied moment about Y-axis on suction nozzle, to be assessed using equation set 6
M_{zs} = applied moment about Z-axis on suction nozzle, to be assessed using equation set 6
F_{xd} = applied force on X-axis on discharge nozzle, to be assessed using equation set 6
F_{yd} = applied force on Y-axis on discharge nozzle, to be assessed using equation set 6
F_{zd} = applied force on Z-axis on discharge nozzle, to be assessed using equation set 6
M_{xd} = applied moment about X-axis on discharge nozzle, to be assessed using equation set 6
M_{yd} = applied moment about Y-axis on discharge nozzle, to be assessed using equation set 6
M_{zd} = applied moment about Z-axis on discharge nozzle, to be assessed using equation set 6
$F_{x\,max}$ = maximum value of force on X-axis on suction or discharge nozzles, to be used with equation set 6
$F_{y\,max}$ = maximum value of force on Y-axis on suction or discharge nozzles, to be used with equation set 6
$F_{z\,max}$ = maximum value of force on Z-axis on suction or discharge nozzles, to be used with equation set 6
$M_{x\,max}$ = maximum value of moment about X-axis on either nozzle, to be used with equation set 6
$M_{y\,max}$ = maximum value of moment about Y-axis on either nozzle, to be used with equation set 6
$M_{z\,max}$ = maximum value of moment about Z-axis on either nozzle, to be used with equation set 6

A2.1 ANSI/ASME B73.2 pump assessment of applied nozzle loads

Loads given in Table B above are applicable for ASME B73.2 pumps constructed of ASTM A351/A351M – Grade CF8M (Type 316SS) operated between -20 and 100^0 F.

For an individual force or moment or for a combination of more than one force and/or moment, pumps should be capable of satisfactory operation when subjected to loads shown in Table A2.1b (adjusted if applicable) while meeting the criteria of equation set 6 in Table A2.1a.

Table A2.1a – Equation set 6

Set	Equation	Reference	Remarks
6	$\left\|\frac{F_{XS}}{F_{Xmax}}\right\| \le 1.0, \left\|\frac{F_{YS}}{F_{Ymax}}\right\| \le 1.0, \left\|\frac{F_{ZS}}{F_{Zmax}}\right\| \le 1.0, \left\|\frac{M_{XS}}{M_{Xmax}}\right\| \le 1.0, \left\|\frac{M_{YS}}{M_{Ymax}}\right\| \le 1.0, \left\|\frac{M_{ZS}}{M_{Zmax}}\right\| \le 1.0$ $\left\|\frac{F_{Xd}}{F_{Xmax}}\right\| \le 1.0, \left\|\frac{F_{Yd}}{F_{Ymax}}\right\| \le 1.0, \left\|\frac{F_{Zd}}{F_{Zmax}}\right\| \le 1.0, \left\|\frac{M_{Xd}}{M_{X\,max}}\right\| \le 1.0, \left\|\frac{M_{Yd}}{M_{Ymax}}\right\| \le 1.0, \left\|\frac{M_{Zd}}{M_{Zmax}}\right\| \le 1.0$	-	Individual loading

Table A2.1b – Maximum forces and moments for use with equation set 6 to assess applied loads

Discharge Nozzle Size (in)	Nominal Impeller Diameter (in)	Nominal overall length, flange face to flange face (in)	Forces (lb)			Moments (lb•ft)		
			$F_{x\,max}$	$F_{y\,max}$	$F_{z\,max}$	$M_{x\,max}$	$M_{y\,max}$	$M_{z\,max}$
1.5	6	15	410	3976	410	510	720	510
1.5	8	17	360	3976	360	510	720	510
1.5	10	19	320	3976	320	510	720	510
1.5	13	24	255	3976	255	510	720	510
2	6	17	635	6328	635	900	1270	900
2	8 & 10	20	540	6328	540	900	1270	900
2	13	24	450	6328	450	900	1270	900
3	8	22	725	6328	725	1330	1880	1330
3	10	25	638	6328	638	1330	1880	1330
3	13	28	570	6328	570	1330	1880	1330
4	10	28	700	18,704	700	1630	2300	1630
4	13	30	650	18,704	650	1630	2300	1630

A2.1.1 Temperature and material adjustment factors

Adjustments of allowable load values are performed when any of the following occurs:

a. Temperature is above 100^0 F
b. The pump material construction is not ASTM A351/A351M – Grade CF8M

A2.1.2 Adjustment factors

For temperatures above 100^0 F and/or the use of a material other than ASTM A351/A351M – Grade CF8M, the loads in Table A2.1b are reduced by multiplying them by the proper adjustment factor from Table A2.1d. Material group numbers used in Table A2.1d are defined in Table A2.1c.

Table A2.1c – List of materials specifications as used in Table A2.1d

Material Groups (See NOTE 1)		Castings		
Material Group No.	Nominal Designation	Spec. No.	Grade(s)	NOTES
1.0	Ductile Iron	A395	---	(2)
1.1	Carbon Steel	A216	WCB	
2.1	Type 304	A744	CF-8	
2.2	Type 316	A744	CF-8M	
2.3	Type 304L Type 316L	A744	CF-3 CF-3M	
2.4	Type 321	---	---	
2.8	CD-4MCu CD-4MCu	A744 A890	CD-4MCu CD-4MCu Grade 1A, 1B	
3.1	Alloy 20	A744	CN-7M	
3.2	Nickel	A494	CZ-100	(3)
3.4	Monel	A744	M-35-1 M-30C M-35-2	
3.5	Inconel 600 Inconel 625 Inconel 825	A744 A744 A744	CY-40 CW-6MC Cu-5MCuC	
3.7	Hastelloy B	A494	N-12MV N-7M	
3.8	Hastelloy C	A494	CW-6M CW-2M CW-12MW CX-2MW	

NOTES:
(1) Material groups are similar to material classes taken from ANSI B16.5 except for Class 1.0 - ductile iron, which is not listed in ANSI B16.5. Note that the material grades are not the same as listed in ANSI B16.5. However, they are comparable grades as far as strength is concerned.

(2) Operating temperature range is 20 °F to 650 °F for ductile iron.

(3) Operating temperature range is –20 °F to 600 °F for nickel.

Table A2.1d – ASME B73.2 metallic pump temperature and material adjustment values used

	Material Group No.:												
	1.0	1.1	2.1	2.2	2.3	2.4	2.8	3.1	3.2	3.4	3.5	3.7	3.8
			Austenitic Steels					Nickel and Nickel Alloys					
Temp, °F	Ductile Iron	Carbon Steel	Type 304	Type 316	Type 304L Type 316L	Type 321	CD-4M Cu	Alloy 20	Nickel	Monel	Inconel	Hast. B	Hast. C
–20 to 100	0.89	1.00	1.00	1.00	0.83	1.00	1.00	0.83	0.50	0.83	1.00	1.00	1.00
200	0.83	0.94	0.83	0.86	0.70	0.98	1.00	0.77	0.50	0.74	0.93	1.00	1.00
300	0.78	0.91	0.74	0.78	0.63	0.83	1.00	0.73	0.50	0.69	0.89	1.00	1.00
400	0.73	0.88	0.65	0.72	0.58	0.69	0.98	0.67	0.50	0.67	0.85	0.98	0.98
500	0.69	0.83	0.60	0.67	0.53	0.64	0.92	0.65	0.50	0.66	0.83	0.92	0.92

Coordinate System for Axial split case pumps (single-stage double suction and two-stage single suction)

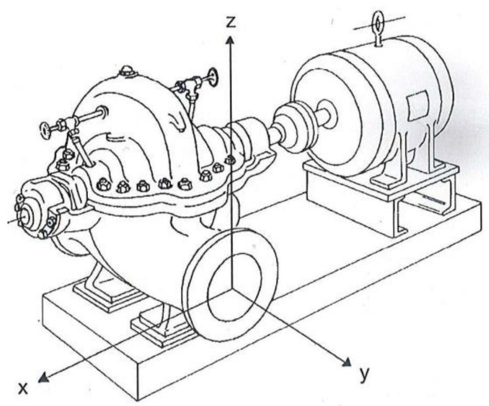


Figure 3 – Coordinate system for axial split case pumps

A3.0 Definitions (refer to Figure above)

F_{xs} = applied force on X-axis on suction nozzle, to be assessed using equation 1
F_{ys} = applied force on Y-axis on suction nozzle, to be assessed using equation 1
F_{zs} = applied force on Z-axis on suction nozzle, to be assessed using equation 1
M_{xs} = applied moment about X-axis on suction nozzle, to be assessed using equation 1
M_{ys} = applied moment about Y-axis on suction nozzle, to be assessed using equation 1
M_{zs} = applied moment about Z-axis on suction nozzle, to be assessed using equation 1
F_{xd} = applied force on X-axis on discharge nozzle, to be assessed using equation 1
F_{yd} = applied force on Y-axis on discharge nozzle, to be assessed using equation 1
F_{zd} = applied force on Z-axis on discharge nozzle, to be assessed using equation 1
M_{xd} = applied moment about X-axis on discharge nozzle, to be assessed using equation 1
M_{yd} = applied moment about Y-axis on discharge nozzle, to be assessed using equation 1
M_{zd} = applied moment about Z-axis on discharge nozzle, to be assessed using equation 1
$F_{x\,max}$ = maximum value of force on X-axis on either nozzle, to be used with equation1
$F_{y\,max}$ = maximum value of force on Y-axis on either nozzle, to be used with equation 1
$F_{z\,max}$ = maximum value of force on Z-axis on either nozzle, to be used with equation 1
$M_{x\,max}$ = maximum value of moment about X-axis on either nozzle, to be used with equation 1
$M_{y\,max}$ = maximum value of moment about Y-axis on either nozzle, to be used with equation 1
$M_{z\,max}$ = maximum value of moment about Z-axis on on either nozzle, to be used with equation 1

A3.1 Axial split case pumps assessment of applied loads

The lowest values of maximum forces and moments from Tables A3.1a and A3.1b are used. The combined applied loads should satisfy the criteria defined by equation 1 below.

$$\left\{ \begin{array}{l} \left(\frac{F_{xs}}{F_{x\,max}}\right)^2 + \left(\frac{F_{ys}}{F_{y\,max}}\right)^2 + \left(\frac{F_{zs}}{F_{z\,max}}\right)^2 + \left(\frac{M_{xs}}{M_{x\,max}}\right)^2 + \left(\frac{M_{ys}}{M_{y\,max}}\right)^2 + \left(\frac{M_{zs}}{M_{z\,max}}\right)^2 + \\ \left(\frac{F_{xd}}{F_{x\,max}}\right)^2 + \left(\frac{F_{yd}}{F_{y\,max}}\right)^2 + \left(\frac{F_{zd}}{F_{z\,max}}\right)^2 + \left(\frac{M_{xd}}{M_{x\,max}}\right)^2 + \left(\frac{M_{yd}}{M_{y\,max}}\right)^2 + \left(\frac{M_{zd}}{M_{z\,max}}\right)^2 \end{array} \right\}^{0.5} \le 1 \qquad \text{(Eq. 1)}$$

Table A3.1a – Maximum forces and moments for use with equation 1 to assess applied loads based on the hold-down bolts

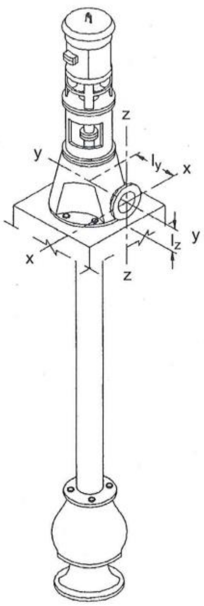
Nominal Bolt Diameter (in)	Forces (lb)		Moments (lb•ft)	
	$F_{x\,max}$ and $F_{y\,max}$	$F_{z\,max}$	$M_{x\,max}$ and $M_{y\,max}$	$M_{z\,max}$
0.625	600	4000	6000	450
0.75	800	6000	12,000	800
0.875	1200	8000	17,000	1500
1.00	5000	11,000	22,000	2400

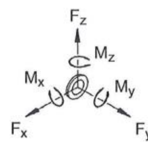
Table A3.1b – Maximum forces and moments for use with equation 1 to assess applied loads based on the nozzle stress

Nozzle size (in)	Force (lb)			Moment (lb•ft)		
	$F_{x\,max}$	$F_{y\,max}$	$F_{z\,max}$	$M_{x\,max}$	$M_{y\,max}$	$M_{z\,max}$
2	1800	1400	1800	600	720	600
3	2400	2700	2400	734	900	734
4	3300	2700	3300	1200	1300	1200
6	4400	2700	4400	2400	1300	2400
8	6500	3500	6500	3800	1500	3800
10	8200	3500	8200	5400	1500	5400

Coordinate System for Vertical turbine short set pumps

Category	Configuration	Flange Position	Application Limits		
Shaft-driven, suspended pump, for water	Submerged suction	Discharge above base	Max. Pressure (psi)	Max. Temp. (°F)	Max. Nozzle Size (in)
			300	100	36

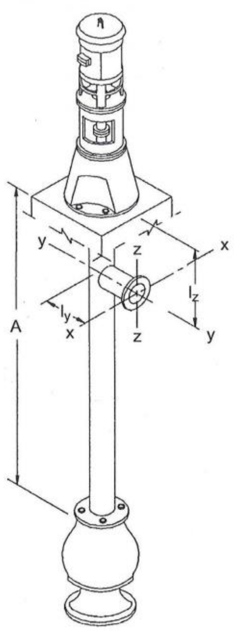


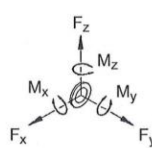


Maximum Allowable Individual Nozzle Loads

Nozzle Size	Nozzle Material: Steel					
Dia	Forces (lb)			Moments (lb•ft)		
(in)	F_x	F_y	F_z	M_x	M_y	M_z
2	202	182	225	302	409	260
3	323	291	360	474	619	407
4	404	364	450	588	753	506
6	606	546	674	892	1099	770
8	808	728	899	1244	1499	1076
10	1010	910	1124	1667	1994	1445
12	1212	1092	1349	2178	2613	1890
14	1414	1274	1574	2790	3372	2422
16	1616	1456	1798	3507	4272	3043
18	1818	1638	2023	4329	5306	3753
20	2020	1820	2248	5251	6450	4545
22	2222	2002	2473	6260	7669	5406
24	2424	2184	2698	7338	8916	6319
30	3079	2774	3426	10,980	12,343	9327
36	3694	3329	4111	13,691	15,528	11,367

Category	Configuration	Flange Position	Application Limits		
Shaft-driven, suspended pump, for water	Submerged suction	Discharge below base	Max. Pressure (psi)	Max. Temp. (°F)	Max. Nozzle Size (in)
			300	100	36





Maximum Allowable Individual Nozzle Loads

Nozzle Size	Nozzle Material: Steel					
Dia	Forces (lb)			Moments (lb•ft)		
(in)	F_x	F_y	F_z	M_x	M_y	M_z
2	67	60	75	122	150	106
3	108	97	119	183	223	159
4	134	121	149	220	269	191
6	202	181	224	314	383	272
8	269	242	299	420	513	363
10	336	302	373	551	672	476
12	403	363	448	715	873	619
14	470	423	523	918	1121	796
16	538	484	567	1161	1419	1008
18	605	544	672	1442	1762	1252
20	672	605	747	1755	2142	1524
22	739	665	822	2091	2548	1815
24	806	726	896	2435	2962	2112
30	1024	922	1138	3378	4061	2908
36	1229	1106	1366	4029	4920	3523

A4.0 Definitions

fx, fy and fz are the actual applied nozzle forces in their respective coordinate direction

mx, my and mz are actual applied nozzle moments in their respective coordinate direction

Fx, Fy and Fz are tabulated maximum permissible nozzle forces in their respective coordinate direction

Mx, My and Mz are tabulated maximum permissible nozzle moments in their respective coordinate direction

A4.1 Vertical turbine short set pumps assessment of applied loads

The tables above show maximum permissible forces and moments for each coordinate direction of each flange. Each value in the tables represents the maximum allowable load in a particular direction acting alone. For cases in which more than one load is applied simultaneously, the following formula should be satisfied.

$$\frac{f_x}{F_x} + \frac{f_y}{F_y} + \frac{f_z}{F_z} + \frac{m_x}{M_x} + \frac{m_y}{M_Y} + \frac{m_z}{M_z} \leq 1$$

NEMA SM-23 (1991) for Turbines

There are two types of allowables.

1. Allowables for each nozzle and
2. Combined allowables for each turbine.

1. Allowables for each Nozzle

The resultant force and the resultant moment at any connection must not exceed

$$3F_R + M_R \leq 500D_e$$

where
F_R = resultant force at the nozzle (lb)
M_R = resultant moment at the nozzle (ft.-lb)
D_e = nominal pipe size (inches) of the connection up to 8" in diameter
= $(16 + D_{nom})/3$ If the size is greater than 8"

2. Combined Allowables for the Turbine

The combined resultants of the forces and moments at the inlet, exhaust and extraction nozzles resolved at the centerline of the exhaust nozzle must not exceed the following two conditions:

(a) These resultant should not exceed:

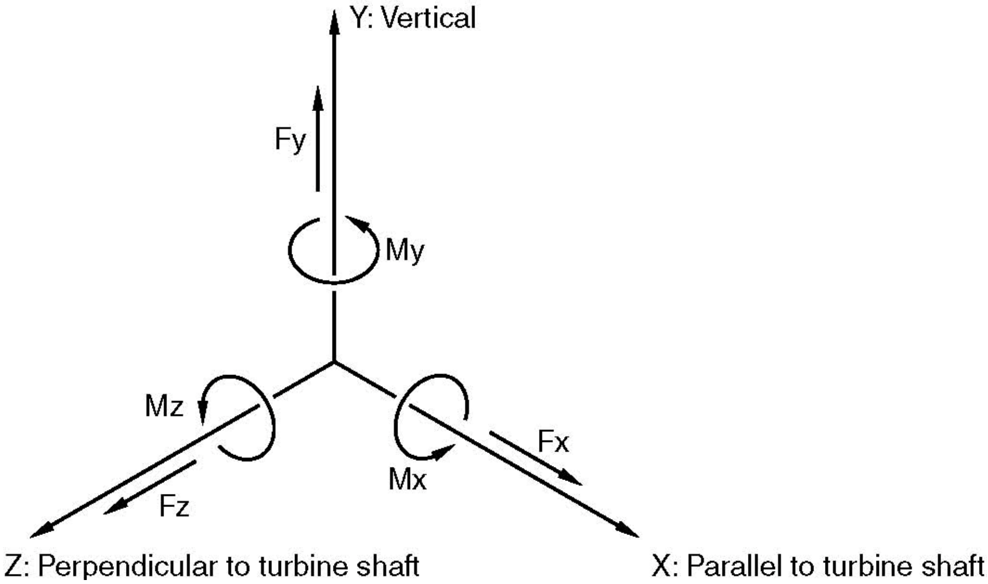
$$2F_C + M_C \leq 250D_C$$

where
F_C = combined resultant of inlet, exhaust and extraction forces (lb)
M_C = combined resultant of inlet, exhaust and extraction moments (ft.-lb.)
D_C = diameter (in inches) of a circular opening equal to the total areas of the inlet, exhaust and extraction nozzles up to a value of 9" in diameter
= (18 + Equivalent diameter) / 3 (in.) For values > 9"

(b) The components of these resultants shall not exceed:

$$F_X = 50D_C M_X = 250D_C$$
$$F_Y = 125D_C M_Y = 125D_C$$
$$F_Z = 100D_C M_Z = 125D_C$$

where
F_X = horizontal component of F_R parallel to the turbine shaft
F_Y = vertical component of F_R
F_Z = horizontal component of F_R at right angles to the turbine shaft
M_X = horizontal component of M_R parallel to the turbine shaft
M_Y = vertical component of M_R
M_Z = horizontal component of M_R at right angles to the turbine shaft


Y: Vertical
Fy
My
Mz
Fx
Mx
Fz
Z: Perpendicular to turbine shaft
X: Parallel to turbine shaft

API 617 (Seventh edition, June 2003) for Compressors

1. Allowables for each Nozzle

The total resultant force and resultant moment imposed on the compressor at any connection should not exceed

$$3F_r + M_r \leq 927D_e$$

Where

F_r = resultant force at the Nozzle (lb)

M_r = resultant moment at the Nozzle (ft.-lb)

D_e = nominal pipe size (inches) of the connection up to 8" in diameter

= $(16 + D_{nom})/3$ If the size is greater than 8"

2. Combined Allowables for Compressors

The combined resultants of the forces and moments of the inlet, sidestream, and discharge connections resolved at the centerlines of the largest connection should not exceed the following two conditions:

(a) The resultant should not exceed:

$$2F_c + M_c \leq 462D_c$$

Where

F_c = combined resultant of inlet, sidestream, and discharge forces (lb)

M_c = combined resultant of inlet, sidestream, and discharge moments, and moments resulting from forces (ft.-lb)

D_c = diameter of one circular opening equal to the total areas of the inlet, sidestream, and discharge openings. If the equivalent nozzle diameter is greater than 9", use a value of D_c equal to (18 + Equivalent Diameter) / 3

(b) The components of these resultants shall not exceed:

$$F_x = 92D_c \qquad M_x = 462D_c$$

$$F_y = 231D_c \qquad M_y = 231D_c$$

$$F_z = 185D_c \qquad M_z = 231D_c$$

Where

F_x = horizontal component of F_c parallel to the compressor shaft (lb)

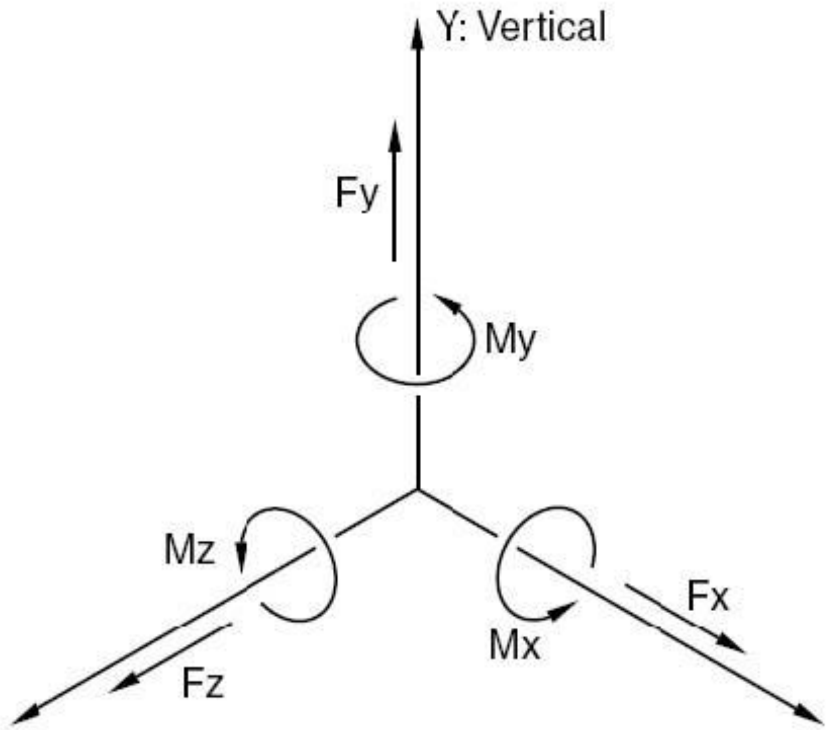
F_y = vertical component of F_c (lb)

F_z = horizontal component of F_c at right angles to be compressor shaft (lb)

M_x = component of M_c around the horizontal axis (ft-lb)

M_y = component of M_c around the vertical axis (ft-lb)

M_z = component of M_c around the horizontal axis at right angles to the compressor (ft-lb)



Z: Perpendicular to compressor shaft X: Parallel to compressor shaft

Flange Qualification

Notation based on ASME Section VIII, Division 1, Appendix 2 (2013)

The symbols described below are used in the formulas for the design of flanges

A = outside diameter of flange

A_b = cross-sectional area of the bolts using the root diameter of the thread

A_m = total required cross-sectional area of bolts taken as greater of A_{m1} and A_{m2}

A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions

$$= \frac{W_{m1}}{S_b}$$

A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress

$$= \frac{W_{m2}}{S_a}$$

B = inside diameter of flange

B' = inside diameter of reverse flange

b = effective gasket or joint-contact-surface seating width

b_0 = basic gasket seating width (from Table 2-5.2)

C = bolt-circle diameter

c = basic dimension used for the minimum sizing of welds

e = factor = $\frac{F}{h_o}$

d = factor = $\frac{U}{V} h_o g_0^2$ for integral type flanges

d = factor =$\frac{U}{V_L} h_o g_0^2$ for loose type flanges

e = factor =$\frac{F}{h_o}$ for integral type flanges

c = factor =$\frac{F_L}{h_o}$ for loose type flanges

F = factor for integral type flanges (from Fig. 2-7.2)

F_L = factor for loose type flanges (from Fig. 2-7.4)

f = hub stress correction for integral flanges from Fig. 2-7.6 (when greater than one, this is the ratio of the stress in the small end of hub to the stress in the large end), (for values below limit of figure, use f = 1.)

