The *FASTEST* Solutions for Piping Design and Analysis.

Readme Supplement

CAEPIPE

Version 7.0

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Annexure A
Code Compliance

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 (2012) 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 = $t_n \times$ (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). In addition,

Y = 0.0, for cast iron and non-ferrous materials.

$Y = \frac{d}{d + D_o}$, if $D_o/t_a < 6$, for ferritic and austenitic steels designed for temperatures of 900°F (480°C) and below

W = weld strength reduction factor as per Table 102.4.7. Refer to Annexure B 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 (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 = uncorroded 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.

$$S_{Lo} = \frac{P_{peak}D_o}{4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

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.

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

where

M_C = resultant moment due to thermal expansion

$S_A = f(1.25S_C + 0.25S_h)$, 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 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 Annexure C for the details of “Thickness” and the “Section Modulus” used for weight, pressure and stress calculations.

MANDATORY APPENDIX D

Table D-1 Flexibility and Stress Intensification Factors

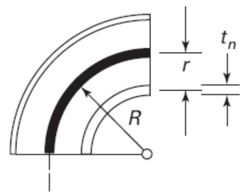
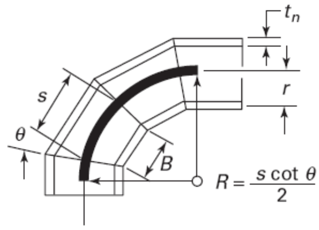
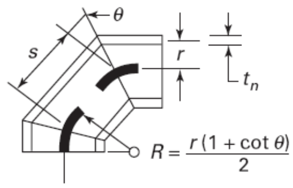
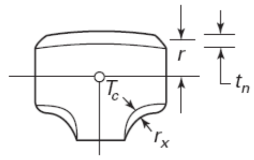
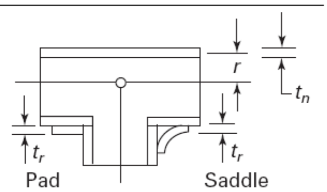
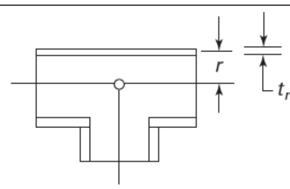