G = diameter at location of gasket load reaction

$g0$ = thickness of hub at small end

$g1$ = thickness of hub at back of flange

H = total hydrostatic end force = $0.785G^2P$

H_D = hydrostatic end force on area inside of flange =$0.785B^2P$

H_G = gasket load (difference between flange design bolt load and total hydrostatic end force) = W – H

H_P = total joint-contact surface compression load = 2b x 3.14 $G_m P$

H_T = difference between total hydrostatic end force and the hydrostatic end force on area inside of flange = $H - H_D$

h = hub length

h_D = radial distance from the bolt circle, to the circle on which HD acts, as prescribed in Table 2-6
h_G = radial distance from gasket load reaction to the bolt circle = $\frac{C-G}{2}$
h_O = factor = $\sqrt{B_{g0}}$
h_T = distance from the bolt circle, to the circle on which H_T acts, as prescribed in Table 2-6
K = ratio of outside diameter of flange to inside diameter of flange = A / B
L = factor = $\frac{(t_e+1)}{T} + \frac{t^3}{d}$
M_D = component of moment due to $H_D = H_D h_D$
M_G = component of moment due to $H_G = H_G h_G$
M_T = component of moment due to $H_T = H_T h_T$
M_O = total moment acting upon the flange for the operating conditions or gasket seating as may apply
M_O = $W\frac{(C-G)}{2}$for gasket seating condition
M_O = $H_D h_D + H_G h_G + H_T h_T$for operating condition
N = width used to determine the basic gasket seating with b_0, based upon the possible contact width of the gasket (see Table 2-5.2)
P = internal design pressure
R = radial distance from bolt circle to point of intersection of hub and back of flange. For integral and hub flanges, R = (C-B / 2) – g1
S_a = allowable bolt stress at reference temperature
S_b = allowable bolt stress at design temperature
S_f = allowable stress for material of flange at design temperature (operating condition)
S_H = calculated longitudinal stress in hub
S_R = calculated radial stress in flange
S_T = calculated tangential stress in flange
T = factor involving K (from Fig. 2-7.1)
t = flange thickness
U = factor involving K (from Fig. 2-7.1)
V = factor for integral type flanges (from Fig. 2-7.3)
V_L = factor for loose type flanges (from Fig. 2-7.5)
W = flange design bolt load, for the operating condition or gasket seating
= W_{m1} for operating condition
= $\frac{(A_m+A_b)S_a}{2}$for gasket seating condition
W_{m1}= minimum required bolt load for the operating conditions
W_{m1}= minimum required bolt load for gasket seating
w = nubbin width used to determine the basic gasket seating width b_0, based on contact width between the flange and the gasket (see Table 2-5.2)11
Y = factor involving K (from Fig. 2-7.1)
y = gasket or joint-contact-surface unit seating load
Z = factor involving K (from Fig. 2-7.1)

Calculation of Flange Stresses

The stresses in the flange shall be determined for both the operating conditions and gasket seating condition, in accordance with the following formulas:

(1) Integral type flanges

Longitudinal hub stress $S_H = \frac{fM_O}{Lg_1^2B} < 1.5S_f$

Radial flange stress $S_R = \frac{(1.33te+1)M_O}{Lt^2B} < S_f$

Tangential flange stress $S_T = \frac{YM_O}{t^2B} - ZS_R < S_f$

Combined stress
$\frac{S_H+S_R}{2} < S_f$ and
$\frac{S_H+S_T}{2} < S_f$

(2) Loose type flanges with hubs

Longitudinal hub stress $S_H = \frac{fM_O}{Lg_1^2B} < 1.5S_f$

Radial flange stress $S_R = \frac{(1.33te+1)M_O}{Lt^2B} < S_f$

Tangential flange stress $S_T = \frac{YM_O}{t^2B} - ZS_R < S_f$

Combined stress

$\frac{S_H+S_R}{2} < S_f$ and
$\frac{S_H+S_T}{2} < S_f$

where,

L = factor = $\frac{(te+1)}{T} + \frac{t^3}{d}$

d = factor = $\frac{U}{V_L} h_o g_0^2$ for integral type flanges

e = factor = $\frac{F_L}{h_o}$

V_L = factor for loose type flanges (from Fig. 2-7.5)
F_L = factor for loose type flanges (from Fig. 2-7.4)

(3) Loose type flanges without hubs

Longitudinal hub stress $S_H = 0$
Radial flange stress $S_R = 0$
Tangential flange stress $S_T = \frac{YM_O}{t^2B} < S_f$

Combined stress

$\frac{S_H+S_R}{2} < S_f$ and

$$\frac{S_H + S_T}{2} < S_f$$

where,

L = factor = $\dfrac{\dfrac{(te+1)}{T}+\dfrac{t^3}{d}}{}$

d = factor = $\dfrac{U}{V_L} h_0 g_0^2$

e = factor = $\dfrac{F_L}{h_0}$

V_L = factor for loose type flanges (from Fig. 2-7.5)
F_L = factor for loose type flanges (from Fig. 2-7.4)

(4) <u>Optional type flanges (calculated as loose flanges without hubs)</u>

Longitudinal hub stress $S_H = 0$
Radial flange stress $S_R = 0$
Tangential flange stress $S_T = \frac{YM_O}{t^2B} < S_f$

Combined stress

$\frac{S_H+S_R}{2} < S_f$ and

$$\frac{S_H + S_T}{2} < S_f$$

where,

L = factor = $\dfrac{\dfrac{(te+1)}{T}+\dfrac{t^3}{d}}{}$

d = factor = $\dfrac{U}{V_L} h_0 g_0^2$

e = factor = $\dfrac{F_L}{h_0}$

V_L = factor for loose type flanges (from Fig. 2-7.5)
F_L = factor for loose type flanges (from Fig. 2-7.4)

(5) <u>Reverse type flanges</u>

Longitudinal hub stress $S_H = \frac{fM_O}{L_r g_1^2 B\prime} < 1.5S_f$

Radial flange stress $S_R = \frac{(1.33te_r+1)M_O}{L_r t^2 B\prime} < S_f$

Tangential flange stress $S_r = \frac{YM_O}{t^2 B} - ZS_R \frac{0.67te_r+1}{1.33te_r+1} < S_f$

Combined stress

$\frac{S_H+S_R}{2} < S_f$ and

$$\frac{S_H + S_T}{2} < S_f$$

where,

L_r = factor = $\frac{(te_r+1)}{T} + \frac{t^3}{d_r}$

d_r = factor = $\frac{U_r}{V} h_o g_0^2$

e_r = factor = $\frac{F}{h_o}$

h_o = factor = $\sqrt{Ag_0}$

α_r = $\frac{1+0.668\frac{(K+1)}{Y}}{K^2}$

T_r = $\frac{Z+0.3}{Z-0.3}\alpha_r T$

U_r = $\alpha_Y U$

Y_r = $\alpha_Y Y$

TABLE 2-5.1
GASKET MATERIALS AND CONTACT FACINGS[1]
Gasket Factors *m* for Operating Conditions and Minimum Design Seating Stress *y*

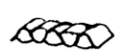
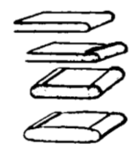
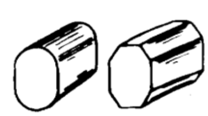
Gasket Material	Gasket Factor *m*	Min. Design Seating Stress *y*, psi (MPa)	Sketches	Facing Sketch and Column in Table 2-5.2
Self-energizing types (0 rings, metallic, elastomer, other gasket types considered as self-sealing)	0	0 (0)	. . .	. . .
Elastomers without fabric or high percent of asbestos fiber:				(1a),(1b),(1c),(1d), (4),(5); Column II
Below 75A Shore Durometer	0.50	0 (0)		
75A or higher Shore Durometer	1.00	200 (1.4)		
Asbestos with suitable binder for operating conditions:				(1a),(1b),(1c),(1d), (4),(5); Column II
$\frac{1}{8}$ in. (3.2 mm) thick	2.00	1,600 (11)		
$\frac{1}{16}$ in. (1.6 mm) thick	2.75	3,700 (26)		
$\frac{1}{32}$ in. (0.8 mm) thick	3.50	6,500 (45)		
Elastomers with cotton fabric insertion	1.25	400 (2.8)		(1a),(1b),(1c),(1d), (4),(5); Column II
Elastomers with asbestos fabric insertion (with or without wire reinforcement):				(1a),(1b),(1c),(1d), (4),(5); Column II
3-ply	2.25	2,200 (15)		
2-ply	2.50	2,900 (20)		
1-ply	2.75	3,700 (26)		
Vegetable fiber	1.75	1,100 (7.6)		(1a),(1b),(1c),(1d), (4)(5); Column II
Spiral-wound metal, asbestos filled:				(1a),(1b); Column II
Carbon	2.50	10,000 (69)		
Stainless, Monel, and nickel-base alloys	3.00	10,000 (69)		
Corrugated metal, asbestos inserted, or corrugated metal, jacketed asbestos filled:			 	(1a),(1b); Column II
Soft aluminum	2.50	2,900 (20)		
Soft copper or brass	2.75	3,700 (26)		
Iron or soft steel	3.00	4,500 (31)		
Monel or 4%–6% chrome	3.25	5,500 (38)		
Stainless steels and nickel-base alloys	3.50	6,500 (45)		

TABLE 2-5.1
GASKET MATERIALS AND CONTACT FACINGS[1] (CONT'D)
Gasket Factors *m* for Operating Conditions and Minimum Design Seating Stress *y*

Gasket Material	Gasket Factor *m*	Min. Design Seating Stress *y*, psi (MPa)	Sketches	Facing Sketch and Column in Table 2-5.2
Corrugated metal:				(1a),(1b),(1c),(1d); Column II
Soft aluminum	2.75	3,700 (26)		
Soft copper or brass	3.00	4,500 (31)		
Iron or soft steel	3.25	5,500 (38)		
Monel or 4%–6% chrome	3.50	6,500 (45)		
Stainless steels and nickel-base alloys	3.75	7,600 (52)		
Flat metal, jacketed asbestos filled:				(1a),(1b),(1c),[2] (1d)[2];(2)[2]; Column II
Soft aluminum	3.25	5,500 (38)		
Soft copper or brass	3.50	6,500 (45)		
Iron or soft steel	3.75	7,600 (52)		
Monel	3.50	8,000 (55)		
4%–6% chrome	3.75	9,000 (62)		
Stainless steels and nickel-base alloys	3.75	9,000 (62)		
Grooved metal:				(1a),(1b),(1c),(1d), (2),(3); Column II
Soft aluminum	3.25	5,500 (38)		
Soft copper or brass	3.50	6,500 (45)		
Iron or soft metal	3.75	7,600 (52)		
Monel or 4%–6% chrome	3.75	9,000 (62)		
Stainless steels and nickel-base alloys	4.25	10,100 (70)		
Solid flat metal:				(1a),(1b),(1c),(1d), (2),(3),(4),(5); Column I
Soft aluminum	4.00	8,800 (61)		
Soft copper or brass	4.75	13,000 (90)		
Iron or soft steel	5.50	18,000 (124)		
Monel or 4%–6% chrome	6.00	21,800 (150)		
Stainless steels and nickel-base alloys	6.50	26,000 (180)		
Ring joint:				(6); Column I
Iron or soft steel	5.50	18,000 (124)		
Monel or 4%–6% chrome	6.00	21,800 (150)		
Stainless steels and nickel-base alloys	6.50	26,000 (180)		

NOTES:

(1) This Table gives a list of many commonly used gasket materials and contact facings with suggested design values of *m* and *y* that have generally proved satisfactory in actual service when using effective gasket seating width *b* given in Table 2-5.2. The design values and other details given in this Table are suggested only and are not mandatory.

(2) The surface of a gasket having a lap should not be against the nubbin.

TABLE 2-5.2
EFFECTIVE GASKET WIDTH[2]

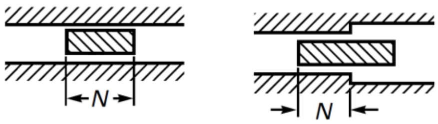
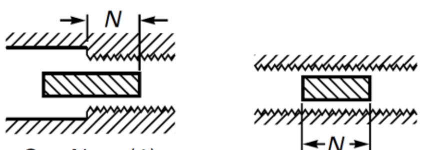
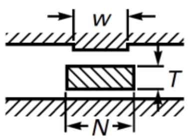
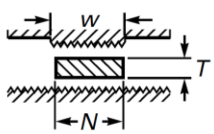
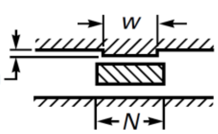
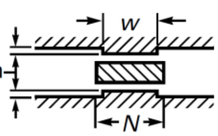
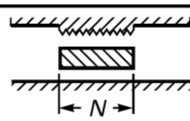
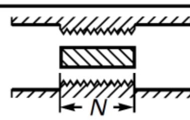
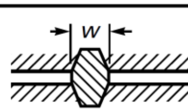
Facing Sketch (Exaggerated)	Basic Gasket Seating Width b_o	
	Column I	Column II
(1a)  (1b)  See Note (1)	$\frac{N}{2}$	$\frac{N}{2}$
(1c)  $w \leq N$ (1d)  See Note (1) $w \leq N$	$\frac{w+T}{2}; \left(\frac{w+N}{4} \max\right)$	$\frac{w+T}{2}; \left(\frac{w+N}{4} \max\right)$
(2) 1/64 in. (0.4 mm) nubbin  $w \leq N/2$	$\frac{w+N}{4}$	$\frac{w+3N}{8}$
(3) 1/64 in. (0.4 mm) nubbin  $w \leq N/2$	$\frac{N}{4}$	$\frac{3N}{8}$
(4)  See Note (1)	$\frac{3N}{8}$	$\frac{7N}{16}$
(5)  See Note (1)	$\frac{N}{4}$	$\frac{3N}{8}$
(6) 	$\frac{w}{8}$	. . .

TABLE 2-6
MOMENT ARMS FOR FLANGE LOADS UNDER OPERATING CONDITIONS

	h_D	h_T	h_G
Integral type flanges [see Fig. 2–4 sketches (5), (6), (6a), (6b), and (7)]; and optional type flanges calculated as integral type [see Fig. 2-4 sketches (8), (8a), (9), (9a), (10), (10a), and (11)]	$R + 0.5g_1$	$\frac{R + g_1 + h_G}{2}$	$\frac{C - G}{2}$
Loose type, except lap-joint flanges [see Fig. 2-4 sketches (2), (2a), (3), (3a), (4), and (4a)]; and optional type flanges calculated as loose type [see Fig. 2-4 sketches (8), (8a), (9), (9a), (10), (10a), and (11)]	$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{C - G}{2}$
Lap-type flanges [see Fig. 2-4 sketches (1) and (1a)]	$\frac{C - B}{2}$	$\frac{C - G}{2}$	$\frac{C - G}{2}$

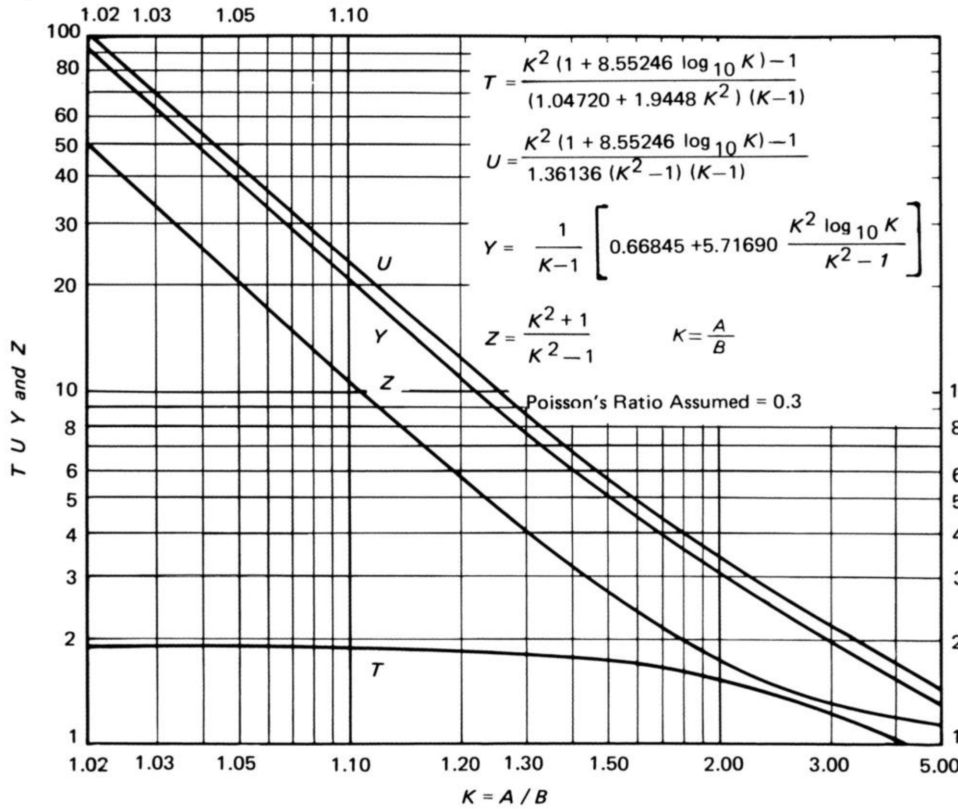


FIG. 2-7.1 VALUES OF *T, U, Y,* AND *Z*
(Terms Involving K)

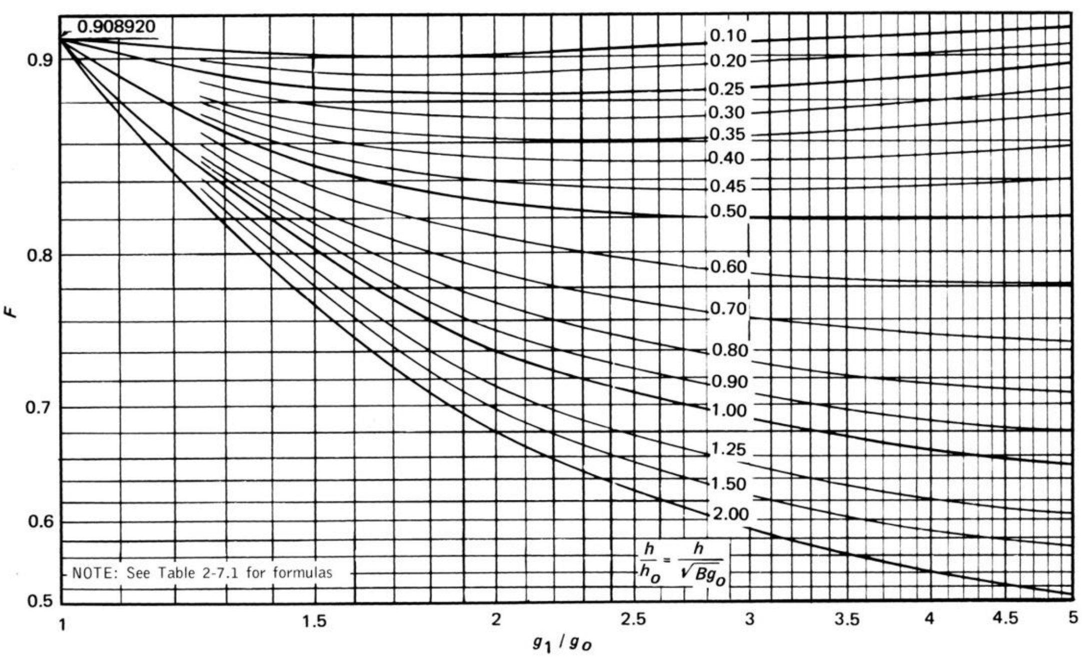


FIG. 2-7.2 VALUES OF *F*
(Integral Flange Factors)

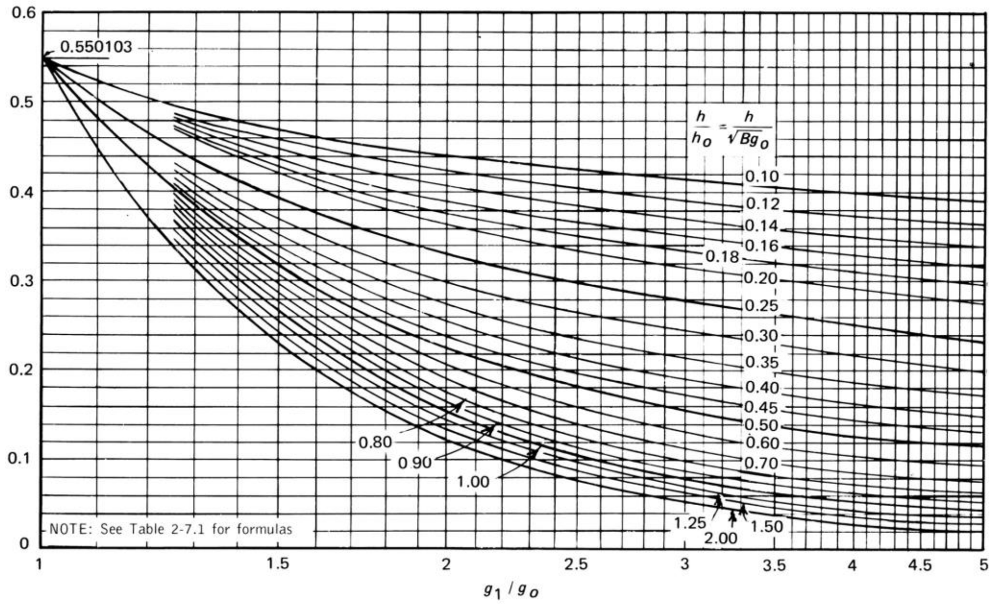


FIG. 2-7.3 VALUES OF V
(Integral Flange Factors)

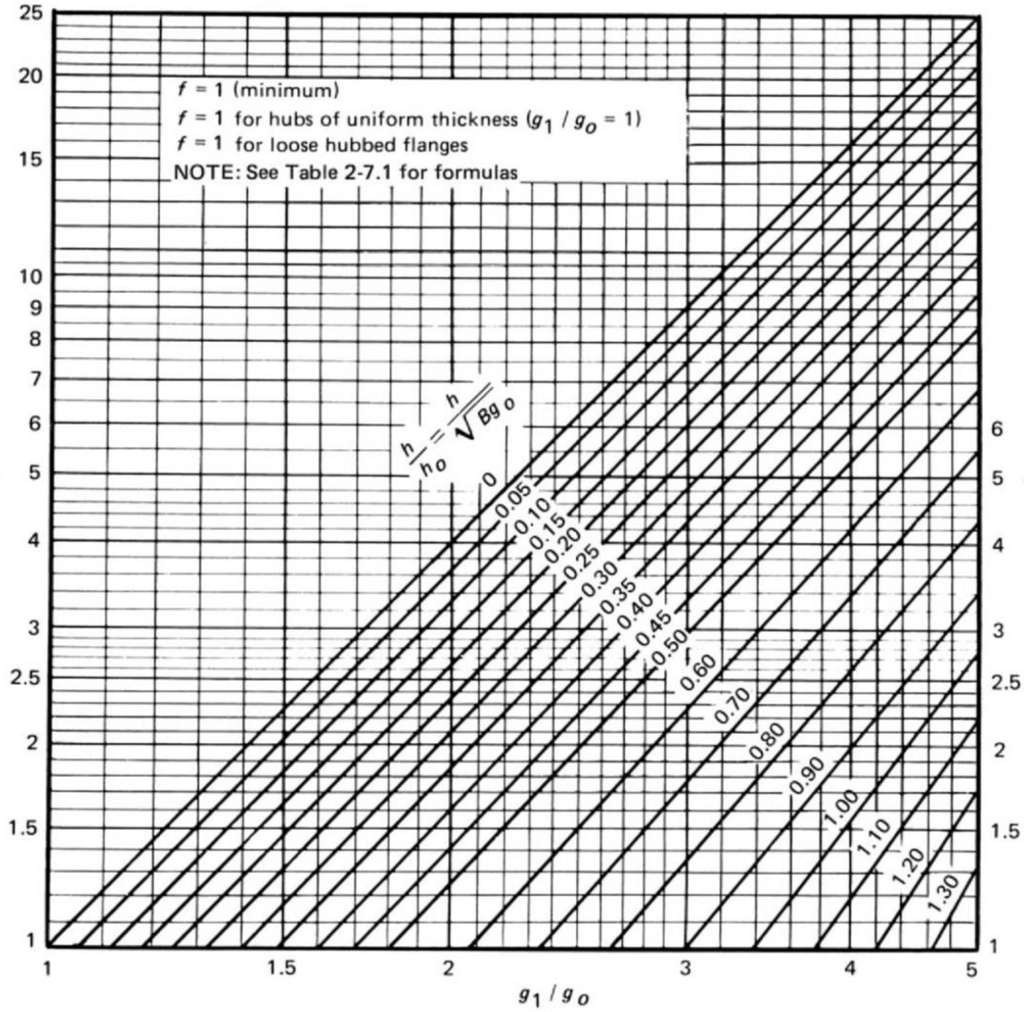


FIG. 2-7.6 VALUES OF f
(Hub Stress Correction Factor)

Problem 1:

(Example from "Taylor Forge & Pipe Works, 1961")

Flange Details:

Flange Type : Loose Flanges with Hubs
Flange Outside Diameter [A] = 40.375 (inch)
Flange Inside Diameter [B] = 33.25 (inch)
Inside Diameter of Reverse Flange [B'] = 20 (inch)
Flange Thickness [t] = 2.125 (inch)
Small End Hub Thickness [g0] = 0.875 (inch)
Large End Hub Thickness [g1] = 1.125 (inch)
Hub Length [h] = 2.5 (inch)
All. Stress @ Design Temp [sf] = 17500 (psi)
All. Stress @ Ref. Temp [sfa] = 17500 (psi)
Modulus @ Design Temp [E] = 2.7E+7 (psi)
Modulus @ Ref. Temp [Ea] = 2.92E+7 (psi)

Bolting Information:

Bolt Circle Diameter = 38.25 (inch)
Number of Bolts = 44
Bolt Diameter = 1 (inch)
All. Stress @ Ref. Temp [sa] = 20000 (psi)
All. Stress @ Design Temp [sb] = 20000 (psi)

Gasket Information:

Gasket Outside Diameter = 35.75 (inch)
Gasket Inner Diameter = 34.25 (inch)
Leak Pressure Ratio [m] = 2.75
Gasket Seating Stress [y] = 3700 (psi)
Facing Sketch = 1
Facing Column = 1

Load Data:

Design Pressure = 400 (psi)
Design Temperature = 500 (F)
Axial Force = 1000 (lb)
Bending Moment = 200 (ft-lb)
Allowable Pressure = 665 (psi)

Comparison of Results:

Flange Stresses	**Text Book Results (psi)**	**CAEPIPE (psi)**	**CAESAR II (psi)**
Operating condition			
Longitudinal Hub (SH)	20800	21153	21214
Radial Flange (SR)	11100	11110	11155
Tangential Flange (ST)	13800	13826	13797
0.5(SH + SR)	15950	16132	16185
0.5(SH + ST)	17300	17489	17506
Gasket Seating Condition			
Longitudinal Hub (SH)	14400	14623	15095
Radial Flange (SR)	7660	7681	7938
Tangential Flange (ST)	9500	9558	9818
0.5(SH + SR)	11030	11152	11517
0.5(SH + ST)	11950	12091	12457

Problem 2:

(Example 10.5 on page 209 Chapter 10 on “CASTI Guidebook to ASME Section VIII Div.1 – Pressure Vessels – Third Edition”)

Flange Details:

Flange Type : Reverse Flanges
Flange Outside Diameter [A] = 49 (inch)
Flange Inside Diameter [B] = 48.25 (inch)
Inside Diameter of Reverse Flange [B'] = 20.25 (inch)
Flange Thickness [t] = 5.25 (inch)
Small End Hub Thickness [g0] = 0.375 (inch)
Large End Hub Thickness [g1] = 1.375 (inch)
Hub Length [h] = 6 (inch)
All. Stress @ Design Temp [sf] = 12000 (psi)
All. Stress @ Ref. Temp [sfa] = 20000 (psi)
Modulus @ Design Temp [E] = 2.7E+7 (psi)
Modulus @ Ref. Temp [Ea] = 2.92E+7 (psi)

Bolting Information:

Bolt Circle Diameter = 44 (inch)
Number of Bolts = 32
Bolt Diameter = 1.25 (inch)
All. Stress @ Ref. Temp [sa] = 25000 (psi)
All. Stress @ Design Temp [sb] = 21000 (psi)

Gasket Information:

Gasket Outside Diameter = 24 (inch)
Gasket Inner Diameter = 22 (inch)
Leak Pressure Ratio [m] = 2.50
Gasket Seating Stress [y] = 10000 (psi)
Facing Sketch = 1

Facing Column = 1

Load Data:

Design Pressure = 150 (psi)
Design Temperature = 800 (F)
Axial Force = 1000 (lb)
Bending Moment = 200 (ft-lb)
Allowable Pressure = 665 (psi)

Comparison of Results:

Flange Stresses	Text Book Results (psi)	CAEPIPE (psi)	CAESAR II (psi)
Operating condition			
Longitudinal Hub (SH)	2060	2257	2055
Radial Flange (SR)	280	307	280
Tangential Flange (ST)	1340	1314	1336
0.5(SH + SR)	1170	1282	1168
0.5(SH + ST)	1700	1785	1695
Gasket Seating Condition			
Longitudinal Hub (SH)	9220	10082	9220
Radial Flange (SR)	1260	1372	1257
Tangential Flange (ST)	6000	7004	5997
0.5(SH + SR)	5240	5727	5239
0.5(SH + ST)	7610	8543	8703

Problem 3:

(Example from KEDKEP CONSULTING, INC. dated May 27, 2008)

Flange Details:

Flange Type : Loose Flanges without Hubs / Optional Flanges
Flange Outside Diameter [A] = 38.4 (inch)
Flange Inside Diameter [B] = 32 (inch)
Inside Diameter of Reverse Flange [B'] = 32 (inch)
Flange Thickness [t] = 4 (inch)
Small End Hub Thickness [g0] = 0.001 (inch)
Large End Hub Thickness [g1] = 0.001 (inch)
Hub Length [h] = 0.001 (inch)
All. Stress @ Design Temp [sf] = 20000 (psi)
All. Stress @ Ref. Temp [sfa] = 20000 (psi)
Modulus @ Design Temp [E] = 2.7E+7 (psi)
Modulus @ Ref. Temp [Ea] = 2.92E+7 (psi)

Bolting Information:

Bolt Circle Diameter = 36 (inch)
Number of Bolts = 28
Bolt Diameter = 1 (inch)

All. Stress @ Ref. Temp [sa] = 25000 (psi)
All. Stress @ Design Temp [sb] = 25000 (psi)

Gasket Information:

Gasket Outside Diameter = 32.75 (inch)
Gasket Inner Diameter = 32 (inch)
Leak Pressure Ratio [m] = 0.50
Gasket Seating Stress [y] = 0 (psi)
Facing Sketch = 2
Facing Column = 2

Load Data:

Design Pressure = 300 (psi)
Design Temperature = 295 (F)
Axial Force = 1000 (lb)
Bending Moment = 200 (ft-lb)
Allowable Pressure = 665 (psi)

Comparison of Results:

Flange Stresses	**Text Book Results (psi)**	**CAEPIPE (psi)**	**CAESAR II (psi)**
Operating Condition			
Longitudinal Hub (SH)	0	0	3
Radial Flange (SR)	0	0	0
Tangential Flange (ST)	10577	10569	10618
0.5(SH + SR)	0	0	1.5
0.5(SH + ST)	0	0	5310.5
Bolt Stress	16378	16371	16445
Gasket Seating Condition			
Longitudinal Hub (SH)	0	0	3
Radial Flange (SR)	0	0	0
Tangential Flange (ST)	12147	11987	12166
0.5(SH + SR)	0	0	1.5
0.5(SH + ST)	0	0	6085
Bolt Stress	0	0	124

Pressure Design of Pipe & Pipe Fittings
as per EN 13480-3 (2017)

Internal pressure according to SS EN 13480-3 (2017)

Straight Pipes

The minimum required wall thickness for a straight pipe without allowances and tolerances, ep, is calculated from equation 6.1-1 and 6.1-3 depending on the ratio between inner and outer diameter as follows:

For $D_o/D_i <= 1.7$

$$ep = \frac{P_c D_0}{2fz + P_c}$$

For $D_o/D_i > 1.7$

$$ep = \frac{D_o}{2}\left[1 - \sqrt{\frac{fz - p_c}{fz + p_c}}\right]$$

where,

D_o = outside diameter of pipe

D_i = inside diameter of pipe = Do – 2 x e_n

e_n = nominal wall thickness of pipe

f = Allowable stress for material at maximum temperature

z = weld efficiency factor = 1.0

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

ep = minimum required wall thickness

Elbows

The minimum required wall thickness of the intrados and the extrados of the elbow without allowances and tolerances, ep1 / ep2, is calculated from equation B.4.1-3

ep1 = ep2 = e.B

$$B = \frac{D_0}{2e} - \frac{R}{e} + \sqrt{\left[\frac{D_0}{2e} - \frac{R}{e}\right]^2 + 2\frac{R}{e} - \frac{D_0}{2e}}$$

where

D_o = outside diameter of elbow

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the elbow

ep1 = ep2 = minimum required wall thickness of the elbow

Bends (formed by cold bending of straight pipes)

Wall thickness of the intrados of the bend

The minimum required wall thickness of the intrados of the bend without allowances and tolerances, ep1, is calculated from equation B.4.1-1

ep1 = e .Bint

$$B_{int} = \frac{D_0}{2e} + \frac{r}{e} - \left[\frac{D_o}{2e} + \frac{r}{e} - 1\right] \sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)}}$$

r/e is calculated from

$$\frac{r}{e} = \sqrt{\frac{1}{2}\left\{\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right\} + \sqrt{\frac{1}{4}\left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)\left(\frac{R}{e}\right)^2}}$$

where

D_o = outside diameter of bend

D_i = inside diameter of bend = $D_o - 2 \times e_n$

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the bend

ep1 = minimum required wall thickness of the intrados

Wall thickness of the extrados of the bend

The minimum required wall thickness of the extrados of the bend without allowances and tolerances, ep2, is calculated from equation B.4.1-8

ep2 = e .Bext

$$B_{ext} = \frac{D_0}{2e} - \frac{r}{e} - \left[\frac{D_o}{2e} - \frac{r}{e} - 1\right] \sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)}}$$

r/e is calculated from

$$\frac{r}{e} = \sqrt{\frac{1}{2}\left\{\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right\} + \sqrt{\frac{1}{4}\left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)\left(\frac{R}{e}\right)^2}}$$

where

D_o = outside diameter of bend

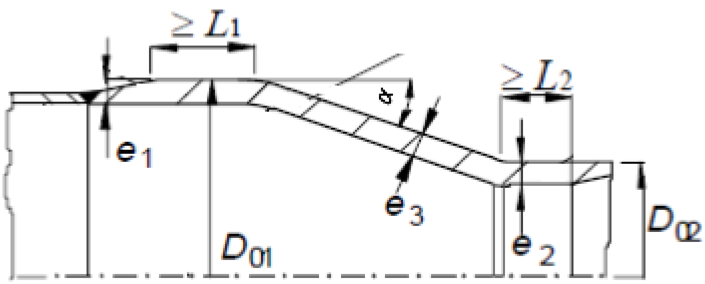
D_i = inside diameter of bend = Do – 2 x e_n

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the bend

ep2 = minimum required wall thickness of the extrados

Reducers



Junction between the large end of a cone and a cylinder without a knuckle

The minimum required wall thickness (e1) of the larger cylinder adjacent to the junction is calculated from Subsection 6.4.6.2 as the greater of ecyl and ej where ej is determined from

$$\beta = \frac{1}{3}\sqrt{\frac{D_c}{e_j}\frac{\tan\propto}{1+\frac{1}{\sqrt{\cos\propto}}}} - 0.15 \qquad (\text{Eq. } 6.4.6-2)$$

$$e_j = \frac{p_c\beta D_c}{2f} \qquad (\text{Eq. } 6.4.6-1)$$

The value of ej is acceptable, if the value given by Eq. 6.4.6-1 is not less than that assumed in Eq. 6.4.6-2

$$e_{con} = \frac{p_c D_e}{2fZ + p_c}\frac{1}{\mathrm{COS}(\alpha)} \qquad (\text{Eq. } 6.4.4-2)$$

$$e_{cyl} = \frac{p_c D_{01}}{2fZ+p_c}$$

$$e_1 = \text{thickness of larger cylinder} = \max(e_j, e_{cyl})$$

$$e_3 = \text{thickness of cone shell} = \max(e_j, e_{con})$$

where

D_e = outside diameter of the cone

D_{01} = outside diameter of the larger cylinder

D_{02} = outside diameter of the small cylinder

D_c = mean diameter of the larger cylinder at the junction with the cone = D_{01} - e_n

e_n = nominal wall thickness of the larger cylinder at the junction with the cone

$\propto$ = cone angle

e1 = minimum required wall thickness for larger cylinder adjacent to the junction.

e3 = minimum required wall thickness at cone.

f = Allowable stress for material at maximum temperature

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

Z = weld efficiency factor = 1.0

Junction between the small end of a cone and a cylinder without a knuckle

The minimum required wall thickness (e2) of the small cylinder adjacent to the junction is calculated according to Subsection 6.4.8.2 as follows.

$$s = \frac{e_3}{e_{j2}}$$

With e3 already determined in the earlier section, assume value of ej2 and calculate the values of s, τ and β_H

When s < 1.0, then

$$\tau = s\sqrt{\frac{s}{\cos\propto}} + \sqrt{\frac{1+s^2}{2}}$$

When s >= 1.0, then

$$\tau = 1 + \sqrt{s\frac{1+s^2}{2\cos\propto}}$$

$$\beta_H = 0.4\sqrt{\frac{D_c}{e_{j2}}\frac{\tan\propto}{\tau}} + 0.5 \qquad \text{(Eq. 6.4.8 − 4)}$$

$$e_{j2} = \frac{p_c D_c \beta_H}{2fZ} \qquad \text{(Eq. 6.4.8 − 5)}$$

The value of ej2 is acceptable, if the value given by Eq. 6.4.8-5 is not less than that assumed for Eq. 6.4.8-4

$$e_{cyl} = \frac{p_c D_{02}}{2fZ + p_c}$$

$$e_2 = \max(e_{j2}, e_{cyl})$$

where

D_{02} = outside diameter of the small cylinder at the junction with the cone

D_c = mean diameter of the small cylinder at the junction with the cone = D_{02} - e_n

e_n = nominal wall thickness of the small cylinder at the junction with the cone

$\propto$ = cone angle

e2 = minimum required wall thickness of the small cylinder at the junction with the cone

f = Allowable stress for material at maximum temperature

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

Z = weld efficiency factor = 1.0

External Pressure Design according to SS EN 13480-3 (2017)

Pipes, Elbows, Mitre Bends and Reducers

Interstiffener collapse

The thickness of the pipe within the unstiffened length L shall not be less than that determined by the following.

$$P_r \geq k.P_c$$

$$P_y = \frac{Se_a}{R_m}$$

$$P_m = \frac{E_t e_a \varepsilon}{R_m}$$

$$\varepsilon = \frac{1}{n_{cyl}^2 - 1 + \frac{Z^2}{2}} \left\{ \frac{1}{\left(\frac{n_{cyl}^2}{Z^2} + 1\right)^2} + \frac{{e_a}^2}{12R_{m^2(1-v^2)}} \left(n_{cyl}^2 - 1 + Z^2\right)^2 \right\}$$

$$Z = \frac{\pi R_m}{L}$$

using the calculated value of Pm/Py, Pr/Py is determined from Table 9.3.2.1 of Subsection 9.3.2

where

n_{cyl} = integer >= 2 to minimize the value of P_m.

CAEPIPE goes through an iterative routine by increasing the value of ncyl from 2 and above until the minimum collapse pressure (pm) is reached.

R_m = mean radius of the pipe

L = length between the stiffener, is calculated from CAEPIPE input as follows

for Pipe, L = length of pipe (= distance between the "From" and "To" node of CAEPIPE)

for Elbow and Miter bend, L = arc length measured on extrados of elbow and miter bend

for Reducer, L = Length of the reducer

E_t = Young's modulus of material at design temperature (max of CAEPIPE Temperature T1 through T10)

e_a = analysis thickness of reducer at smaller end = en – corr.all – mill tolerance

e_n = nominal thickness of reducer at smaller end

k = factor = 1.5

Pc = external pressure = maximum negative CAEPIPE input pressures P1 through P10

S = elastic stress limits for pipe and stiffener for External Pressure Design

= “Rp0.2t” for non-austenitic steels

= “Rp0.2t/1.25” for austenitic steels

Note:

Generally, allowable stress is (2/3) x Yield. So, for Piping code = EN 13480-3, the value of Rp0.2t is computed as “Rp0.2t = f x 1.5”

For all other Piping Codes, the value of Rp0.2t is computed as “Rp0.2t = allowable stress x 1.5”.

Additional check for Reducers

In addition to the above, as stated in Subsection 9.4.2 of EN 13480-3, the moment of inertia, Ix taken parallel to the axis of the cylinder, of the part of the cone and cylinder with a distance of $\sqrt{D_{eq}.e}$ on either side of the junction is not less than:

$$I_x = 0.18 D_{eq} L D_s^2 \frac{p_c}{E_t} \leq I_{xa}$$

where

D_{eq} = equivalent diameter = $\frac{\frac{D_1+D_2}{2}}{\cos(\alpha)}$

D_1 = outside diameter of larger end of reducer

D_2 = outside diameter of smaller end of reducer

α =cone angle of reducer input in CAEPIPE

Ixa = moment of inertia of reducer at smaller end

Ds = diameter of the centroid of the moment of inertia of the stiffening cross section calculated as shown below

$$I_{cone} = \left(\sqrt{D_{eq} e_1}.e_1\right)\left(\frac{D_{mcon}}{2}\right)^2 = (A_{cone})\left(\frac{D_{mcon}}{2}\right)^2$$

$$I_{Cyl} = \left(\sqrt{D_{eq} e_2}.e_2\right)\left(\frac{D_{mcyl}}{2}\right)^2 = (A_{cyl})\left(\frac{D_{mcyl}}{2}\right)^2$$

$$I_{stiff} = (A_{cone} + A_{cyl})\left(\frac{D_s}{2}\right)^2$$

From the above,

$I_{cone} + I_{Cyl} = I_{stiff}$

and

$$D_s = 2\sqrt{\frac{I_{stiff}}{(A_{cone} + A_{cyl})}}$$

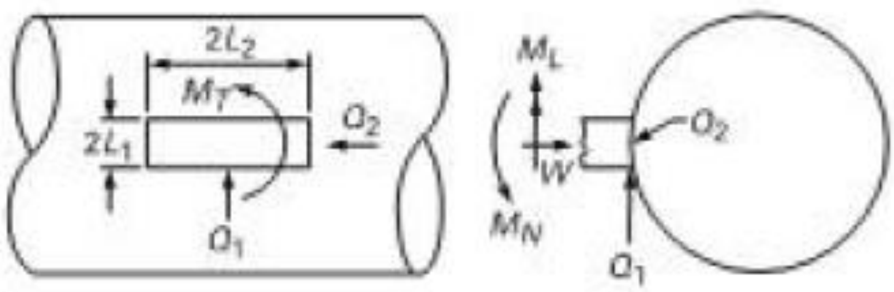
e_1 = analysis thickness of reducer at larger end = en1 – corr.all – mill tolerance

e_2 = analysis thickness of reducer at smaller end = en2 – corr.all – mill tolerance

e_{n1}& e_{n2} = nominal thickness of reducer at larger end and smaller end respectively

Lug Evaluation

Rectangular Cross-section Welded Attachments



The notations described below are used in the formulas for the design.

$L1$=half length of attachment in circumferential direction of the run pipe

$L2$= half length of attachment in longitudinal direction of the run pipe

R= mean pipe radius

D_o=outside diameter of run pipe

T= nominal run pipe wall thickness

L_a= lesser of L_2 and T

L_b= lesser of L_1 and T

L_c= lesser of L_1 and L_2

L_d= greater of L_1 and L_2

$A_T = 4.L_1.L_2$= cross-sectional area of the rectangular attachment

$$Z_{tL} = \left(\frac{4}{3}\right).L_1.{L_2}^2$$

$$Z_{tN} = \left(\frac{4}{3}\right).{L_1}^2.L_2$$

$$\beta_1 = \frac{L_1}{R}$$

$$\beta_2 = \frac{L_2}{R}$$

$$\gamma = \frac{R}{T}$$

Limits of Applicability

$\boldsymbol{\beta_1 \leq 0.5}$

$\boldsymbol{\beta_2 \leq 0.5}$

$\boldsymbol{\beta_1.\beta_2 \leq 0.75}$

M_L = bending moment applied to the attachment as shown in figure above

M_N = bending moment applied to the attachment as shown in figure above
M_T = torsional moment applied to the attachment as shown in figure above
Q_1 = shear load applied to the attachment as shown in figure above.
Q_2 = shear load applied to the attachment as shown in figure above
W = thrust load applied to the attachment as shown in figure above

M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

Calculate η, X_1 *and* Y_1 using the factors listed in Table below.

Load	Index	A_o	θ	X_o	Y_o
Thrust (W)	C_W	2.2	40^0	0	0.05
Longitudinal Moment (M_L)	C_L	2.0	50^0	-0.45	-0.55
Circumferential Moment (M_N)	C_N	1.8	40^0	-0.75	-0.60

$$X_1 = X_o + log_{10}\beta_1$$

$$Y_1 = Y_o + log_{10}\beta_2$$

$$\eta = -(X_1 Cos\theta + Y_1 Sin\theta) - \frac{1}{A_o}(X_1 Sin\theta - Y_1 Cos\theta)^2$$

$C_W = 3.82(\gamma)^{1.64}\beta_1\beta_2\eta^{1.54}$ but not less than 1.0

$C_L = 0.26(\gamma)^{1.74}\beta_1{\beta_2}^2\eta^{4.74}$ but not less than 1.0

$C_N = 0.38(\gamma)^{1.90}{\beta_1}^2\beta_2\eta^{3.40}$ but not less than 1.0

B_L = (2/3) C_L but not less than 1.0
B_N = (2/3) C_N but not less than 1.0
B_W = (2/3) C_W but not less than 1.0
K_T = 2.0 for full penetration weldsandfillet or partial penetration welds welded on 4 sides
= 3.6 for fillet or partial penetration welds welded on 2 or 3 sides
S_A= f(1.25S_c+0.25S_h) as defined in NC/ND-3611.2 (lesser of pipe or attachment material allowable)
S_c= allowable stress at ambient temperature (lesser of pipe or attachment material allowable)
S_h= allowable stress at Max. Temperature (lesser of pipe or attachment material allowable)
S_y= yield stress (lesser of pipe or attachment material yield stress)

(A) Calculate Pipe Stress S_{MTS} due to Sustained Loads on Attachment

$$M_{TTS} = max\left(\frac{M_{TS}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]}; \frac{M_{TS}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]{L_c}^2 L_d}\right)$$

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_{tN}} + \frac{B_L M_{LS}}{Z_{tL}} + \frac{Q_{1S}}{2L_1L_a} + \frac{Q_{2S}}{2L_2L_b} + M_{TTS}$$

where

W_S, Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS}, M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate PipeStress S_{MTO} due to Occasional Loads on Attachment

$$M_{TTO} = max\left(\frac{M_{TO}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_{TO}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]{L_c}^2 L_d}\right)$$

$$S_{MTO} = \frac{B_W W_o}{A_T} + \frac{B_N M_{NO}}{Z_{tN}} + \frac{B_L M_{LO}}{Z_{tL}} + \frac{Q_{1O}}{2L_1 L_a} + \frac{Q_{2O}}{2L_2 L_b} + M_{TTO}$$

where

W_O, Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO}, M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate PipeStresses S_{NTE} and S_{PTE} due to Thermal Loads on Attachment

$$M_{TTE} = max\left(\frac{M_{TE}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_{TE}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]{L_c}^2 L_d}\right)$$

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_{tN}} + \frac{C_L M_{LE}}{Z_{tL}} + \frac{Q_{1E}}{2L_1 L_a} + \frac{Q_{2E}}{2L_2 L_b} + M_{TTE}$$

$$S_{PTE} = K_T . S_{NTE}$$

where

W_E, Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE}, M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{NTD} and S_{PTD} due to Settlement Loads on Attachment

$$M_{TTD} = max\left(\frac{M_{TD}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_{TD}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]L_c{}^2 L_d}\right)$$

$$S_{NTD} = \frac{C_W W_D}{A_T} + \frac{C_N M_{ND}}{Z_{tN}} + \frac{C_L M_{LD}}{Z_{tL}} + \frac{Q_{1D}}{2L_1 L_a} + \frac{Q_{2D}}{2L_2 L_b} + M_{TTD}$$

$$S_{PTD} = K_T.S_{NTD}$$

where

W_D, Q_{1D} and Q_{2D} are the thrust load and shear forces applied at the attachment due to Settlement Loads

M_{TD}, M_{LD} and M_{ND} are the torsional moment and bending moments applied at the attachment due to Settlement Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTD} Stresses.

(E) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads

S_{MTR} = Stress S_{MTS} calculated in Subsection A above

S_{PTR} = Stress S_{PTE} calculated in Subsection C above

(F) Calculate Attachment Stresses: S_{NT}** due to Abs. Max. Loads

$$M_{TT}{}^{**} = max\left(\frac{M_T{}^{**}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_T{}^{**}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]L_c{}^2 L_d}\right)$$

$$S_{NT}{}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N{}^{**}}{Z_{tN}} + \frac{C_L M_L{}^{**}}{Z_{tL}} + \frac{Q_1{}^{**}}{2L_1 L_a} + \frac{Q_2{}^{**}}{2L_2 L_b} + M_{TT}{}^{**}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SL}) = S_L + $S_{MTS} \leq 1.5S_h$

Occasional Stress (S_{SO}) = S_{LO} + S_{MTS} + $S_{MTO} \leq k.S_y$

Thermal Stress (S_{SE}) = S_E + (S_{PTE} / 2.0) ≤ S_A

Settlement Stress (S_{SD}) = S_D + (S_{PTD} / 2.0) ≤ $3.0S_h$

Sustained + Thermal Stress (S_{SR}) = S_{TE} + S_{MTR} + (S_{PTR} / 2.0) ≤ (S_h + S_A)

Additional Check

$S_{NT}{}^{**} \leq 2.Sy$

$$\left|\frac{Q_1{}^{**}}{2L_1 L_a} + \frac{Q_2{}^{**}}{2L_2 L_b} + M_{TT}{}^{**}\right| \leq S_Y$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SL}) = $S_L + S_{MTS} \leq 1.5S_h$

Occasional Stress (S_{SO}) = $S_{LO} + S_{MTS} + S_{MTO} \leq k.S_y$

Thermal Stress (S_{SE}) = $S_E + (S_{PTE} / 2.0) \leq S_A$

Settlement Stress (S_{SD}) = $S_D + (S_{PTD} / 2.0) \leq 3.0S_h$

Sustained + Thermal Stress (S_{SR}) = $S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$

Additional Check

$|S_{NT}^{**}| \leq 2.Sy$

$$\left| \frac{Q_1^{**}}{2L_1L_a} + \frac{Q_2^{**}}{2L_2L_b} + M_{TT}^{**} \right| \leq S_Y$$

Note: Additional compliance check as per Eq. 7 and Eq. 8 of Y-3420 (b) are not performed in CAEPIPE at this time

where,

k = 1.5 for Level A& B loadings, 1.8 for Level C loadings and 2.0 for Level D loadings

S_L = Sustained Stress on Run Pipe as per NC-3652 Eq. (8)

S_{LO} = Sustained + Occasional Stress on Run Pipe as per NC-3653.1 Eq. (9)

S_E = Thermal Stress on Run Pipe as per NC-3653.2 Eq. (10)

S_D = Settlement Stress on Run Pipe as per NC-3653.2 Eq. (10a)

S_{TE} = Sustained + Thermal Stress on Run Pipe as per NC-3653.2 Eq. (11)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

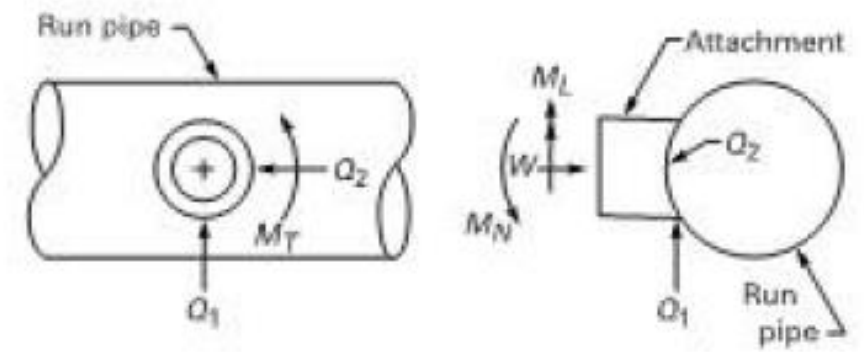
S_{PTD} = Pipe Stress S_{PTD} computed in Subsection D above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTR} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}^{**}= Pipe Stress S_{NT}^{**} computed in Subsection F above

HollowCircular Cross-section Welded Attachments



The notations described below are used in the formulas for the design.

R= mean run pipe radius

R_o= run pipe outside radius

r_o= attachment outside radius

r_i= attachment inside radius

D_o = outside diameter of run pipe

d_o = outside diameter of attachment

T= nominal run pipe wall thickness

t= nominal attachment wall thickness

$A_T = \pi({r_o}^2 - {r_i}^2)$= cross-sectional area of the circular attachment

$$I_T = \frac{\pi}{4}({r_o}^4 - {r_i}^4)$$

$$Z_T = \frac{I_T}{r_o}$$

$$J = \min(\pi {r_o}^2 T,\ Z_T)$$

$$\gamma = \frac{R_o}{T}$$

$$\beta = \frac{d_o}{D_o}$$

$$\tau = \frac{t}{T}$$

Limits of Applicability

$\mathbf{4.0 \leq \gamma \leq 50}$

$$0.2 \leq \tau \leq 1.0$$

$$0.3 \leq \beta \leq 1.0$$

M_L = bending moment applied to the attachment as shown in figure above
M_N = bending moment applied to the attachment as shown in figure above
M_T = torsional moment applied to the attachment as shown in figure above
Q_1 = shear load applied to the attachment as shown in figure above.
Q_2 = shear load applied to the attachment as shown in figure above
W = thrust load applied to the attachment as shown in figure above

M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

$C = A_o(2\gamma)^{n1}\beta^{n2}\tau^{n3}$ but not less than 1.0

Equation for C is used to determine C_W, C_L and C_N based on the following Table. Maximum values of C_W, C_L and C_N among the values calculated for the pipe and the attachment are used subsequently.

Load	Index	Part	β range	A_o	n1	n2	n3
Thrust (W)	C_W	Pipe	0.3 to1.0	1.40	0.81	(a)	1.33
		Attachment	0.3 to1.0	4.00	0.55	(b)	1.00
Longitudinal	C_L	Pipe	0.3 to1.0	0.46	0.60	-0.04	0.86
Moment (M_L)		Attachment	0.3 to1.0	1.10	0.23	-0.38	0.38
Circumferential	C_N	Pipe	0.3 to 0.55	0.51	1.01	0.79	0.89
Moment (M_N)		Attachment	0.3 to 0.55	0.84	0.85	0.80	0.54
Circumferential	C_N	Pipe	>0.55 to 1.0	0.23	1.01	-0.62	0.89
Moment (M_N)		Attachment	>0.55 to 1.0	0.44	0.85	-0.28	0.54

(a) - Replace β^{n2} with $e^{-1.2\beta^3}$
(b) - Replace β^{n2} with $e^{-1.35\beta^3}$

C_T = 1.0 for β<= 0.55
= C_N for β = 1.0, but not less than 1.0;
C_T should be linearly interpolated for 0.55 <= β< 1.0, but not less than 1.0

B_W = 0.5 C_W but not less than 1.0
B_L = 0.5 C_L but not less than 1.0
B_N = 0.5 C_N but not less than 1.0
B_T = 0.5 C_T but not less than 1.0
K_T = 1.8 for full penetration welds
= 2.0 for fillet or partial penetration welds
S_A = f(1.25S_c + 0.25S_h) as defined in NC/ND-3611.2 (lesser of pipe or attachment material allowable)
S_c = allowable stress at ambient temperature (lesser of pipe or attachment material allowable)
S_h = allowable stress at maximum temperature (lesser of pipe or attachment material allowable)
S_y = yield stress (lesser of pipe or attachment material yield stress)

M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

(A) Calculate PipeStress S_{MTS} due to Sustained Loads on Attachment

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_T} + \frac{B_L M_{LS}}{Z_T} + \frac{2Q_{1S}}{A_T} + \frac{2Q_{2S}}{A_T} + \frac{B_T M_{TS}}{J}$$

where

W_S, Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS}, M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate PipeStress S_{MTO} due to Occasional Loads on Attachment

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_T} + \frac{B_L M_{LO}}{Z_T} + \frac{2Q_{1O}}{A_T} + \frac{2Q_{2O}}{A_T} + \frac{B_T M_{TO}}{J}$$

where

W_O, Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO}, M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate PipeStresses S_{NTE} and S_{PTE} due to Thermal Loads on Attachment

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_T} + \frac{C_L M_{LE}}{Z_T} + \frac{2Q_{1E}}{A_T} + \frac{2Q_{2E}}{A_T} + \frac{C_T M_{TE}}{J}$$

$$S_{PTE} = K_T . S_{NTE}$$

where

W_E, Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE}, M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{NTD} and S_{PTD} due to Settlement Loads on Attachment

$$S_{NTD} = \frac{C_W W_D}{A_T} + \frac{C_N M_{ND}}{Z_T} + \frac{C_L M_{LD}}{Z_T} + \frac{2Q_{1D}}{A_T} + \frac{2Q_{2D}}{A_T} + \frac{C_T M_{TD}}{J}$$

$$S_{PTD} = K_T . S_{NTD}$$

where

W_D, Q_{1D} and Q_{2D} are the thrust load and shear forces applied at the attachment due to Settlement Loads

M_{TD}, M_{LD} and M_{ND} are the torsional moment and bending moments applied at the attachment due to SettlementLoads

Note: Absolute values of Forces and Moments are used while calculating S_{NTD} Stresses.

(E) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads on Attachment

S_{MTR} = Stress S_{MTS} calculated in Subsection A above

S_{PTR} = Stress S_{PTE} calculated in Subsection C above

(F) Calculate Attachment Stresses: S_{NT} due to Abs. Max. Loads**

$$S_{NT}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N^{**}}{Z_T} + \frac{C_L M_L^{**}}{Z_T} + \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{C_T M_T^{**}}{J}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SL}) = $S_L + S_{MTS} \leq 1.5S_h$

Occasional Stress (S_{SO}) = $S_{LO} + S_{MTS} + S_{MTO} \leq k.S_y$

Thermal Stress (S_{SE}) = $S_E + (S_{PTE} / 2.0) \leq S_A$

Settlement Stress (S_{SD}) = $S_D + (S_{PTD} / 2.0) \leq 3.0S_h$

Sustained + Thermal Stress (S_{SR}) = $S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$

Additional Check

$|S_{NT}^{**}| \leq 2.Sy$

$$\left|\frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{M_T^{**}}{J}\right| \leq S_Y$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SL}) = $S_L + S_{MTS} \leq 1.5S_h$

Occasional Stress (S_{SO}) = $S_{LO} + S_{MTS} + S_{MTO} \leq k.S_y$

Thermal Stress (S_{SE}) = $S_E + (S_{PTE} / 2.0) \leq S_A$

Settlement Stress (S_{SD}) = $S_D + (S_{PTD} / 2.0) \leq 3.0S_h$

Sustained + Thermal Stress (S_{SR}) = $S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$

Additional Check

$|S_{NT}^{**}| \leq 2.Sy$

$$\left|\frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{M_T^{**}}{J}\right| \leq S_Y$$

Note: Additional compliance checks as per Eq. 7 and Eq. 8 of Y-5420 (b) are not performed in CAEPIPE at this time

where,

k = 1.5 for Level A& B Loadings, 1.8 for Level C loadings and 2.0 for Level D loadings

S_L = Sustained Stress on Run Pipe as per NC-3652 Eq. (8)

S_{LO} = Sustained + Occasional Stress on Run Pipe as per NC-3653.1 Eq. (9)

S_E = Thermal Stress on Run Pipe as per NC-3653.2 Eq. (10)

S_D = Settlement Stress on Run Pipe as per NC-3653.2 Eq. (10a)

S_{TE} = Sustained + Thermal Stress on Run Pipe as per NC-3653.2 Eq. (11)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

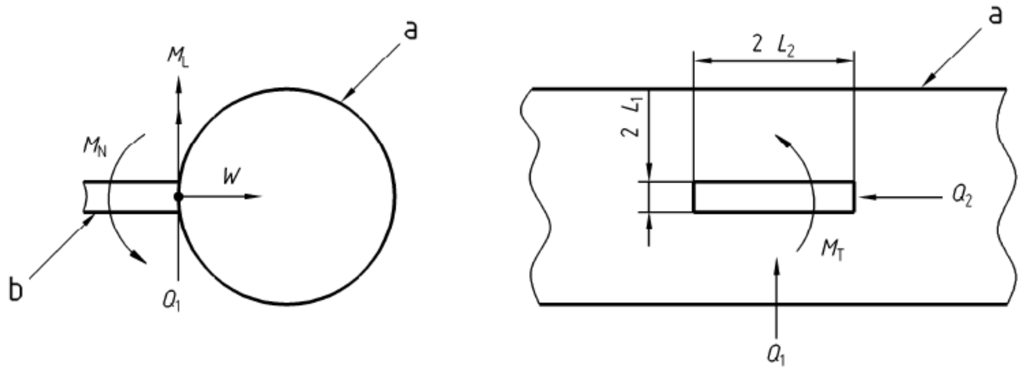
S_{PTD} = Pipe Stress S_{PTD} computed in Subsection D above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTR} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}^{**}= Pipe Stress S_{NT}^{**} computed in Subsection F above

Rectangular Cross-section Welded Attachments



The notations described below are used in the formulas for the design.

$L1$= half length of attachment in circumferential direction of the run pipe

$L2$= half length of attachment in longitudinal direction of the run pipe

R= mean pipe radius

D_o= outside diameter of run pipe

T= nominal run pipe wall thickness

L_a= lesser of L_2 and T

L_b= lesser of L_1 and T

L_c= lesser of L_1 and L_2

L_d= greater of L_1 and L_2

$A_T = 4.L_1.L_2$= cross-sectional area of the rectangular attachment

$$Z_{tL} = \left(\frac{4}{3}\right).L_1.{L_2}^2$$

$$Z_{tN} = \left(\frac{4}{3}\right).{L_1}^2.L_2$$

$$\beta_1 = \frac{L_1}{R}$$

$$\beta_2 = \frac{L_2}{R}$$

$$\gamma = \frac{R}{T}$$

Limits of Applicability

$\boldsymbol{\beta_1 \leq 0.5}$

$\boldsymbol{\beta_2 \leq 0.5}$

$\boldsymbol{\beta_1 . \beta_2 \leq 0.75}$

M_L = bending moment applied to the attachment as shown in figure above
M_N = bending moment applied to the attachment as shown in figure above
M_T = torsional moment applied to the attachment as shown in figure above
Q_1 = shear load applied to the attachment as shown in figure above.
Q_2 = shear load applied to the attachment as shown in figure above
W = thrust load applied to the attachment as shown in figure above

M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

Calculate $\boldsymbol{\eta, X_1}$ *and* $\boldsymbol{Y_1}$ using the factors listed in Table below.

Load	Index	A_o	θ	X_o	Y_o
Thrust (W)	C_W	2.2	40^0	0	0.05
Longitudinal Moment (M_L)	C_L	2.0	50^0	-0.45	-0.55
Circumferential Moment (M_N)	C_N	1.8	40^0	-0.75	-0.60

$$X_1 = X_o + log_{10}\beta_1$$

$$Y_1 = Y_o + log_{10}\beta_2$$

$$\eta = -(X_1 Cos\theta + Y_1 Sin\theta) - \frac{1}{A_o}(X_1 Sin\theta - Y_1 Cos\theta)^2$$

$C_W = 3.82(\gamma)^{1.64}\beta_1\beta_2\eta^{1.54}$ but not less than 1.0

$C_L = 0.26(\gamma)^{1.74}\beta_1{\beta_2}^2\eta^{4.74}$ but not less than 1.0

$C_N = 0.38(\gamma)^{1.90}{\beta_1}^2\beta_2\eta^{3.40}$ but not less than 1.0

B_L = (2/3) C_L but not less than 1.0
B_N = (2/3) C_N but not less than 1.0
B_W = (2/3) C_W but not less than 1.0
K_T = 2.0 for full penetration welds and fillet or partial penetration welds welded on 4 sides
= 3.6 for fillet or partial penetration welds welded on 2 or 3 sides
f_a = allowable stress range as defined in Clause 12.1.3 of EN 13480-3 (2017)
S_c = allowable stress at ambient temperature
f_h = allowable stress at max temperature as provided in Clause 12.1.3 of EN 13480-3 (2017)
f_{cr} = design stress in the creep range as defined in Clause 5.3 of EN 13480-3 (2017)
R_{eHt} = yield stress

Pipe Stresses are calculated using the equations 11.5.3-1, 11.5.3-2, 11.5.3-3 and 11.5.3-4 provided in Clause 11.5.3.

(A) Calculate PipeStress S_{MTS} due to Sustained Loads on Attachment

$$M_{TTS} = max\left(\frac{M_{TS}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_{TS}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]L_c{}^2 L_d}\right)$$

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_{tN}} + \frac{B_L M_{LS}}{Z_{tL}} + \frac{Q_{1S}}{2L_1 L_a} + \frac{Q_{2S}}{2L_2 L_b} + M_{TTS}$$

where

W_S, Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS}, M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate PipeStress S_{MTO} due to Occasional Loads on Attachment

$$M_{TTO} = max\left(\frac{M_{TO}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_{TO}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]L_c{}^2 L_d}\right)$$

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_{tN}} + \frac{B_L M_{LO}}{Z_{tL}} + \frac{Q_{1O}}{2L_1 L_a} + \frac{Q_{2O}}{2L_2 L_b} + M_{TTO}$$

where

W_O, Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO}, M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate Attachment Stresses: S_{NTE} and S_{PTE} due to Thermal Loads

$$M_{TTE} = max\left(\frac{M_{TE}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]};\frac{M_{TE}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right]L_c{}^2 L_d}\right)$$

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_{tN}} + \frac{C_L M_{LE}}{Z_{tL}} + \frac{Q_{1E}}{2L_1 L_a} + \frac{Q_{2E}}{2L_2 L_b} + M_{TTE}$$

$$S_{PTE} = K_T . S_{NTE}$$

where

W_E, Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE}, M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads on Attachment

S_{MTR} = additional stress resulting from sustained loads = S_{MTS} calculated in Subsection A above

S_{PTR} = additional stress resulting from restrained thermal loads = S_{PTE} calculated in Subsection C above

(E) Calculate PipeStresses S_{MTC} and S_{PTC} due to Creep on Attachment

S_{MTC} = additional stress resulting from sustained loads = S_{MTS} calculated in Subsection A above

S_{PTC} = additional stress resulting from restrained thermal loads = S_{PTE} calculated in Subsection C above

(F) Calculate PipeStress S_{NT} due to Abs. Max. Loads**

$$M_{TT}^{**} = max\left(\frac{M_T^{**}}{L_c L_d T\left[1+\left(\frac{L_c}{L_d}\right)\right]}; \frac{M_T^{**}}{\left[0.8+0.05\left(\frac{L_d}{L_c}\right)\right] L_c^2 L_d}\right)$$

$$S_{NT}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N^{**}}{Z_T} + \frac{C_L M_L^{**}}{Z_T} + \frac{Q_1^{**}}{2L_1 L_a} + \frac{Q_2^{**}}{2L_2 L_b} + M_{TT}^{**}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SL}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

$S_{NT}^{**} \leq 2R_{eHt}$

$$\left|\frac{Q_1^{**}}{2L_1 L_a} + \frac{Q_2^{**}}{2L_2 L_b} + M_{TT}^{**}\right| \leq R_{eHt}$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SL}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

S_{NT}** $\leq 2R_{eHt}$

$$\left|\frac{Q_1^{**}}{2L_1L_a} + \frac{Q_2^{**}}{2L_2L_b} + M_{TT}^{**}\right| \leq \mathrm{R}_{eHt}$$

Note: Additional compliance checks as per Eq. 11.5.4-1 and Eq. 11.5.4-2 of Clause 11.5.4 are not performed in CAEPIPE at this time.

where,

S_1 = Sustained Stress on Run Pipe as per 12.3.2-1 of EN 13480-3 (2017)

S_2 = Sustained + Occasional Stress on Run Pipe as per 12.3.3-1 of EN 13480-3 (2017)

S_3 = Thermal Stress on Run Pipe as per 12.3.4-1 of EN 13480-3 (2017)

S_4 = Sustained + Thermal Stress on Run Pipe as per 12.3.4-2 of EN 13480-3 (2017)

S_5 = Settlement Stress on Run Pipe as per 12.3.5-1 of EN 13480-3 (2017)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection D above

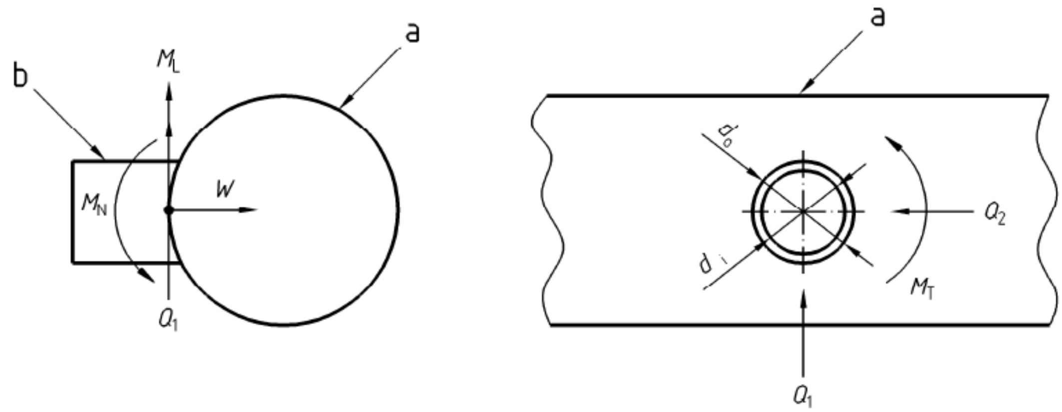
S_{PTR} = Pipe Stress S_{PTR} computed in Subsection D above

S_{MTC} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTC} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}**= Pipe Stress S_{NT}** computed in Subsection F above

HollowCircular Cross-section Welded Attachments



The symbols described below are used in the formulas for the design.

$R =$ mean run pipe radius

$R_o =$ run pipe outside diameter

$r_o =$ attachment outside radius

$r_i =$ attachment inside radius

D_o = outside diameter of run pipe

d_o = outside diameter of attachment

$T =$ nominal run pipe wall thickness

$t =$ nominal attachment wall thickness

$A_T = \pi({r_o}^2 - {r_i}^2) =$ cross-sectional area of the circular attachment

$$I_T = \frac{\pi}{4}({r_o}^4 - {r_i}^4)$$

$$Z_T = \frac{I_T}{r_o}$$

$$J = \min(\pi {r_o}^2 T,\ Z_T)$$

$$\gamma = \frac{R_o}{T}$$

$$\beta = \frac{d_o}{D_o}$$

$$\tau = \frac{t}{T}$$

Limits of Applicability

$\mathbf{4.0 \leq \gamma \leq 50}$

$$0.2 \leq \tau \leq 1.0$$

$$0.3 \leq \beta \leq 1.0$$

M_L = bending moment applied to the attachment as shown in figure above
M_N = bending moment applied to the attachment as shown in figure above
M_T = torsional moment applied to the attachment as shown in figure above
Q_1 = shear load applied to the attachment as shown in figure above.
Q_2 = shear load applied to the attachment as shown in figure above
W = thrust load applied to the attachment as shown in figure above

M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

$C = A_o(2\gamma)^{n1}\beta^{n2}\tau^{n3}$but not less than 1.0

Equation for C is used to determine C_W, C_L and C_N based on the following Table. Maximum values of C_W, C_L and C_N among the values calculated for the pipe and the attachment are used subsequently.

Load	Index	Part	β range	A_o	n1	n2	n3
Thrust (W)	C_W	Pipe	0.3 to1.0	1.40	0.81	(a)	1.33
		Attachment	0.3 to1.0	4.00	0.55	(b)	1.00
Longitudinal	C_L	Pipe	0.3 to1.0	0.46	0.60	-0.04	0.86
Moment (M_L)		Attachment	0.3 to1.0	1.10	0.23	-0.38	0.38
Circumferential	C_N	Pipe	0.3 to 0.55	0.51	1.01	0.79	0.89
Moment (M_N)		Attachment	0.3 to 0.55	0.84	0.85	0.80	0.54
Circumferential	C_N	Pipe	>0.55 to 1.0	0.23	1.01	-0.62	0.89
Moment (M_N)		Attachment	>0.55 to 1.0	0.44	0.85	-0.28	0.54

(a) - Replace β^{n2} with $e^{-1.2\beta^3}$
(b) - Replace β^{n2} with $e^{-1.35\beta^3}$

C_T = 1.0 for β<= 0.55
= C_N for β = 1.0, but not less than 1.0;
C_T should be linearly interpolated for 0.55 <= β< 1.0, but not less than 1.0

B_W = 0.5 C_W but not less than 1.0
B_L = 0.5 C_L but not less than 1.0
B_N = 0.5 C_N but not less than 1.0
B_T = 0.5 C_T but not less than 1.0
K_T = 1.8 for full penetration welds
= 2.0 for fillet or partial penetration welds
f_a = allowable stress range as defined in Clause 12.1.3 of EN 13480-3 (2017)
S_c = allowable stress at ambient temperature
f_h = allowable stress at max temperature as provided in Clause 12.1.3 of EN 13480-3 (2017)
f_{cr} = design stress in the creep range as defined in Clause 5.3 of EN 13480-3 (2017)

R_{eHt} = yield stress

(A) Calculate PipeStress S_{MTS} due to Sustained Loads on Attachment

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_T} + \frac{B_L M_{LS}}{Z_T} + \frac{2Q_{1S}}{A_T} + \frac{2Q_{2S}}{A_T} + \frac{B_T M_{TS}}{J}$$

where

W_S, Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS}, M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate Pipe Stress S_{MTO} due to Occasional Loads on Attachment

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_T} + \frac{B_L M_{LO}}{Z_T} + \frac{2Q_{1O}}{A_T} + \frac{2Q_{2O}}{A_T} + \frac{B_T M_{TO}}{J}$$

where

W_O, Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO}, M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate PipeStresses S_{NTE} and S_{PTE} due to Thermal Loads on Attachment

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_T} + \frac{C_L M_{LE}}{Z_T} + \frac{2Q_{1E}}{A_T} + \frac{2Q_{2E}}{A_T} + \frac{C_T M_{TE}}{J}$$

$$S_{PTE} = K_T . S_{NTE}$$

where

W_E, Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE}, M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads on Attachment

S_{MTR} = Stress S_{MTS} calculated in Subsection A above

S_{PTR} = Stress S_{PTE} calculated in Subsection C above

(E) Calculate PipeStresses S_{MTC} and S_{PTC}due to Creep on Attachment

S_{MTC} = Stress S_{MTS} calculated in Subsection A above

S_{PTC} = Stress S_{PTE} calculated in Subsection C above

(F) Calculate PipeStress S_{NT} due to Abs. Max. Loads on Attachment**

$$S_{NT}{}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N{}^{**}}{Z_T} + \frac{C_L M_L{}^{**}}{Z_T} + \frac{2Q_1{}^{**}}{A_T} + \frac{2Q_2{}^{**}}{A_T} + \frac{C_T M_T{}^{**}}{J}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SL}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

$|S_{NT}{}^{**}| \leq 2.R_{eHt}$

$$\left|\frac{2Q_1{}^{**}}{A_T} + \frac{2Q_2{}^{**}}{A_T} + \frac{M_T{}^{**}}{J}\right| \leq R_{eHt}$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SL}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

$|S_{NT}{}^{**}| \leq 2.R_{eHt}$

$$\left|\frac{2Q_1{}^{**}}{A_T} + \frac{2Q_2{}^{**}}{A_T} + \frac{M_T{}^{**}}{J}\right| \leq R_{eHt}$$

Note: Additional compliance checks as perEq. 11.4.4-1 and Eq. 11.4.4-2 of Clause 11.4.4 are not performed in CAEPIPE at this time

where,

S_1 = Sustained Stress on Run Pipe as per 12.3.2-1 of EN 13480-3 (2017)

S_2 = Sustained + Occasional Stress on Run Pipe as per 12.3.3-1 of EN 13480-3 (2017)

S_3 = Thermal Stress on Run Pipe as per 12.3.4-1 of EN 13480-3 (2017)

S_4 = Sustained + Thermal Stress on Run Pipe as per 12.3.4-2 of EN 13480-3 (2017)

S_5 = Settlement Stress on Run Pipe as per 12.3.5-1 of EN 13480-3 (2017)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection D above

S_{PTR} = Pipe Stress S_{PTR} computed in Subsection D above

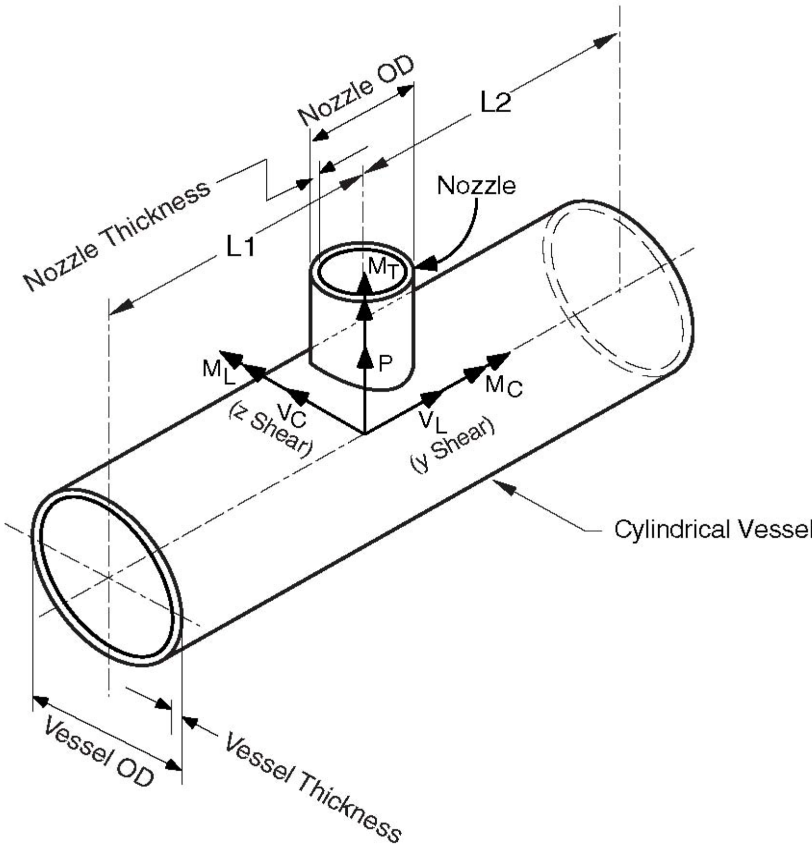
S_{MTC} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTC} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}**= Pipe Stress S_{NT}** computed in Subsection F above

Nozzle Stiffness Calculations

Six stiffnesses are shown below at the nozzle-vessel interface - three are calculated and the other three are assumed rigid.



The coordinate system is as shown in the figure. The six components of the forces and moments at the nozzle-vessel interface are:

P = Radial load	M_C = Circumferential moment
V_C = Circumferential load	M_T = Torsional moment
V_L = Longitudinal load	M_L = Longitudinal moment

Of the six components of stiffnesses, only three stiffnesses, axial (K_x), circumferential (K_{yy}), and longitudinal (K_{zz}), are calculated. The remaining three are assumed to be rigid.

Several graphs are given at the end of this annexure. The stiffness coefficients are obtained by interpolating logarithmically from these graphs.

The first two, Figures D-1 and D-2, are used to calculate nozzle stiffness coefficients for Nozzles on cylindrical vessels. Figure D-1 is used to calculate the axial stiffness coefficient and Figure D-2 is used to calculate circumferential and longitudinal stiffness coefficients.

Nomenclature

D = mean diameter of vessel
d = outside diameter of nozzle
T = thickness of vessel
t = thickness of nozzle
λ = $(d/D)\sqrt{D/T}$
Λ = $L/\sqrt{DT}$
L = unsupported length of cylinder
= $8L_1L_2/\left(\sqrt{L_1}+\sqrt{L_2}\right)^2$
$L1$ = distance from nozzle center line to vessel end
$L2$ = distance from nozzle center line to vessel end
E = modulus of elasticity of vessel material

Axial Stiffness(K_x)

$$K_x = \alpha \times \frac{4.95ET^2}{D\sqrt{\Lambda}} \tag{1}$$

where
α = stiffness coefficient read from Figure D-1

Circumferential Stiffness(K_{yy})

$$K_{yy} = \beta \times ET^3 \tag{2}$$

where
β =1stiffness coefficient read from Figure D-2.
The bottom three curves in Figure D-2, marked Circumferential moment $M_C$are used to findβ.

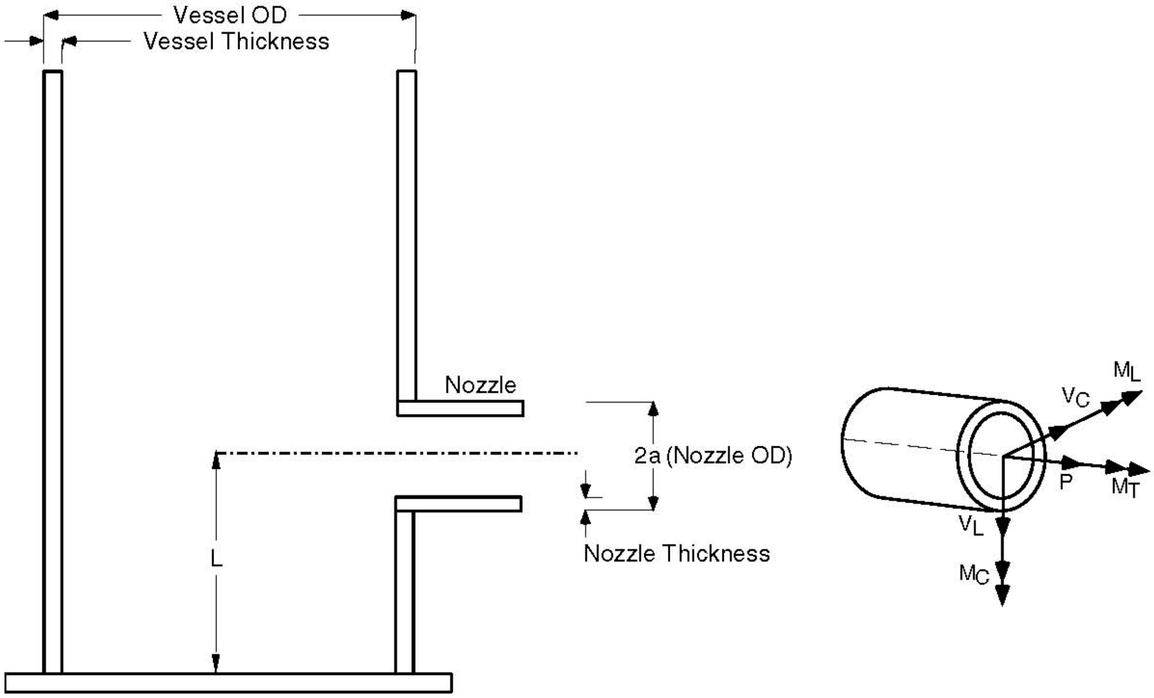
Longitudinal Stiffness(K_{zz})

$$K_{zz} = \gamma \times ET^3 \tag{3}$$

where
γ = stiffness coefficient read from Figure D-2.
The top two curves in Figure D-2, marked Longitudinal moment $M_L$are used to findγ.

Calculation of Nozzle stiffnesses for Nozzles on Flat-bottom tanks

This procedure is similar to the previous one.



As before, only three stiffnesses are calculated as the other three are assumed to be rigid. The ones that are calculated are axial(K_x), circumferential(K_{yy}), and longitudinal (K_{zz}).

For Nozzles on flat-bottom tanks, twelve graphs are given at the end of this annexure, Figures D-3 through D-14. Six are for "with reinforcing pad (on vessel)" with the other six for no reinforcing pad on the vessel. The stiffness coefficients are obtained using the appropriate graph.

Nomenclature

R = Mean radius of vessel
t = thickness of vessel
$2a$ = outside diameter of nozzle

Axial Stiffness($\boldsymbol{K_x}$)

$$K_x = K_R \times E \times (2a) \tag{4}$$

where
K_R = axial stiffness coefficient.

Circumferential Stiffness($\boldsymbol{K_{yy}}$)

$$K_{yy} = K_C \times E \times (2a)^3 \tag{5}$$

where
K_C = circumferential stiffness coefficient.

Longitudinal Stiffness($\boldsymbol{K_{zz}}$)

$$K_{zz} = K_L \times E \times (2a)^3 \tag{6}$$

where
K_L =longitudinal stiffness coefficient.

The graphs for stiffness coefficients follow:

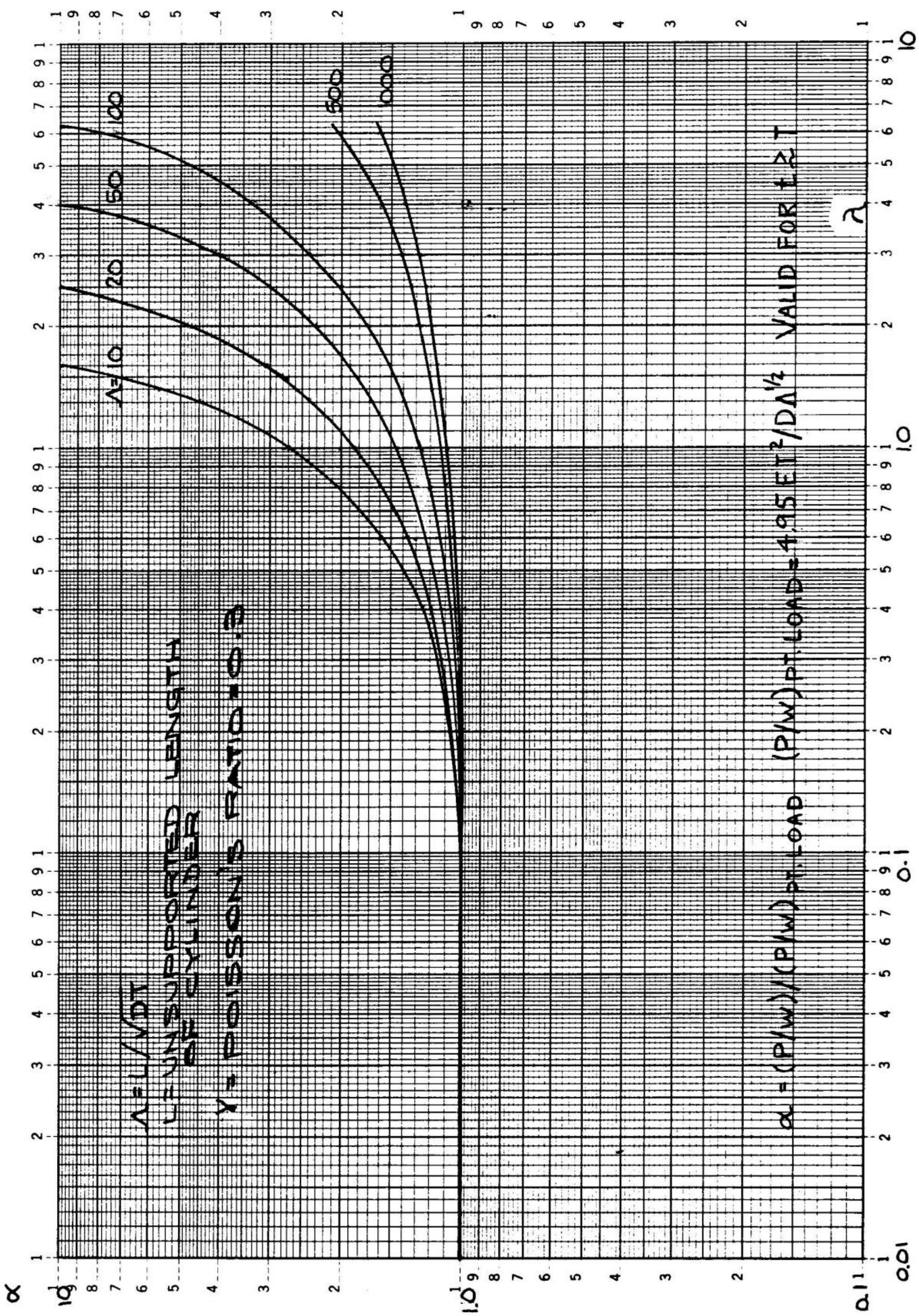


Figure D-1: Stiffness coefficient for axial load on nozzle

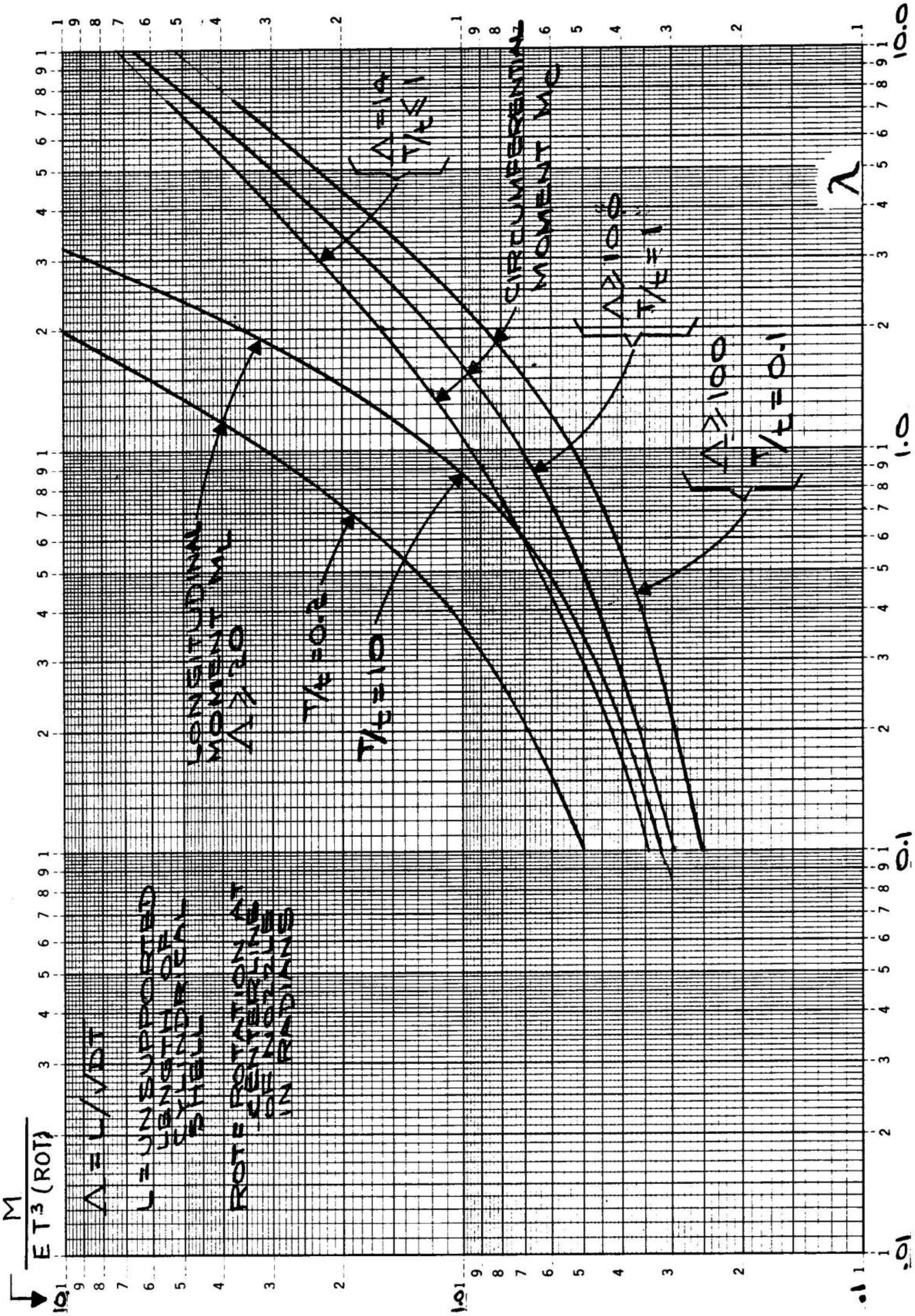


Figure D-2: Stiffness coefficients for moment loads on nozzle

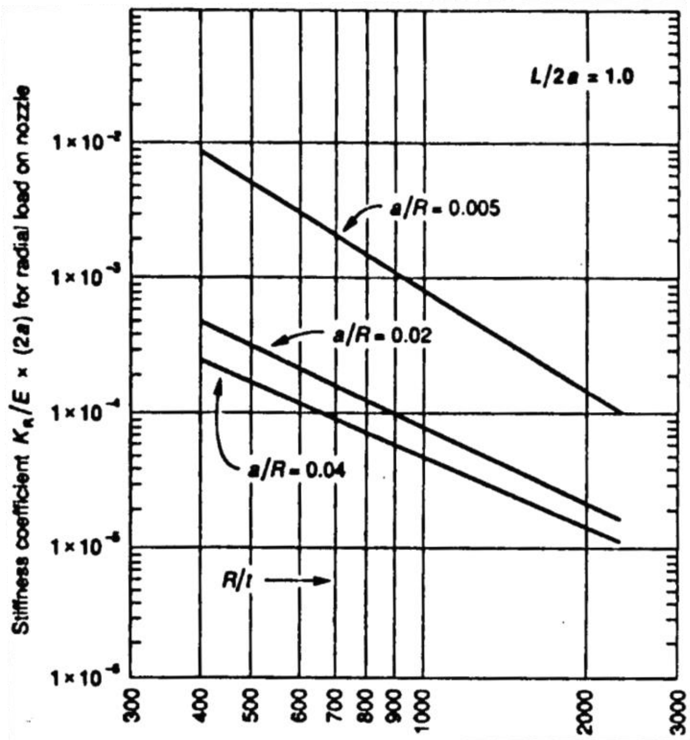


Figure D-3: Stiffness coefficient for axial load (with reinforcing pad)(L/2a = 1.0)

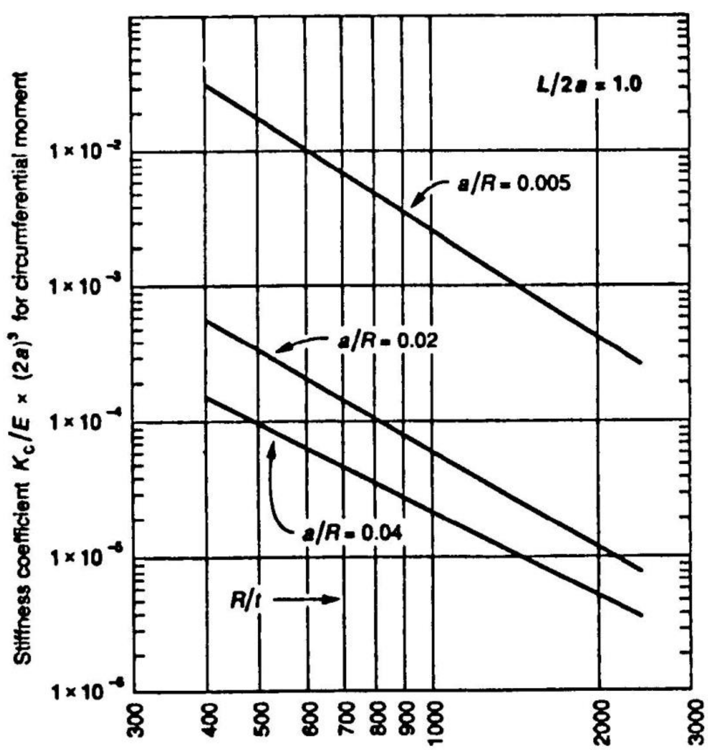


Figure D-4: Stiffness coefficient for circumferential moment (with reinforcing pad)(L/2a=1.0)

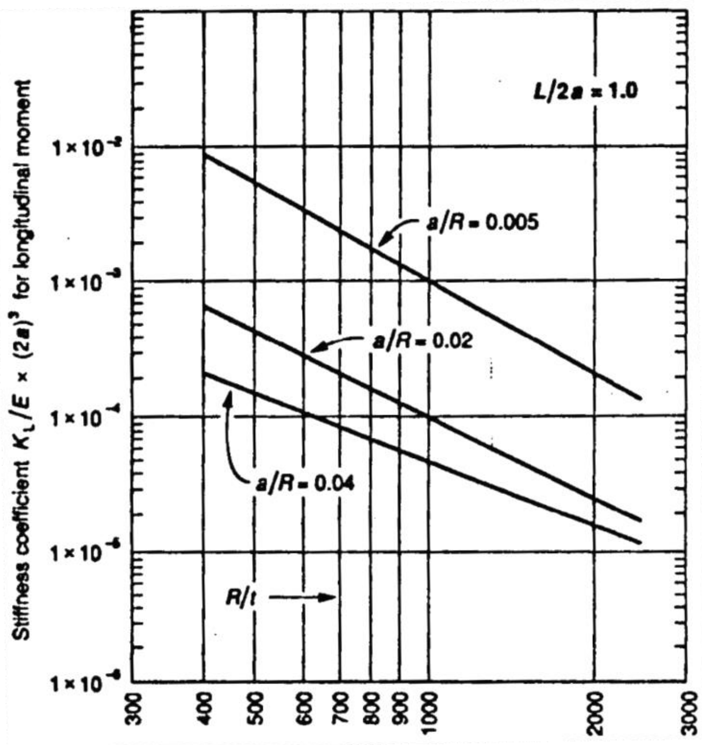


Figure D-5: Stiffness coefficient for longitudinal moment (with reinforcing pad)(L/2a = 1.0)

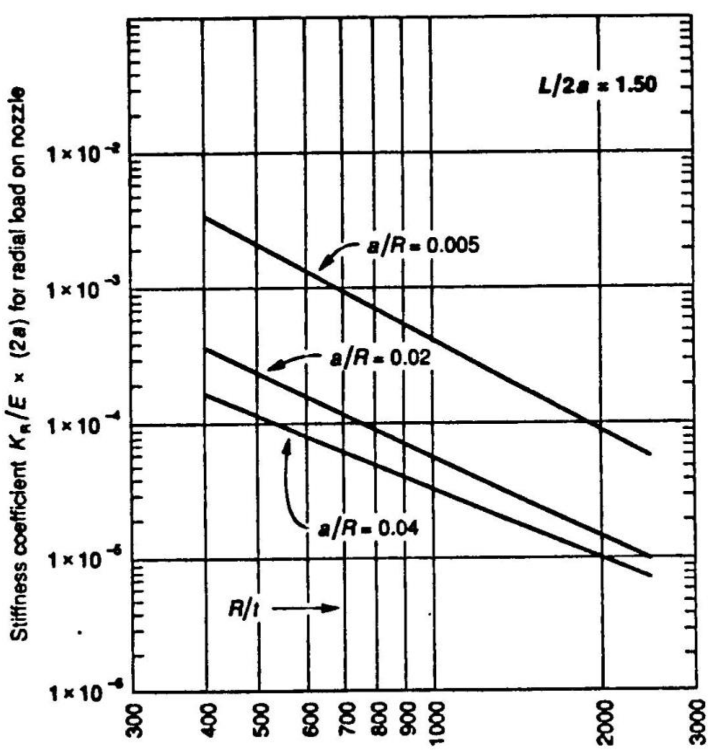


Figure D-6: Stiffness coefficient for axial load (with reinforcing pad)(L/2a = 1.5)

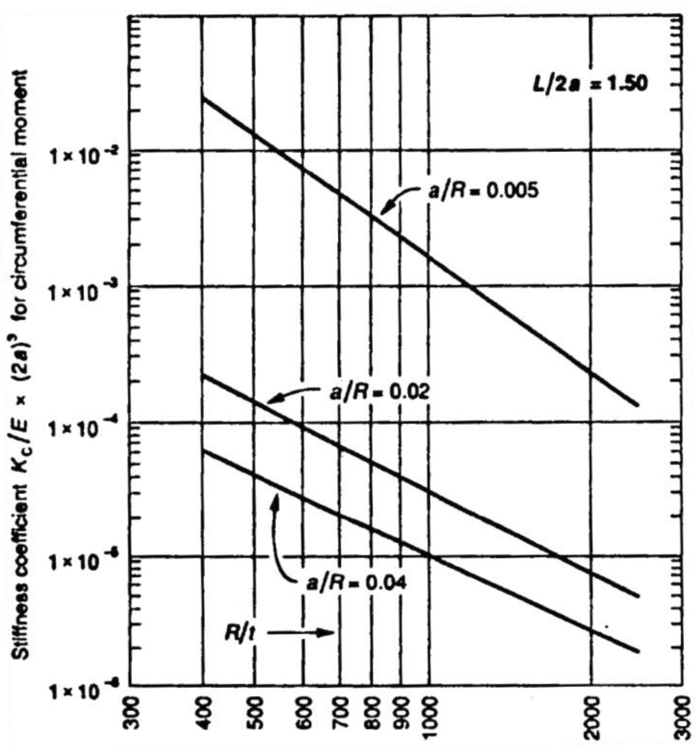


Figure D-7: Stiffness coefficient for circumferential moment (with reinforcing pad) (L/2a = 1.5)

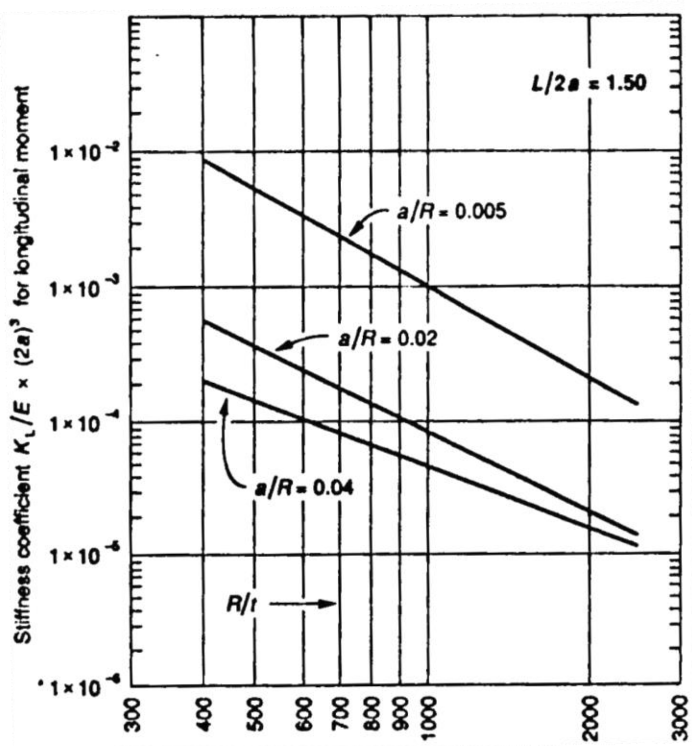


Figure D-8: Stiffness coefficient for longitudinal moment (with reinforcing pad)(L/2a=1.5)

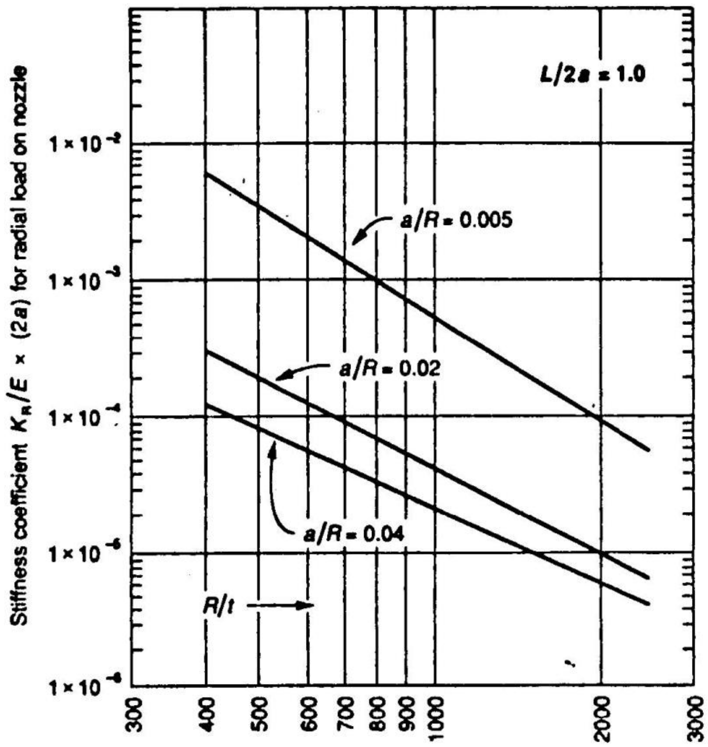


Figure D-9: Stiffness coefficient for axial load (no reinforcing pad)(L/2a = 1.0)

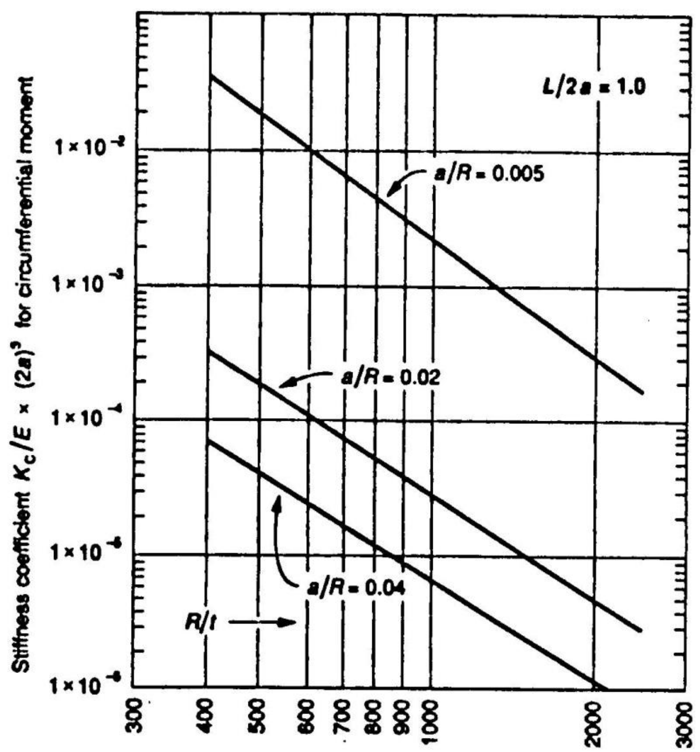


Figure D-10: Stiffness coefficient for circumferential moment (no reinforcing pad)(L/2a= 1.0)

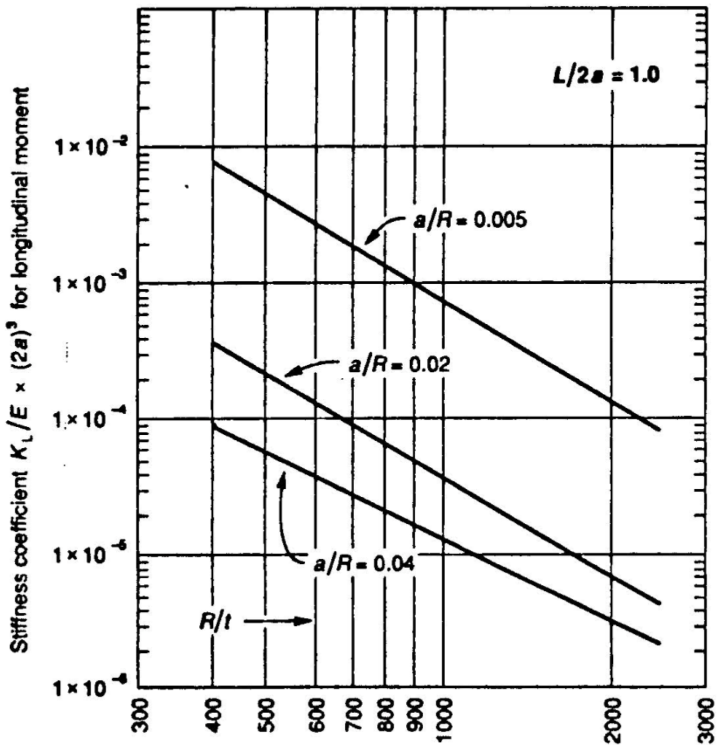


Figure D-11: Stiffness coefficient for longitudinal moment (no reinforcing pad)(L/2a = 1.0)

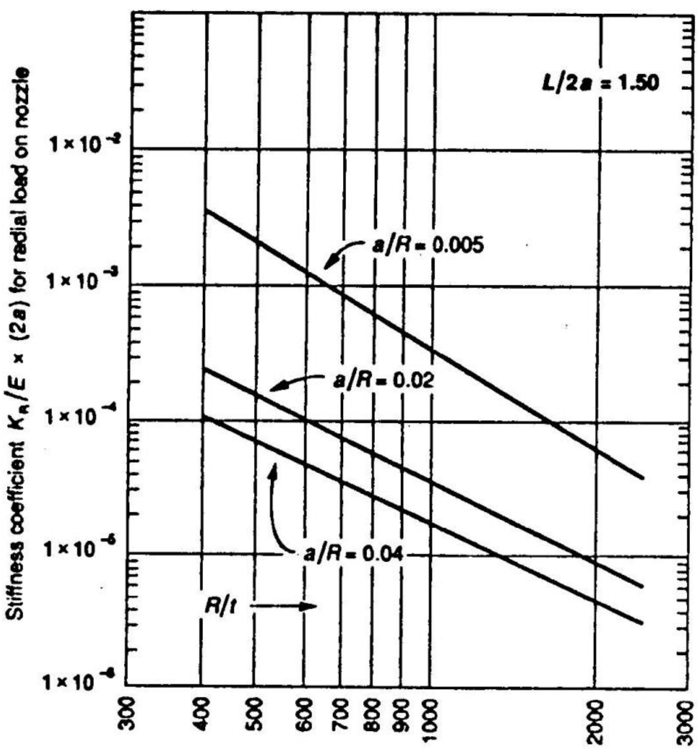


Figure D-12: Stiffness coefficient for axial load (no reinforcing pad)(L/2a = 1.5)

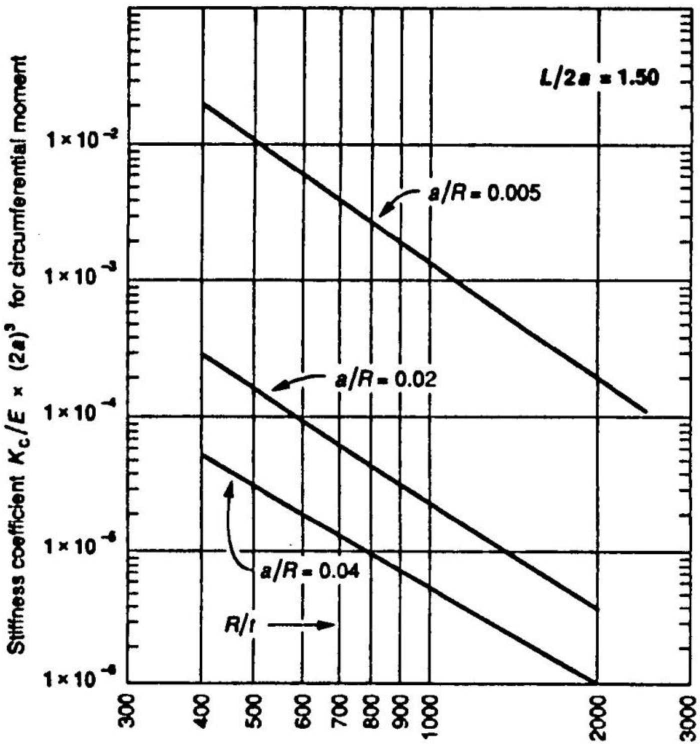


Figure D-13: Stiffness coefficient for circumferential moment (no reinforcing pad) (L/2a = 1.5)

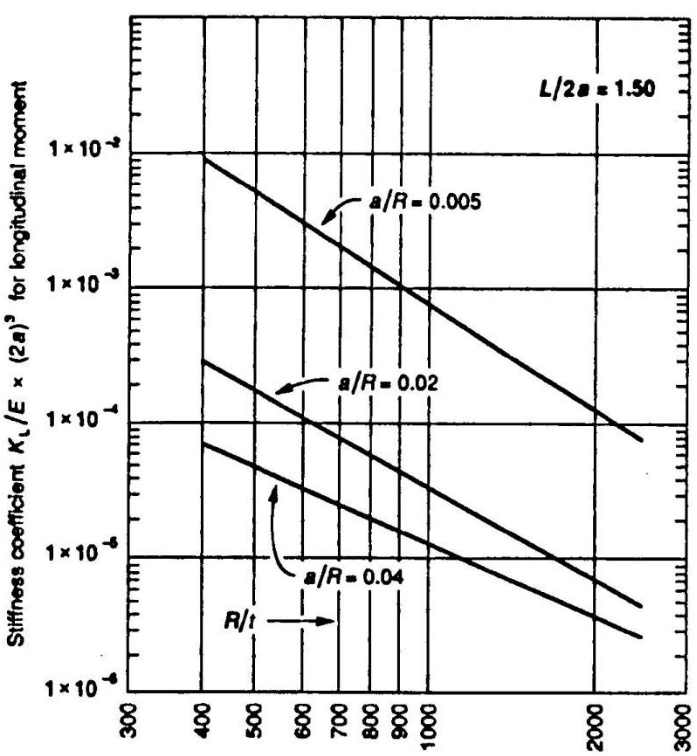


Figure D-14: Stiffness coefficient for longitudinal moment (no reinforcing pad)(L/2a=1.5

Calculation of Nozzle stiffnesses on Spherical Vessels

As before, only three stiffnesses are calculated as the other three are assumed to be rigid. The ones that are calculated are axial(K_x), circumferential(K_{yy}), and longitudinal (K_{zz}).

For Nozzles on Spherical Vessels, Figures G.2.4.3 and G.2.4.9 from PD 5500 (2009) have been referred as given below.

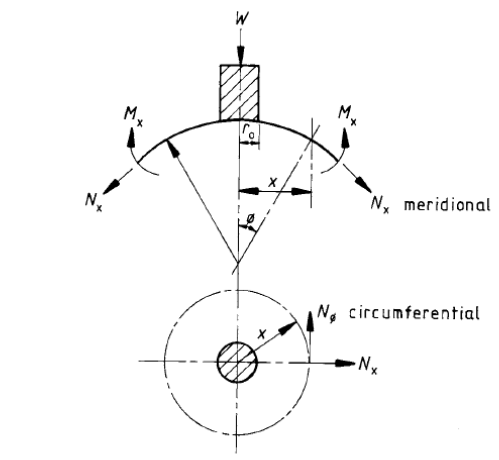


Figure G.2.4-2 — Spherical shell subjected to a radial load

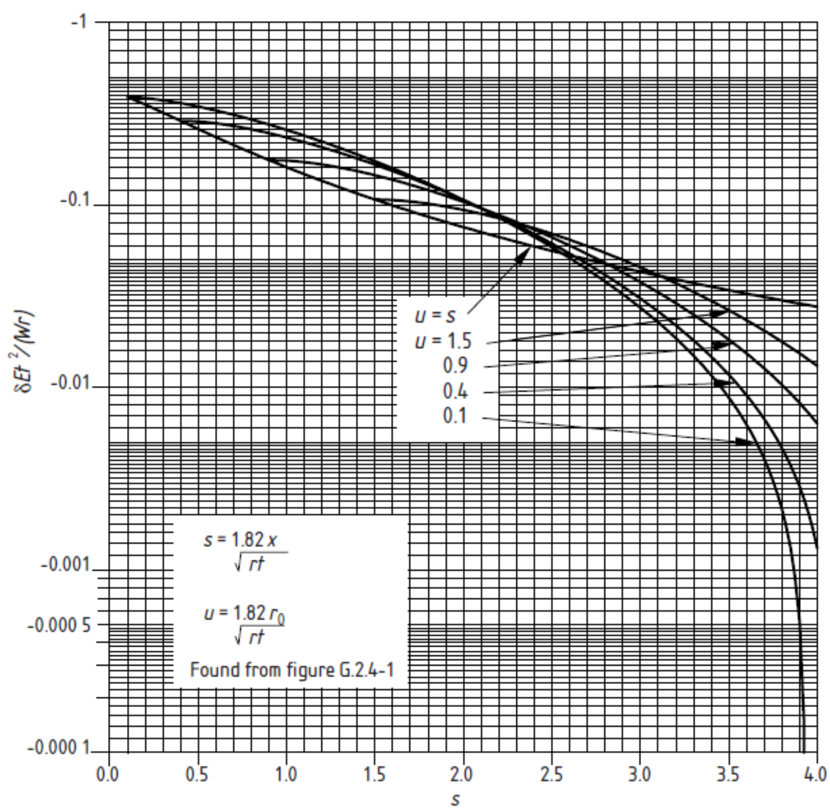


Figure G.2.4-3 — Deflections of a spherical shell subjected to a radial load *W*

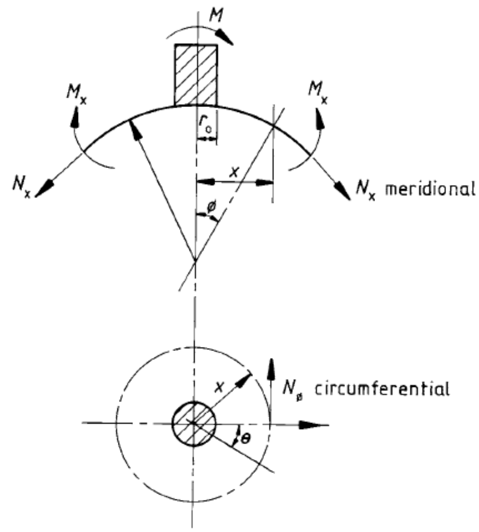


Figure G.2.4-8 — Spherical shell subjected to an external moment

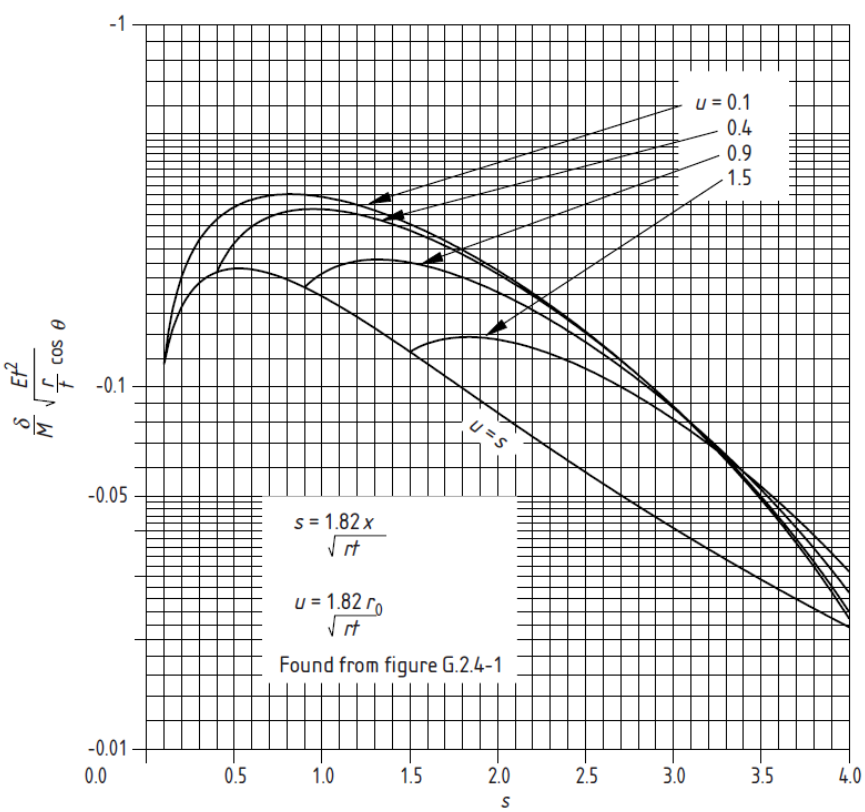


Figure G.2.4-9 — Deflections of a spherical shell subjected to an external moment M

Nozzle Evaluation

Local Loads on nozzles in spherical shells

Conditions of applicability

$a)$ $0.001 \leq e_a/R \leq 0.1$

b) distances to any other local load in any direction shall be not less than $\sqrt{R.e_c}$

c) nozzle thickness shall be maintained over a distance of $L \geq \sqrt{d.e_b}$

where,

e = nominal shell thickness

e_a = analysis shell thickness = e – corrosion allowance

e_b = nozzle thickness

e_c = analysis thickness of the combined shell and reinforcing plate

= $e_a + e_2 . \min(f_2/f;1)$ when a reinforcing plate is fitted

= e_a when no reinforcing plate is fitted

R = mean shell radius at the nozzle

e_2 = reinforcing pad thickness

f_2 = allowable design stress of reinforcing pad plate

f = allowable design stress of shell material

Maximum allowable individual loads

Allowable axial nozzle load

Allowable axial nozzle load $F_{z.max}$ is computed using Eq. (16.4-7)

$$F_{z.max} = f.e_c^2\left(1.82 + 2.4\sqrt{1+k}.\lambda_s + 0.91.k.\lambda_s^2\right)$$

where

$$k = \min\left(\frac{2f_b e_b}{f e_c}\sqrt{\frac{e_b}{d}}; 1.0\right)$$

$$\lambda_s = \frac{d}{\sqrt{Re_c}}$$

d = mean nozzle diameter

f_b = allowable design stress of nozzle material

Allowable bending moment

Allowable bending moment $M_{B.max}$ is computed using Eq. (16.4-8)

$$M_{B.max} = f.e_c^2\frac{d}{4}\left(4.90 + 2.0\sqrt{1+k}.\lambda_s + 0.91.k.\lambda_s^2\right)$$

Local Loads on nozzles in cylindrical shells

Conditions of applicability

$a)\ 0.001 \leq e_a/D \leq 0.1$

b) $\lambda_C = \frac{d}{\sqrt{De_c}}$

b) distances to any other local load in any direction shall be not less than $\sqrt{D.e_c}$

c) nozzle thickness shall be maintained over a distance of $L \geq \sqrt{d.e_b}$

where,

e = nominal shell thickness

e_a = analysis shell thickness = e – corrosion allowance

e_b = nozzle thickness

e_c = analysis thickness of the combined shell and reinforcing plate

= $e_a + e_2$. min(f_2/f;1) when a reinforcing plate is fitted

= e_a when no reinforcing plate is fitted

D = mean shell diameter at the opening

e_2 = reinforcing pad thickness

f_2 = allowable design stress of reinforcing pad plate

f = allowable design stress of shell material

Maximum allowable individual loads

Allowable axial nozzle load

Allowable axial nozzle load $F_{z.max}$ is computed using Eq. (16.5-3)

$$F_{z.max} = f.e_c^2.C_1$$

where

$C_1 = max[(a_o + a_1.\lambda_C + a_2.\lambda_C^2 + a_3.\lambda_C^3 + a_4.\lambda_C^4); 1.81]$ as per Eq. (16.5-4)

Table 16.5-1 — Coefficients for C_1

e_b/e_c	a_0	a_1	a_2	a_3	a_4
All	0,60072181	0,95196257	0,0051957881	-0,001406381	0

$$\lambda_C = \frac{d}{\sqrt{De_c}}$$

Allowable circumferential moment

Allowable bending moment $M_{X.max}$ is computed using Eq. (16.5-5)

$$M_{X.max} = f.e_c^2 \frac{d}{4} C_2$$

where,

$C_2 = max[(a_o + a_1.\lambda_C + a_2.\lambda_C^2 + a_3.\lambda_C^3 + a_4.\lambda_C^4); 4.90]$ as per Eq. (16.5-6)

Table 16.5-2 — Coefficients for C_2

e_b / e_c	a_0	a_1	a_2	a_3	a_4
All	4,526315	0,064021889	0,15887638	-0,021419298	0,0010350407

Allowable longitudinal moment

Allowable longitudinal moment $M_{Y.max}$ is computed using Eq. (16.5-7)

$$M_{Y.max} = f.e_c^2 \frac{d}{4} C_3$$

where,

$C_3 = max[(a_o + a_1.\lambda_C + a_2.\lambda_C^2 + a_3.\lambda_C^3 + a_4.\lambda_C^4); 4.90]$ as per Eq. (16.5-8)

Table 16.5-3 — Coefficients for C_3

e_b / e_c	a_0	a_1	a_2	a_3	a_4
≤ 0,2	4,8517511	0,0251012	0,7428624	- 0,0153153	0
≥ 0,5	4,8588639	2,1870887	1,4567053	- 0,3316430	0,0253850

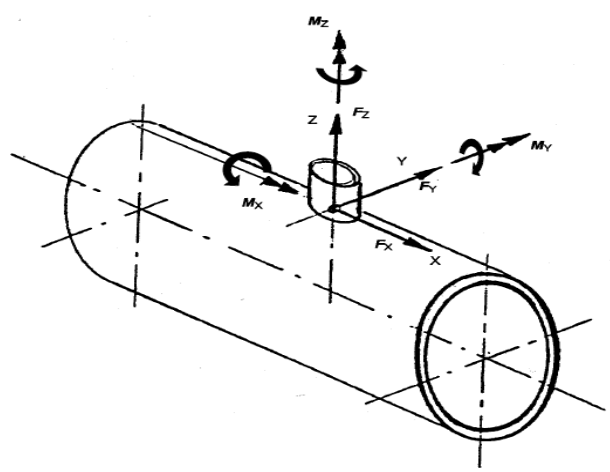


Figure 16.5-1 — Moment and Force Vectors

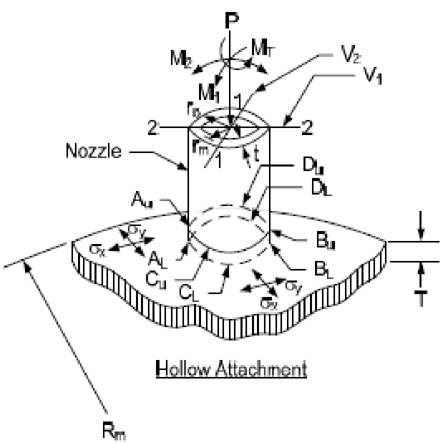
General

CAEPIPE computes Local Shell Stresses at Nozzles as per WRC Bulletin 537 (2013) and performs Stress Compliance as per ASME Section VIII Division 2 (2017).

As stated in ASME Section VIII Division 2 (2017) code, shell stresses computed for primary loads of Sustained and Sustained + Occasional should exclude the Radial and Tangential Bending Stresses. On the other hand, for Operating load which includes secondary loads due to temperature change and thermal anchor movements, Radial and Tangential Bending Stresses should be included for compliance as per ASME Section VIII Division 2 (2017). Refer to the extract from ASME Section VIII Division 2 (2017) provided at the end of this section for details on the implementation of Stress Compliance in CAEPIPE.

Local Stresses in Spherical Shells at Hollow Circular Attachments

As per Section 3.5.1 of WRC Bulletin 537, the below procedure provides one with a tool to compute stresses in the shell, but not in the nozzle. In some instances, stresses will be higher in the nozzle wall than they are in the vessel wall. This possibility is most likely if the nozzle opening is not reinforced, or if the reinforcement is placed on the vessel wall and not on the nozzle.



V_1	concentrated external shear load in 2-2 direction
V_2	concentrated external shear load in 1-1 direction
M_1	external overturning moment in 1-1 direction
M_2	external overturning moment in 2-2 direction
R_m	mean radius of spherical shell
T	thickness of spherical shell
r_0	outside radius of cylindrical attachment
r_m	mean radius of hollow cylindrical attachment
t	thickness of hollow cylindrical attachment
Υ	r_m / t
ρ	T / t
U	$r_0 / \sqrt{R_m T}$
N_x	membrane force in shell wall in the radial direction, respectively (see Figure 1)
N_y	membrane force in shell wall in the circumferential direction (see Figure 1)
M_x	bending moment in shell wall in the radial direction (see Figure 1)
M_y	bending moment in shell wall in the circumferential direction (see Figure 1)
σ_x	normal stress in radial direction (see Figure 1)
σ_y	normal stress in circumferential direction (see Figure 1)
τ_{xy}	shear stress on the x-face in the y-direction
τ_{yx}	shear stress on the y-face in the x-direction
τ_1	shear stress on the 1-1 face
τ_2	shear stress on the 2-2 face

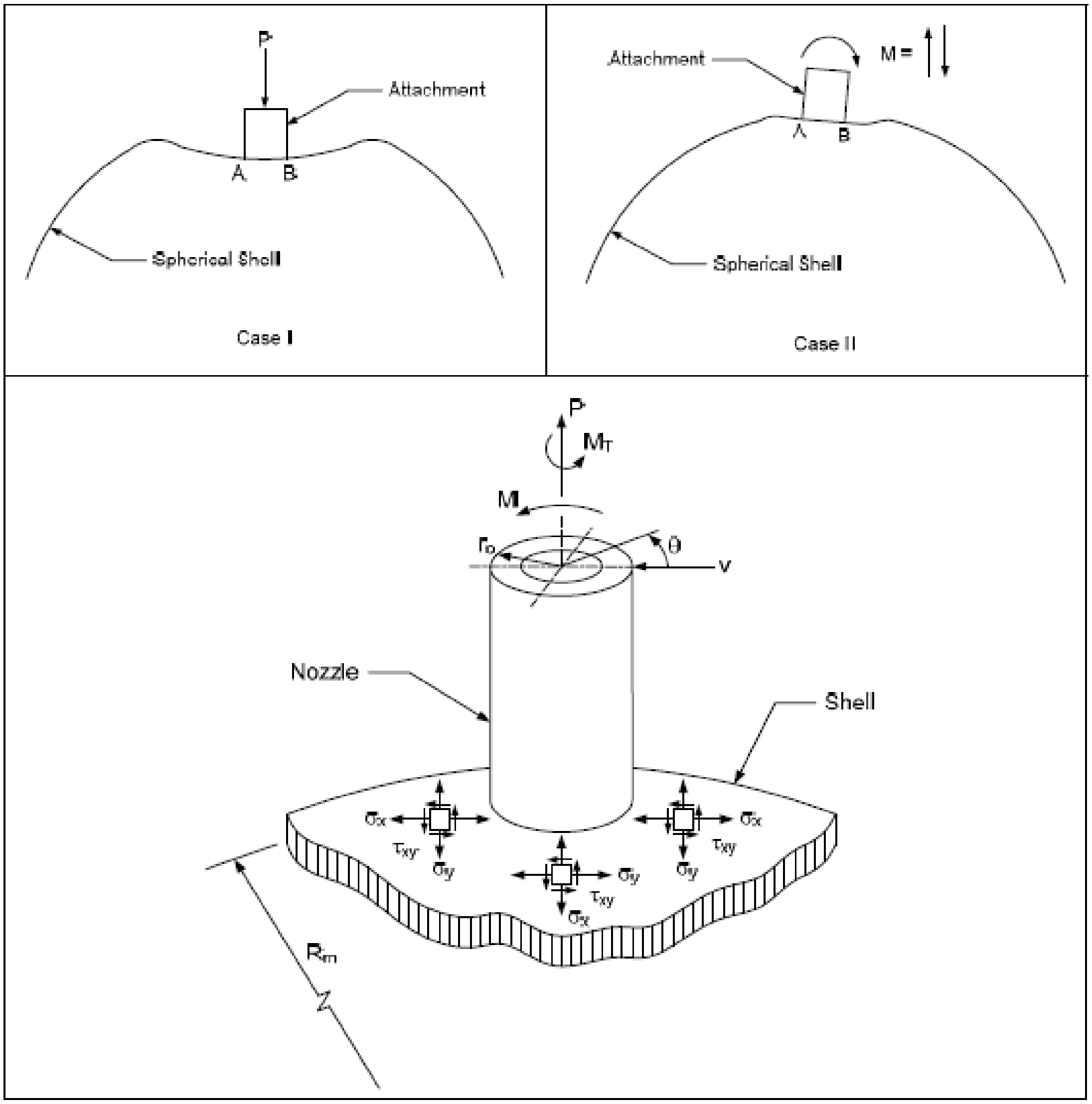


Figure 1 – Types of Loading Conditions at an Attachment to a Spherical Shell

Reference Figure No.	Read Curves for	Calculate absolute values of stress and enter result	STRESSES - If load is opposite that shown, reverse signs shown							
			A_u	A_L	B_u	B_L	C_u	C_L	D_u	D_L
SP-1 to 10	$\frac{N_x T}{P} =$	$K_n\left(\frac{N_x T}{P}\right)\left(\frac{P}{T^2}\right) =$	−	−	−	−	−	−	−	−
SP-1 to 10	$\frac{M_x}{P} =$	$K_b\left(\frac{M_x}{P}\right)\left(\frac{6P}{T^2}\right) =$	−	+	−	+	−	+	−	+
SM-1 to 10	$\frac{N_x T\sqrt{R_m T}}{M_1} =$	$K_n\left(\frac{N_x T\sqrt{R_m T}}{M_1}\right)\left(\frac{M_1}{T^2\sqrt{R_m T}}\right) =$					−	−	+	+
SM-1 to 10	$\frac{M_x\sqrt{R_m T}}{M_1} =$	$K_b\left(\frac{M_x\sqrt{R_m T}}{M_1}\right)\left(\frac{6M_1}{T^2\sqrt{R_m T}}\right) =$					−	+	+	−
SM-1 to 10	$\frac{N_x T\sqrt{R_m T}}{M_2} =$	$K_n\left(\frac{N_x T\sqrt{R_m T}}{M_2}\right)\left(\frac{M_2}{T^2\sqrt{R_m T}}\right) =$	−	−	+	+				
SM-1 to 10	$\frac{M_x\sqrt{R_m T}}{M_2} =$	$K_b\left(\frac{M_x\sqrt{R_m T}}{M_2}\right)\left(\frac{6M_2}{T^2\sqrt{R_m T}}\right) =$	−	+	+	−				
Add algebraically for summation of radial stresses σ_x		$\sigma_x =$								
SP-1 to 10	$\frac{N_y T}{P} =$	$K_n\left(\frac{N_y T}{P}\right)\left(\frac{P}{T^2}\right) =$	−	−	−	−	−	−	−	−
SP-1 to 10	$\frac{M_y}{P} =$	$K_b\left(\frac{M_y}{P}\right)\left(\frac{6P}{T^2}\right) =$	−	+	−	+	−	+	−	+
SM-1 to 10	$\frac{N_y T\sqrt{R_m T}}{M_1} =$	$K_n\left(\frac{N_y T\sqrt{R_m T}}{M_1}\right)\left(\frac{M_1}{T^2\sqrt{R_m T}}\right) =$					−	−	+	+
SM-1 to 10	$\frac{M_y\sqrt{R_m T}}{M_1} =$	$K_b\left(\frac{M_y\sqrt{R_m T}}{M_1}\right)\left(\frac{6M_1}{T^2\sqrt{R_m T}}\right) =$					−	+	+	−
SM-1 to 10	$\frac{N_y T\sqrt{R_m T}}{M_2} =$	$K_n\left(\frac{N_y T\sqrt{R_m T}}{M_2}\right)\left(\frac{M_2}{T^2\sqrt{R_m T}}\right) =$	−	−	+	+				
SM-1 to 10	$\frac{M_y\sqrt{R_m T}}{M_2} =$	$K_b\left(\frac{M_y\sqrt{R_m T}}{M_2}\right)\left(\frac{6M_2}{T^2\sqrt{R_m T}}\right) =$	−	+		−				
Add algebraically for summation of tangential stresses σ_y		$\sigma_y =$								
Shear stress due to load V_1		$\tau_1 = \frac{V_1}{\pi r_o T} =$					−	−	+	+
Shear stress due to load V_2		$\tau_2 = \frac{V_2}{\pi r_o T} =$	+	+	−	−				
Shear stress due to Torsion, M_T		$\tau_2 = \tau_1 = \frac{M_T}{2\pi r_o^2 T} =$	+	+	+	+	+	+	+	+
Add algebraically for summation of shear stresses τ		$\tau =$								

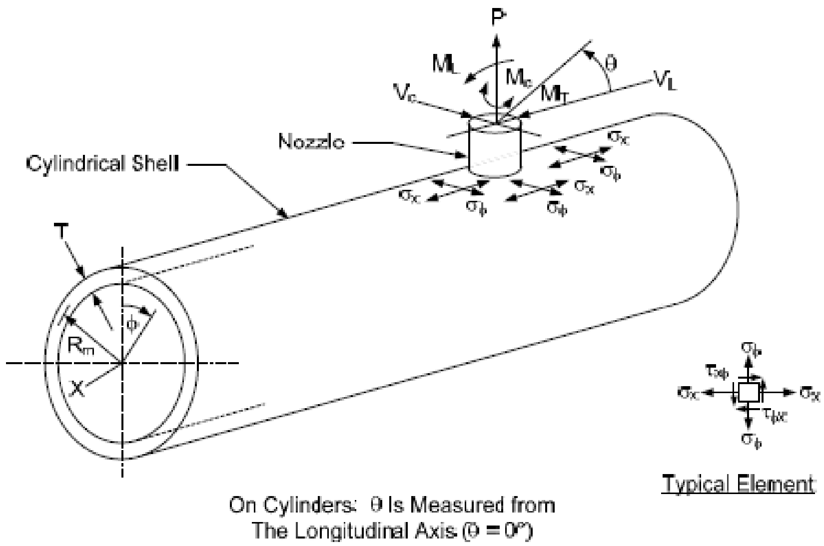
COMBINED STRESS INTENSITY - S

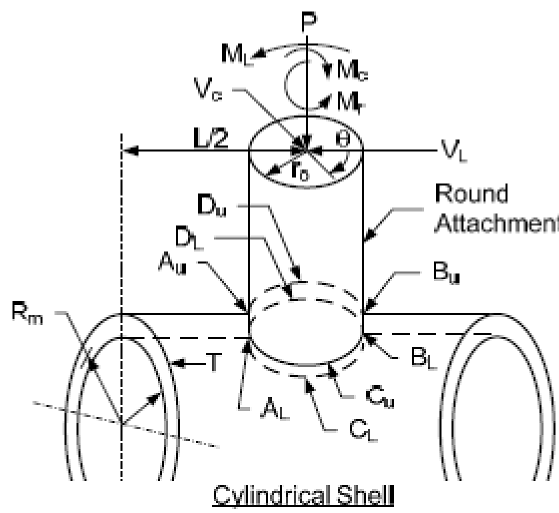
1) When $\tau \neq 0$, $S =$ largest absolute magnitude of either $S = \frac{1}{2}\left[\sigma_x + \sigma_y \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}\right]$ or $\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}$

2) When $\tau = 0$, $S =$ largest absolute magnitude of either $S = \sigma_x, \sigma_y, (\sigma_x - \sigma_y)$

Local Stresses in Cylindrical Shells at Solid Circular Attachments

As per Section 4.5.3 of WRC Bulletin 537, the below procedure provides one with a tool to compute stresses in the shell, but not in the attachment. Under certain conditions, stresses may be higher in the attachment than they are in the vessel. For example, in the case of a nozzle, it is likely that the stresses will be higher in the nozzle wall than they are in the vessel wall if the nozzle opening is unreinforced or if the reinforcement is placed on the vessel wall and not on the nozzle.





V_c	concentrated shear load in the circumferential direction, lb
V_L	concentrated shear load in the longitudinal direction
M_c	external overturning moment in the circumferential direction with respect to the shell
M_L	external overturning moment in the longitudinal direction with respect to the shell
R_m	mean radius of cylindrical shell
l	length of cylindrical shell
r_0	outside radius of cylindrical attachment
T	wall thickness of cylindrical shell
β	attachment parameter

Reference Figure No.	Read Curves for	Calculate absolute values of stress and enter result	STRESSES - If load is opposite that shown, reverse signs shown							
			A_u	A_L	B_u	B_L	C_u	C_L	D_u	D_L
3C	$\frac{N_\phi}{P/R_m} =$	$K_n\left(\frac{N_\phi}{P/R_m}\right)\left(\frac{P}{R_m T}\right) =$	−	−	−	−	−	−	−	−
1C OR 2C-1	$\frac{M_\phi}{P} =$	$K_b\left(\frac{M_\phi}{P}\right)\left(\frac{6P}{T^2}\right) =$ See Note 2 below	−	+	−	+	−	+	−	+
3A	$\frac{N_\phi}{M_c/R_m^2\beta} =$	$K_n\left(\frac{N_\phi}{M_c/R_m^2\beta}\right)\left(\frac{M_c}{R_m^2\beta T}\right) =$					−	−	+	+
1A	$\frac{M_\phi}{M_c/R_m\beta} =$	$K_b\left(\frac{M_\phi}{M_c/R_m\beta}\right)\left(\frac{6M_c}{R_m\beta T^2}\right) =$					−	+	+	−
3B	$\frac{N_\phi}{M_L/R_m^2\beta} =$	$K_n\left(\frac{N_\phi}{M_L/R_m^2\beta}\right)\left(\frac{M_L}{R_m^2\beta T}\right) =$	−	−	+	+				
1B or 1B-1	$\frac{M_\phi}{M_L/R_m\beta} =$	$K_b\left(\frac{M_\phi}{M_L/R_m\beta}\right)\left(\frac{6M_L}{R_m\beta T^2}\right) =$	−	+	+	−				
Add algebraically for summation of ϕ stresses σ_ϕ		$\sigma_\phi =$								
4C	$\frac{N_x}{P/R_m} =$	$K_n\left(\frac{N_x}{P/R_m}\right)\left(\frac{P}{R_m T}\right) =$	−	−	−	−	−	−	−	−
1C-1 OR 2C	$\frac{M_x}{P} =$	$K_b\left(\frac{M_x}{P}\right)\left(\frac{6P}{T^2}\right) =$	−	+	−	+	−	+	−	+
4A	$\frac{N_x}{M_c/R_m^2\beta} =$	$K_n\left(\frac{N_x}{M_c/R_m^2\beta}\right)\left(\frac{M_c}{R_m^2\beta T}\right) =$ See Note 3 below					−	−	+	+
2A	$\frac{M_x}{M_c/R_m\beta} =$	$K_b\left(\frac{M_x}{M_c/R_m\beta}\right)\left(\frac{6M_c}{R_m\beta T^2}\right) =$					−	+	+	−
4B	$\frac{N_x}{M_L/R_m^2\beta} =$	$K_n\left(\frac{N_x}{M_L/R_m^2\beta}\right)\left(\frac{M_L}{R_m^2\beta T}\right) =$	−	−	+	+				
2B or 2B-1	$\frac{M_x}{M_L/R_m\beta} =$	$K_b\left(\frac{M_x}{M_L/R_m\beta}\right)\left(\frac{6M_L}{R_m\beta T^2}\right) =$	−	+	+	−				
Add algebraically for summation of x stresses σ_x		$\sigma_x =$								
Shear stress due to Torsion, M_T		$\tau_{\phi x} = \tau_{x\phi} = \frac{M_T}{2\pi r_o^2 T} =$	+	+	+	+	+	+	+	+
Shear stress due to load V_C		$\tau_{x\phi} = \frac{V_C}{\pi r_o T} =$	+	+	−	−				
Shear stress due to load V_L		$\tau_{x\phi} = \frac{V_L}{\pi r_o T} =$					−	−	+	+
Add algebraically for summation of shear stresses τ		$\tau =$								

COMBINED STRESS INTENSITY - S

1) When σ_ϕ *and* σ_x have like signs $S = \frac{1}{2}\left[\sigma_\phi + \sigma_x \pm \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}\right]$ *or* $\sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}$

2) When $\tau = 0$, $S =$ largest absolute magnitude of either $S = \sigma_\phi, \sigma_x,$ *or* $|\sigma_\phi - \sigma_x|$

3) When σ_ϕ *and* σ_x have unlike signs, $S = \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}$

Note:

1. Original Curves are referred for all figures. For example, 3C-Original is referred to read the parameters required for calculating Circumferential Membrane Stress due to P.
2. Figure 2C-1 – Original is referred to calculate Circumferential Bending Stress due to P at Points A_U, A_L, B_U and B_L. Similarly, Figure 1C is referred to calculate Circumferential Bending Stress due to P at Points C_U, C_L, D_U and D_L.
3. Figure 1C-1 – Original is referred to calculate Longitudinal Bending Stress due to P at Points A_U, A_L, B_U and B_L. Similarly, Figure 2C is referred to calculate Longitudinal Bending Stress due to P at Points C_U, C_L, D_U and D_L.

Stress Compliance of Local Shell Stresses at Nozzles

[Extract from ASME Section VIII Division 2 (2017)]

5.2.2.4 Assessment Procedure. To determine the acceptability of a component, the computed equivalent stresses given in 5.2.2.2 for a component subject to loads shall not exceed the specified allowable values. A schematic illustrating the categorization of equivalent stresses and their corresponding allowable values is shown in Figure 5.1. The following procedure is used to compute and categorize the equivalent stress at a point in a component (see 5.2.2.3), and to determine the acceptability of the resulting stress state.

Step 1. Determine the types of loads acting on the component. In general, separate load cases are analyzed to evaluate "load-controlled" loads such as pressure and externally applied reactions due to weight effects and "strain-controlled" loads resulting from thermal gradients and imposed displacements. The loads to be considered in the design shall include, but not be limited to, those given in Table 5.1. The load combinations that shall be considered for each loading condition shall include, but not be limited to those given in Table 5.3.

Step 2. At the point on the vessel that is being investigated, calculate the stress tensor (six unique components of stress) for each type of load. Assign each of the computed stress tensors to one or to a group of the categories defined below. Assistance in assigning each stress tensor to an appropriate category for a component can be obtained by using Figure 5.1 and Table 5.6. Note that the equivalent stresses Q and F do not need to be determined to evaluate protection against plastic collapse. However, these components are needed for fatigue and ratcheting evaluations that are based on elastic stress analysis (see 5.5.3 and 5.5.6, respectively).

(a) General primary membrane equivalent stress – P_m

(b) Local primary membrane equivalent stress – P_L

(c) Primary bending equivalent stress – P_b

(d) Secondary equivalent stress – Q

(e) Additional equivalent stress produced by a stress concentration or a thermal stress over and above the nominal $(P + Q)$ stress level – F

Step 3. Sum the stress tensors (stresses are added on a component basis) assigned to each equivalent stress category. The final result is a stress tensor representing the effects of all the loads assigned to each equivalent stress category. Note that in applying STEPs in this paragraph, a detailed stress analysis performed using a numerical method such as finite element analysis typically provides a combination of $P_L + P_b$ and $P_L + P_b + Q + F$ directly.

(a) If a load case is analyzed that includes only "load-controlled" loads (e.g., pressure and weight effects), the computed equivalent stresses shall be used to directly represent the P_m, $P_L + P_b$, or $P_L + P_b + Q$. For example, for a vessel subject to internal pressure with an elliptical head; P_m equivalent stresses occur away from the head to shell junction, and P_L and $P_L + P_b + Q$ equivalent stresses occur at the junction.

(b) If a load case is analyzed that includes only "strain-controlled" loads (e.g., thermal gradients), the computed equivalent stresses represent Q alone; the combination $P_L + P_b + Q$ shall be derived from load cases developed from both "load-controlled" and "strain-controlled" loads.

(c) If the stress in category F is produced by a stress concentration or thermal stress, the quantity F is the additional stress produced by the stress concentration in excess of the nominal membrane plus bending stress. For example, if a plate has a nominal primary membrane equivalent stress of S_e, and has a fatigue strength reduction characterized by a factor K_f, then: $P_m = S_e$, $P_b = 0$, $Q = 0$, and $F = P_m(K_f - 1)$. The total equivalent stress is $P_m + F$.

Step 4. Determine the principal stresses of the sum of the stress tensors assigned to the equivalent stress categories, and compute the equivalent stress using Eq. (5.1).

Step 5. To evaluate protection against plastic collapse, compare the computed equivalent stress to their corresponding allowable values (see 5.2.2.2).

The allowable limit on local primary membrane and local primary membrane plus bending, S_{PL}, is computed as the larger of the quantities shown below.

(a) 1.5 times the tabulated allowable stress for the material from Annex 3-A

(b) S_y for the material from Annex 3-A, except that the value from (a) shall be used when the ratio of the minimum specified yield strength to ultimate tensile strength exceeds 0.70, or the value of S is governed by time-dependent properties as indicated in Annex 3-A

$$P_m \le S \tag{5.2}$$

$$P_L \le S_{PL} \tag{5.3}$$

$$(P_L + P_b) \le S_{PL} \tag{5.4}$$

5.5.6 RATCHETING ASSESSMENT — ELASTIC STRESS ANALYSIS

5.5.6.1 Elastic Ratcheting Analysis Method.

(a) To evaluate protection against ratcheting the following limit shall be satisfied.

$$\Delta S_{n,k} \le S_{PS} \tag{5.78}$$

(b) The primary plus secondary equivalent stress range, $\Delta S_{n,k}$, is the equivalent stress range, derived from the highest value across the thickness of a section, of the combination of linearized general or local primary membrane stresses plus primary bending stresses plus secondary stresses $(P_L + P_b + Q)$, produced by specified operating pressure and other specified mechanical loads and by general thermal effects. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. Examples of this stress category for typical pressure vessel components are shown in Table 5.6.

(c) The maximum range of this equivalent stress is limited to S_{PS}. The quantity S_{PS} represents a limit on the primary plus secondary equivalent stress range and is defined in (d). In the determination of the maximum primary plus secondary equivalent stress range, it may be necessary to consider the effects of multiple cycles where the total stress range may be greater than the stress range of any of the individual cycles. In this case, the value of S_{PS} may vary with the specified cycle, or combination of cycles, being considered since the temperature extremes may be different in each case. Therefore, care shall be exercised to assure that the applicable value of S_{PS} for each cycle, or combination of cycles, is used (see 5.5.3).

(d) The allowable limit on the primary plus secondary stress range, S_{PS}, is computed as the larger of the quantities shown below.

(1) Three times the average of the S values for the material from Annex 3-A at the highest and lowest temperatures during the operational cycle.

(2) Two times the average of the S_y values for the material from Annex 3-D at the highest and lowest temperatures during the operational cycle, except that the value from (1) shall be used when the ratio of the minimum specified yield strength to ultimate tensile strength exceeds 0.70 or the value of S is governed by time-dependent properties as indicated in Annex 3-A.

S_{PL} = allowable limit on the local primary membrane and local primary membrane plus bending stress categories (see 5.2.2.4.)

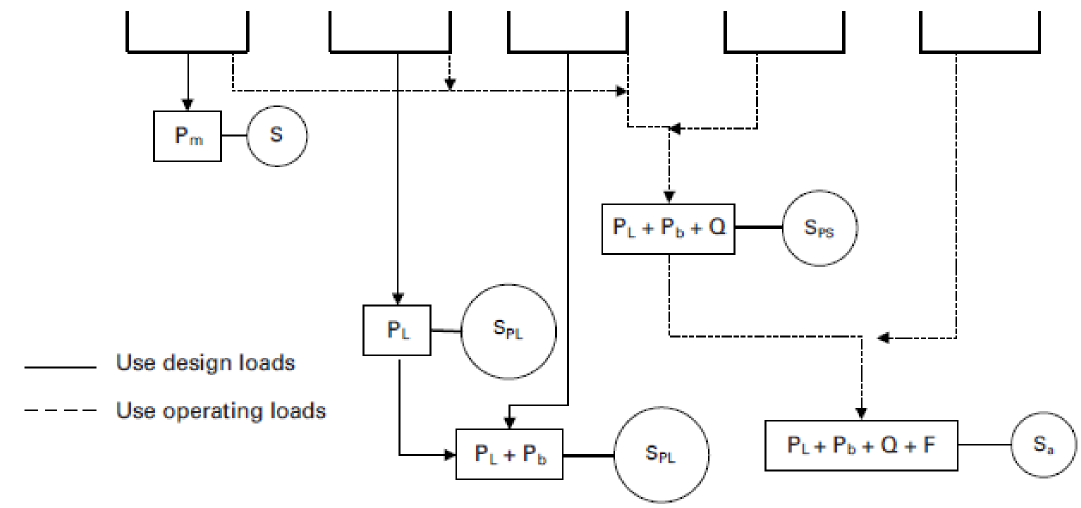
S_{PS} = allowable limit on the primary plus secondary stress range (see 5.5.6.)

Table 5.6
Examples of Stress Classification

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Any shell including cylinders, cones, spheres, and formed heads	Shell plate remote from discontinuities	Internal pressure	General membrane	P_m
			Gradient through plate thickness	Q
		Axial thermal gradient	Membrane	Q
			Bending	
	Near nozzle or other opening	Net-section axial force and/or bending moment applied to the nozzle, and/or internal pressure	Local membrane	P_L
			Bending	Q
			Peak (fillet or corner)	F
	Any location	Temperature difference between shell and head	Membrane	Q
			Bending	
	Shell distortions such as out-of-roundness and dents	Internal pressure	Membrane	P_m
			Bending	Q
Cylindrical or conical shell	Any section across entire vessel	Net-section axial force, bending moment applied to the cylinder or cone, and/or internal pressure	Membrane stress averaged through the thickness, remote from discontinuities; stress component perpendicular to cross section	P_m
			Bending stress through the thickness; stress component perpendicular to cross section	P_b
	Junction with head or flange	Internal pressure	Membrane	P_L
			Bending	Q

Figure 5.1
Stress Categories and Limits of Equivalent Stress

Stress Category	Primary			Secondary Membrane plus Bending	Peak
	General Membrane	Local Membrane	Bending		
Description (For examples, see Table 5.2)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.	1. Increment added to primary or secondary stress by a concentration (notch). 2. Certain thermal stresses which may cause fatigue but not distortion of vessel shape.
Symbol	P_m	P_L	P_b	Q	F



ASCE/SEI 7

Minimum Design Loads for Buildings

and

Other Structures

The Design Earthquake Load – ASCE/SEI 7-16

Chapter 13 titled "Seismic Design Requirements for Nonstructural Components" from ASCE/SEI 7-16 provides Seismic Design requirements for architectural, mechanical and electrical components including specific references to ASME boiler, pressure vessels and piping as detailed below.

Site Coefficients and Risk-Targeted Maximum Considered Earthquake (MCE) Spectral Response Acceleration Parameters

The MCE spectral response acceleration parameter for Site Class effects shall be determined by Eq. 11.4-1.

$$S_{MS} = F_a S_S$$

where,

F_a = Site Coefficient defined in Table 11.4-1.

S_S = the mapped MCE spectral response acceleration parameter at short periods as determined in accordance with Section 11.4.1. The value of Ss can be retrieved from the USGS website http://earthquake.usgs.gov/designmaps.

Table 11.4-1 Site Coefficient, F_a
Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short

SITE CLASS	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S = 1.25$	$S_S \ge 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	See Section 11.4.8		
F	See Section 11.4.8					

Note: Site specific analysis is required for Site Class E with Ss>= 1.0 and Site Class F,

Design Spectral Acceleration Parameters

Design earthquake spectral response acceleration parameter at short period, SDS shall be determined from Eq. 11.4-3.

$$S_{DS} = \left(\frac{2}{3}\right) S_{MS}$$

Seismic Design Force

The horizontal seismic design force (Fp) shall be applied at the component's center of gravity and distributed relative to the component's mass distribution and shall be determined in accordance with Eq. 13.3-1 of para. 13.3.1.

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2\frac{z}{h}\right)$$

F_p is not required to be taken as greater than

$$F_p = 1.6 S_{DS} I_p W_p$$

F_p shall not be taken as less than

$$F_p = 0.3 S_{DS} I_p W_p$$

where,

Fp = seismic design force

S_{DS} = spectral acceleration, short period, as determined above

S_{MS} = maximum MCE spectral acceleration at short periods

a_p = component amplification factor that varies from 1.00 to 2.50(see Table 13.6-1 below)

I_p = component importance factor that varies from 1.00 to 1.50 (see Section 13.1.3)

W_p = component operating weight

Rp = component response modification factor that varies from 1.00 to 12 (see Table 13.6-1 below)

z = height in structure of point of attachment of component with respect to the base. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0.

h = average roof height of structure with respect to the base

Note:

As per 13.1.8, the earthquake loads determined in accordance with Section 13.3.1 shall be multiplied by a factor 0.7. This can be performed in CAEPIPE by entering the value as 0.70 for "All. Stress Factor ADS(a)" through "ASCE/SEI 7-16" Seismic parameter input dialog.

Vertical Seismic Force

As per para. 13.3.1, Vertical Seismic Force shall be computed as

$$V_p = 0.2 S_{DS} W_p$$

where,

S_{DS} and W_p are as defined above.

Table 13.6-1 Seismic Coefficients for Mechanical and Electrical Components

Components	a_p[a]	R_p[b]	Ω_0[c]
MECHANICAL AND ELECTRICAL COMPONENTS			
Air-side HVACR, fans, air handlers, air conditioning units, cabinet heaters, air distribution boxes, and other mechanical components constructed of sheet metal framing	2½	6	2
Wet-side HVACR, boilers, furnaces, atmospheric tanks and bins, chillers, water heaters, heat exchangers, evaporators, air separators, manufacturing or process equipment, and other mechanical components constructed of high-deformability materials	1	2½	2
Air coolers (fin fans), air-cooled heat exchangers, condensing units, dry coolers, remote radiators and other mechanical components elevated on integral structural steel or sheet metal supports	2½	3	1½
Engines, turbines, pumps, compressors, and pressure vessels not supported on skirts and not within the scope of Chapter 15	1	2½	2
Skirt-supported pressure vessels not within the scope of Chapter 15	2½	2½	2
Elevator and escalator components	1	2½	2
Generators, batteries, inverters, motors, transformers, and other electrical components constructed of high-deformability materials	1	2½	2
Motor control centers, panel boards, switch gear, instrumentation cabinets, and other components constructed of sheet metal framing	2½	6	2
Communication equipment, computers, instrumentation, and controls	1	2½	2
Roof-mounted stacks, cooling and electrical towers laterally braced below their center of mass	2½	3	2
Roof-mounted stacks, cooling and electrical towers laterally braced above their center of mass	1	2½	2
Lighting fixtures	1	1½	2
Other mechanical or electrical components	1	1½	2
VIBRATION-ISOLATED COMPONENTS AND SYSTEMS[b]			
Components and systems isolated using neoprene elements and neoprene isolated floors with built-in or separate elastomeric snubbing devices or resilient perimeter stops	2½	2½	2
Spring-isolated components and systems and vibration-isolated floors closely restrained using built-in or separate elastomeric snubbing devices or resilient perimeter stops	2½	2	2
Internally isolated components and systems	2½	2	2
Suspended vibration-isolated equipment including in-line duct devices and suspended internally isolated components	2½	2½	2
DISTRIBUTION SYSTEMS			
Piping in accordance with ASME B31 (2001, 2002, 2008, and 2010), including in-line components with joints made by welding or brazing	2½	12	2
Piping in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings	2½	6	2
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing	2½	9	2
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings	2½	4½	2
Piping and tubing constructed of low-deformability materials, such as cast iron, glass, and nonductile plastics	2½	3	2
Ductwork, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing	2½	9	2
Ductwork, including in-line components, constructed of high- or limited-deformability materials with joints made by means other than welding or brazing	2½	6	2
Ductwork, including in-line components, constructed of low-deformability materials, such as cast iron, glass, and nonductile plastics	2½	3	2
Electrical conduit and cable trays	2½	6	2
Bus ducts	1	2½	2
Plumbing	1	2½	2
Pneumatic tube transport systems	2½	6	2

[a]A lower value for a_p is permitted where justified by detailed dynamic analyses. The value for a_p shall not be less than 1. The value of a_p equal to 1 is for rigid components and rigidly attached components. The value of a_p equal to 2½ is for flexible components and flexibly attached components.
[b]Components mounted on vibration isolators shall have a bumper restraint or snubber in each horizontal direction. The design force shall be taken as $2F_p$ if the nominal clearance (air gap) between the equipment support frame and restraint is greater than 0.25 in. (6 mm). If the nominal clearance specified on the construction documents is not greater than 0.25 in. (6 mm), the design force is permitted to be taken as F_p.
[c]Overstrength as required for anchorage to concrete and masonry. See Section 12.4.3 for seismic load effects including overstrength.

The Design Wind Load – ASCE/SEI 7-16

Chapter 26 titled "Wind Load: Generic Requirements" is used to determine basic parameters for determining wind loads and Chapter 29 titled "Wind Load on Other Structures and Building Appurtenances – MWFRS" of ASCE/SEI 7-16 provides a directional wind force determination procedure for building appurtenances and other structures. Details referred from these two (2) chapters for implementation in CAEPIPE are detailed below.

Type of Element Classification

Type of Element Classification = Other Structures

Figure 26.1-1 directs the ASCE 7 user to the appropriate method to determine wind forces for the particular building or structure the user is concerned with. The method most appropriate for industrial plant piping of any type is detailed in Chapter 29, "Wind Loads on Other Structures and Building Appurtenances – MWFRS".

Wind Load Parameters

The following wind load parameters shall be determined in accordance with Chapter 26.

Basic Wind Speed (V):

The basic wind speed, V, used in the determination of design wind loads on buildings and other structures shall be determined from Fig. 26.5-1 as follows.

Fig. 26-5-1A can be referred for Risk Category I buildings and other structures.

Fig. 26-5-1B can be referred for Risk Category II buildings and other structures

Fig. 26.5-1C can be referred for Risk Category III buildings and other structures.

Fig. 26.5-1D can be referred for Risk Category IV Buildings and Other Structures.

Wind Directionality Factor K_d:

The wind directionality factor, K_d, shall be determined from Table 26.6-1 as given below.

Exposure Categories:

As detailed in Section 26.7.3 of ASCE/SEI 7-16, Exposure Categories can be B, C or D.

Topographical Factor K_{zt}:

As detailed in Section 26.8.2, Wind speed-up effects shall be included in the calculation of design wind loads by using the factor Kzt.

Figure 26.8-1 (given below) can be referred to compute the Topographical Factor Kzt.

$$K_{zt} = (1 + K_1 K_2 K_3)^2$$

where K_1, K_2 and K_3 are given in Fig. 26.8-1.

If site conditions and locations of structures do not meet all the conditions specified in Section 26.8.1 then Kzt = 1.0

Velocity Pressure Exposure Coefficient K_z

Velocity pressure exposure coefficient Kz can be determined from Table 26.10.1 provided below.

Velocity Pressure

Velocity pressure, q_z, evaluated at height z shall be calculated by the following equation:

$$q_z = 0.00256 K_z K_{zt} K_d K_e V^2 \ (lb/ft^2)$$

where

K_d = wind directionality factor as defined above

K_{zt} = velocity pressure exposure coefficient as defined above

K_z = topographic factor as defined above

K_e = ground elevation factor to adjust air density permitted K_e = 1

V = basic wind speed as defined above

Design Wind Loads – Other Structures

The design wind force for other structures (chimneys, tanks, rooftop equipment for h > 60, and similar structures, open signs, lattice frameworks, and trussed towers) shall be determined by section 29.4, ASCE 7-16, with the following equation:

$$F = q_z C_f G A_f \ (lb)$$

where

q_z = velocity pressure evaluated at height z as defined above of the centroid of area A_f

G = gust-effect factor for a rigid building or other structure is permitted to be taken as 0.85

C_f = force coefficients from Fig. 29.4-1 given below

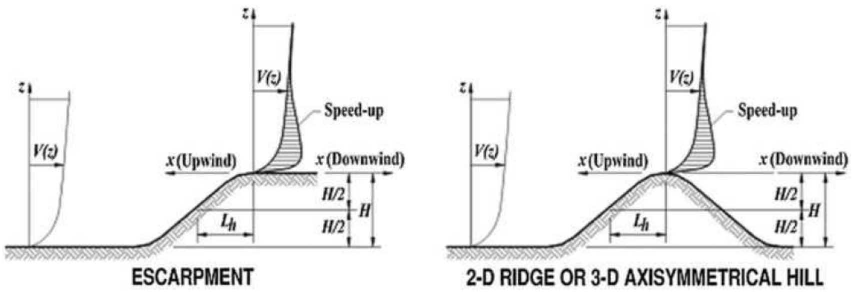
A_f = projected area normal to the wind except where C_f is specified for the actual surface area in ft^2

Table 26.6-1 Wind Directionality Factor, K_d

Structure Type	Directionality Factor K_d
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0[a]
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0[a]
Round	1.0[a]
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

[a]Directionality factor $K_d = 0.95$ shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

Diagrams



Topographic Multipliers for Exposure C[a,b,c]

H/L_h	K_1 Multiplier: 2D Ridge	K_1 Multiplier: 2D Escarpment	K_1 Multiplier: 3D Axisym-metrical Hill	x/L_h	K_2 Multiplier: 2D Escarpment	K_2 Multiplier: All Other Cases	z/L_h	K_2 Multiplier: 2D Ridge	K_2 Multiplier: 2D Escarpment	K_2 Multiplier: 3D Axisym-metrical Hill
0.20	0.29	0.17	0.21	0.00	1.00	1.00	0.00	1.00	1.00	1.00
0.25	0.36	0.21	0.26	0.50	0.88	0.67	0.10	0.74	0.78	0.67
0.30	0.43	0.26	0.32	1.00	0.75	0.33	0.20	0.55	0.61	0.45
0.35	0.51	0.30	0.37	1.50	0.63	0.00	0.30	0.41	0.47	0.30
0.40	0.58	0.34	0.42	2.00	0.50	0.00	0.40	0.30	0.37	0.20
0.45	0.65	0.38	0.47	2.50	0.38	0.00	0.50	0.22	0.29	0.14
0.50	0.72	0.43	0.53	3.00	0.25	0.00	0.60	0.17	0.22	0.09
				3.50	0.13	0.00	0.70	0.12	0.17	0.06
				4.00	0.00	0.00	0.80	0.09	0.14	0.04
							0.90	0.07	0.11	0.03
							1.00	0.05	0.08	0.02
							0.50	0.01	0.02	0.00
							2.00	0.00	0.00	0.00

[a]For values of H/L_h, x/L_h, and z/L_h other than those shown, linear interpolation is permitted.
[b]For $H/L_h > 0.5$, assume that $H/L_h = 0.5$ for evaluating K_1 and substitute $2H$ for L_h for evaluating K_2 and K_3.
[c]Multipliers are based on the assumption that wind approaches the hill or escarpment along the direction of maximum slope.

Notation

H = Height of hill or escarpment relative to the upwind terrain, in ft (m).
K_1 = Factor to account for shape of topographic feature and maximum speed-up effect.
K_2 = Factor to account for reduction in speed-up with distance upwind or downwind of crest.
K_3 = Factor to account for reduction in speed-up with height above local terrain.
L_h = Distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment, in ft (m).
x = Distance (upwind or downwind) from the crest to the site of the building or other structure, in ft (m).
z = Height above ground surface at the site of the building or other structure, in ft (m).
μ = Horizontal attenuation factor.
γ = Height attenuation factor.

Equations

$$K_{zt} = (1 + K_1 K_2 K_3)^2$$

K_1 = determined from table below

$$K_2 = (1 - |x|/\mu L_h)$$

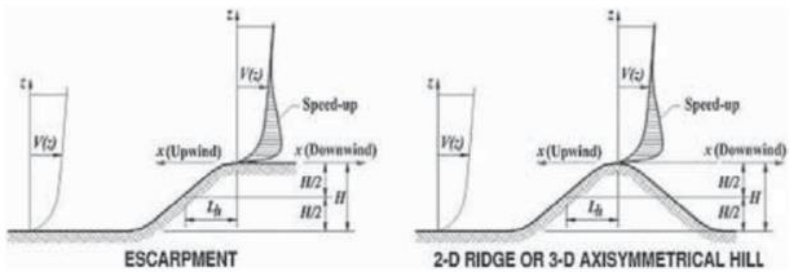
$$K_3 = e^{-\gamma z/L_h}$$

Parameters for Speed-Up over Hills and Escarpments

Hill Shape	$K_1/(H/L_h)$ Exposure B	$K_1/(H/L_h)$ Exposure C	$K_1/(H/L_h)$ Exposure D	γ	μ Upwind of Crest	μ Downwind of Crest
2D ridges (or valleys with negative H in $K_1/(H/L_h)$	1.30	1.45	1.55	3	1.5	1.5
2D escarpments	0.75	0.85	0.95	2.5	1.5	4
3D axisymmetrical hill	0.95	1.05	1.15	4	1.5	1.5

FIGURE 26.8-1 Topographic Factor, K_{zt}

Diagrams



Topographic Multipliers for Exposure C[a,b,c]

	K_1 Multiplier				K_2 Multiplier			K_3 Multiplier		
H/L_h	2D Ridge	2D Escarpment	3D Axisym-metrical Hill	x/L_h	2D Escarpment	All Other Cases	z/L_h	2D Ridge	2D Escarpment	3D Axisym-metrical Hill
0.20	0.29	0.17	0.21	0.00	1.00	1.00	0.00	1.00	1.00	1.00
0.25	0.36	0.21	0.26	0.50	0.88	0.67	0.10	0.74	0.78	0.67
0.30	0.43	0.26	0.32	1.00	0.75	0.33	0.20	0.55	0.61	0.45
0.35	0.51	0.30	0.37	1.50	0.63	0.00	0.30	0.41	0.47	0.30
0.40	0.58	0.34	0.42	2.00	0.50	0.00	0.40	0.30	0.37	0.20
0.45	0.65	0.38	0.47	2.50	0.38	0.00	0.50	0.22	0.29	0.14
0.50	0.72	0.43	0.53	3.00	0.25	0.00	0.60	0.17	0.22	0.09
				3.50	0.13	0.00	0.70	0.12	0.17	0.06
				4.00	0.00	0.00	0.80	0.09	0.14	0.04
							0.90	0.07	0.11	0.03
							1.00	0.05	0.08	0.02
							0.50	0.01	0.02	0.00
							2.00	0.00	0.00	0.00

[a]For values of H/L_h, x/L_h, and z/L_h other than those shown, linear interpolation is permitted.
[b]For $H/L_h > 0.5$, assume that $H/L_h = 0.5$ for evaluating K_1 and substitute $2H$ for L_h for evaluating K_2 and K_3.
[c]Multipliers are based on the assumption that wind approaches the hill or escarpment along the direction of maximum slope.

Notation

H = Height of hill or escarpment relative to the upwind terrain, in ft (m).
K_1 = Factor to account for shape of topographic feature and maximum speed-up effect.
K_2 = Factor to account for reduction in speed-up with distance upwind or downwind of crest.
K_3 = Factor to account for reduction in speed-up with height above local terrain.
L_h = Distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment, in ft (m).
x = Distance (upwind or downwind) from the crest to the site of the building or other structure, in ft (m).
z = Height above ground surface at the site of the building or other structure, in ft (m).
μ = Horizontal attenuation factor.
γ = Height attenuation factor.

Table 26.11-1 Terrain Exposure Constants

Customary Units										
Exposure	α	z_g (ft)	$\hat{\alpha}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (ft)	$\bar{\epsilon}$	z_{min} (ft)[a]
B	7.0	1,200	1/7.0	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7
S.I. Units										
Exposure	α	z_g (m)	$\hat{\alpha}$	$\hat{b}$	$\bar{\alpha}$	$\bar{b}$	c	ℓ (m)	$\bar{\epsilon}$	z_{min} (m)[a]
B	7.0	365.76	1/7	0.84	1/4.0	0.45	0.30	97.54	1/3.0	9.14
C	9.5	274.32	1/9.5	1.00	1/6.5	0.65	0.20	152.40	1/5.0	4.57
D	11.5	213.36	1/11.5	1.07	1/9.0	0.80	0.15	198.12	1/8.0	2.13

[a]z_{min} = minimum height used to ensure that the equivalent height $\bar{z}$ is the greater of $0.6h$ or z_{min}. For buildings or other structures with $h \le z_{min}$, $\bar{z}$ shall be taken as z_{min}.

Table 26.10-1 Velocity Pressure Exposure Coefficients, K_h and K_z

Height above Ground Level, z		Exposure		
ft	m	B	C	D
0–15	0–4.6	0.57 (0.70)[a]	0.85	1.03
20	6.1	0.62 (0.70)[a]	0.90	1.08
25	7.6	0.66 (0.70)[a]	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18.0	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38
90	27.4	0.96	1.24	1.40
100	30.5	0.99	1.26	1.43
120	36.6	1.04	1.31	1.48
140	42.7	1.09	1.36	1.52
160	48.8	1.13	1.39	1.55
180	54.9	1.17	1.43	1.58
200	61.0	1.20	1.46	1.61
250	76.2	1.28	1.53	1.68
300	91.4	1.35	1.59	1.73
350	106.7	1.41	1.64	1.78
400	121.9	1.47	1.69	1.82
450	137.2	1.52	1.73	1.86
500	152.4	1.56	1.77	1.89

[a]Use 0.70 in Chapter 28, Exposure B, when $z < 30$ ft (9.1 m).

Notes

1. The velocity pressure exposure coefficient K_z may be determined from the following formula:
   For 15 ft (4.6 m) $\leq z \leq z_g$ $\quad K_z = 2.01(z/z_g)^{2/\alpha}$
   For $z < 15$ ft (4.6 m) $\quad K_z = 2.01(15/z_g)^{2/\alpha}$
2. α and z_g are tabulated in Table 26.11-1.
3. Linear interpolation for intermediate values of height z is acceptable.
4. Exposure categories are defined in Section 26.7.

Force Coefficients, C_f

Cross Section	Type of Surface	h/D: 1	7	25
Square (wind normal to face)	All	1.3	1.4	2.0
Square (wind along diagonal)	All	1.0	1.1	1.5
Hexagonal or octagonal	All	1.0	1.2	1.4
Round, $D\sqrt{q_z} > 2.5$	Moderately smooth	0.5	0.6	0.7
$D\sqrt{q_z} > 5.3$ (in S.I.)	Rough ($D'/D = 0.02$)	0.7	0.8	0.9
	Very rough ($D'/D = 0.08$)	0.8	1.0	1.2
Round, $D\sqrt{q_z} \leq 2.5$ $D\sqrt{q_z} \leq 5.3$ (in S.I.)	All	0.7	0.8	1.2

Notation

D = Diameter of circular cross section and least horizontal dimension of square, hexagonal, or octagonal cross sections at elevation under consideration, in ft (m)
D' = Depth of protruding elements such as ribs and spoilers, in ft (m)
h = Height of structure, in ft (m)
q_z = Velocity pressure evaluated at height z above ground, in lb/ft^2 (N/m^2).

Notes

1. The design wind force shall be calculated based on the area of the structure projected on a vertical plane normal to the wind direction.
   The force shall be assumed to act parallel to the wind direction.
2. Linear interpolation is permitted for h/D values other than shown.

FIGURE 29.4-1 Other Structures (All Heights): Force Coefficients, C_f, for Chimneys, Tanks, and Similar Structures

The Design Snow Loads – ASCE/SEI 7-22

Chapter 7 titled "Snow Loads" in ASCE/SEI 7-22 provides Snow Loads Design requirements as detailed below.

Ground Snow Loads (P_g)

Ground snow loads, P_g, to be used in the determination of "Design Snow Loads" shall be calculated using the ASCE Design Ground Snow Load Geodatabase. A graphical representation of the data in the ASCE Design Ground Snow Load Geodatabase is shown in Figures 7.2-1A through 7.2-1D for the conterminous United States and Table 7.2-1 for Alaska. Where the results from the geodatabase indicate that a case study needs to be conducted for a specific location, the ground snow load determination for the location shall be based on an analysis of data available in the vicinity of the site, shall meet the reliability targets set forth in Table 1.3-1, and shall be approved by the Authority Having Jurisdiction.

Ground Snow Load Geodatabase of geocoded design ground snow load values are available at https://asce7hazardtool.online/.

Flat Roof Snow Loads (P_f)

The flat roof snow load (P_f) shall be calculated in lb/ft2 (kN/m2) using Eq. 7.3-1 of ASCE/SEI 7-22 as given below.

$$P_f = 0.7 C_e C_t P_g$$

where

P_g = Ground Snow Load based as per Risk Category and Site Class.

C_e = Exposure Factor as per Table 7.3-1.

C_t = Thermal Factor as per Table 7.3-2.

Snow Loads on Pipes

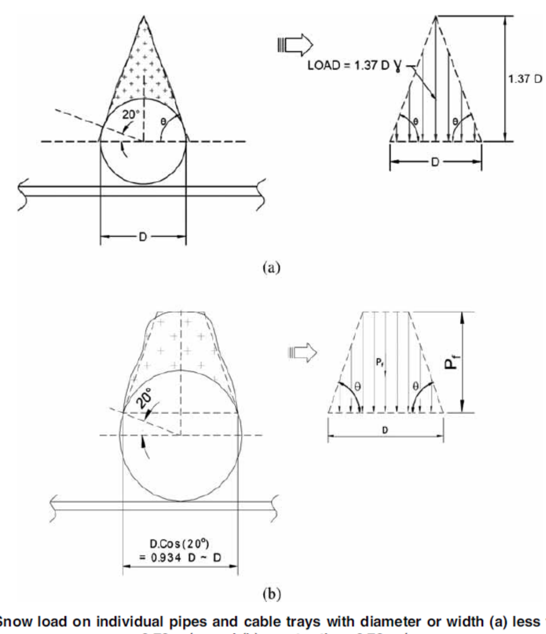


Figure 7.13-2. Snow load on individual pipes and cable trays with diameter or width (a) less than, or equal to, $0.73p_f/\gamma$, and (b) greater than $0.73p_f/\gamma$.

Note: D, pipe diameter $+2x$ insulation thickness (as applicable); P_f, flat roof snow load; θ, assumed angle of repose = 70 degrees.

Pipes with a diameter less than or equal to 0.73 P_f/γ shall be designed for a triangular snow load in accordance with Figure 7.13-2(a). Individual pipes with a diameter greater than 0.73 pf / γ shall be designed for a trapezoidal snow load, in accordance with Figure 7.13-2(b). Snow loads on pipes are not required to be considered if the wintertime external surface temperature of the pipe is greater than 45 °F (7.2 °C).

If D <= 0.73 P_f/γ

$$Snow\ Load = \frac{1}{2} D.h.\gamma.1$$

where

h = 1.37.D

If D > 0.73 P_f/γ

$$Snow\ Load = \frac{1}{2}(a+b).h.\gamma.1$$

where

P_f = Flat Roof Snow Load (lb/ft^2 or kN/m^2)

h = P_f/γ (ft or m)

D = Pipe Outer Diameter + 2 * Insulation Thickness (ft or m)

b = bottom width = 0.934 D (ft or m)

x = Tan(20) * h (ft or m)

a = top width = b – 2x (ft or m)

γ = Snow density, as determined from Equation (7.7-1), lb/ft^3 (kN/m^3)

γ = (0.13P_g + 14) but not more than 30 lb/ft^3

γ = (0.426P_g + 2.2) but not more than 4.7 kN/m^3

Ice Loads – Atmospheric Icing – ASCE/SEI 7-22

Chapter 10 titled "Ice Loads – Atmospheric Icing" in ASCE/SEI 7-22 provides the Ice Loads Design requirements as detailed below.

Ice Load

The ice load shall be determined using the volume or cross-sectional area of glaze ice formed on all exposed surfaces of structural members, guys, components, appurtenances, and cable systems. On structural shapes, prismatic members, and other similar shapes, the cross sectional area of ice shall be determined by

$$A_i = \pi \frac{t_d}{12}\left(D_c + \frac{t_d}{12}\right) \text{ [English Units]}$$

$$A_i = \pi \frac{t_d}{1000}\left(D_c + \frac{t_d}{1000}\right) \text{ [SI Units]}$$

where

A_i = Cross Section Area of Ice (ft^2 or m^2).

t_d = Radial Ice Thickness (inch or mm)

D_c = Diameter of the cylinder circumscribing an object, ft (m). D_c is shown for a variety of cross-sectional shapes in Figure 10.4-1 of ASCE/SEI 7-22.

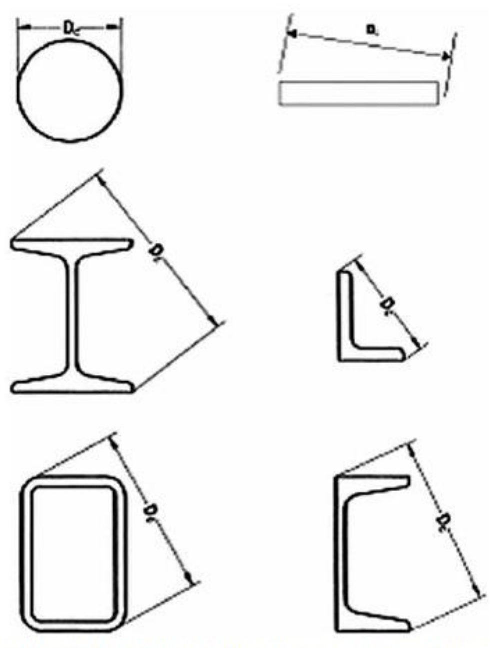


Figure 10.4-1. Characteristic dimension, D_c, for calculating the ice area for a variety of cross-sectional shapes.

Ice Loads on Pipes

$$Ice\ Load = A_i.\gamma.1$$

where

γ = ice density = 56 lb/ft^3 (900 kg/m^3)

A_i = Cross Section Area of Ice (ft^2 or m^2).

EN 1991-1-4 (2010)

General actions - Wind actions

The Design Wind Load

Section 4 titled "Wind velocity and velocity pressure" is used to compute Peak Velocity Pressure at a given elevation.

Basic Values

The fundamental value of the basic wind velocity, Vb,Q, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

The basic wind velocity shall be calculated from Expression (4.1) of EN 1991-1-4 (2010) as given below.

$$\boldsymbol{Vb, Q = C_{dir}.V_b.C_{Season}}$$

where

V_b is the basic wind velocity, defined as a function of wind direction and time of year at 10m above ground of terrain category II.

$V_{b,Q}$ is the fundamental value of the basic wind velocity

C_{dir} is the directional factor, the recommended value is 1.0.

C_{season} is the season factor, the recommended value is 1.0.

Mean Wind

The mean wind velocity $V_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, V_b, and is determined using Expression (4.3) of EN 1991-1-4 (2010) as given below.

$$\boldsymbol{V_m(z) = C_r(z).V_b.C_o(z)}$$

Where

$C_r(z)$ is the terrain roughness factor. This can be computed as given below.

$C_0(z)$ is the orography factor, the recommended value is 1.0. See Section 4.3.3 of EN 1991-1-4 (2010) for further details.

Terrain Roughness Factor[$C_r(z)$]

The roughness factor, $C_r(z)$, accounts for the variability of the mean wind velocity at the site of the structure due to:

a. height above ground level
b. ground roughness of the terrain upwind of the structure in the wind direction considered.

$$\boldsymbol{C_r(z) = K_r.Ln\left(\frac{z}{z_o}\right) for\ z_{min}} < z < z_{\boldsymbol{max}}$$

$$\boldsymbol{C_r(z) = C_r(z_{min}) for\ z} < z_{\boldsymbol{min}}$$

where

$$K_r = 0.19.\left(\frac{z}{z_{o,II}}\right)^{0.07}$$

where

$z_{O,II}$= 0,05 m [terrain category II, as per Table 4.1 of EN 1991-1-4 (2010)]

z_{min} is the minimum height defined in Table 4.1 of EN 1991-1-4 (2010)

z_{max} is to be taken as 200 m

Table 4.1 — Terrain categories and terrain parameters

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE: The terrain categories are illustrated in A.1.			

Wind Turbulence

The turbulence intensity Iv(z) at height z is defined as the standard deviation of the turbulence divided by the mean wind velocity.

$$I_V(z) = \frac{K_t}{C_o(z).\ln\left(\frac{z}{z_o}\right)} \quad \text{for} \quad z_{min} < z < z_{max}$$

$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z < z_{min}$$

where

Kt is the turbulence factor. The value may be given in the National Annex. The recommended value for Kt is 1.0.

$C_0(z)$ is the orography factor as explained above.

$z_0$is the roughness length as given in Table 4.1 of EN 1991-1-4 (2010).

Peak Velocity Pressure [Qp(z)]

The peak velocity pressure **Qp(z)** at height z, which includes mean and short-term velocity fluctuations, is determined using Expression (4.8) of EN 1991-1-4 (2010) as given below.

$$Q_p(z) = [1 + 7.I_v(z)].\frac{1}{2}.\rho.V_m^2(z) = C_e(z).Q_b$$

where

ρ is the air density, which depends on the altitude, temperature and barometric pressure to be expected in the region during wind storms

$C_e(z)$is the exposure factor = $\frac{Q_p(z)}{Q_b}$

$Q_b$is the basic velocity pressure = $\frac{1}{2}.\rho.V_b^2$

Design Wind Loads

The design wind force is then determined as given below.

$$F = \boldsymbol{Q_p(z)}.A_f$$

where

$\boldsymbol{Q_p(z)}$ **=** peak velocity pressure evaluated at height z

A_f = projected area normal to the wind

Note:

In Expression 5.3, Wind Force is computed by multiplying the above Qp(z) with CsCd and Cf. From Section 6.2(d), for chimneys with circular cross-sections (similar to the flow around circular pipes), CsCd is specified as 1.0. So, the only factor that is NOT yet applied in computing the design wind loads above is Cf.

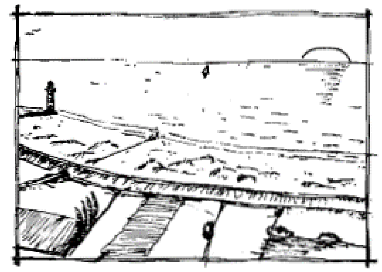
From Section 7.9 for Circular Cylinders, for most piping systems, Cf should be of between 0.7 and 1.0. Surface roughness factors (k) provided in Section 7.9.2 and end-effect factors provided in Section 7.13 (used for computing Cf) are mostly related to structural elements. Since piping elements are connected to either adjoining pipe elements or fittings or components or equipment, the end-effect factor for any element in a pipe stress model should be 1.0; it is equivalent to saying that, from fluid flow point of view, each element in a pipe stress model is behaving as an infinitely long element. Hence, it does not cause the kind of end flow effect created by finite length elements.

In view of the above, applying only Eq. 4.8 to compute design wind force is conservative. Hence, in the current version of CAEPIPE, Expression 5.3 is not implemented to calculate Design Wind Loads.

A.1 Illustrations of the upper roughness of each terrain category

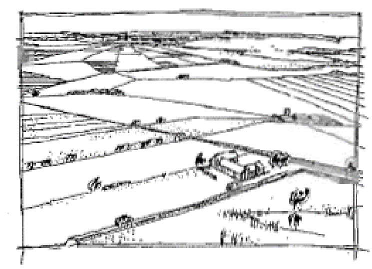
Terrain category 0

Sea, coastal area exposed to the open sea



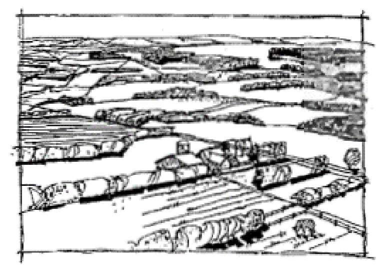
Terrain category I

Lakes or area with negligible vegetation and without obstacles



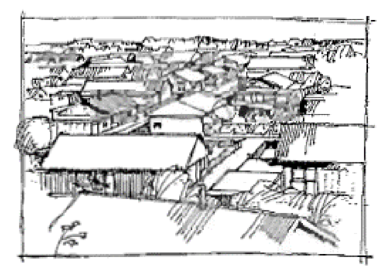
Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights



Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)



Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m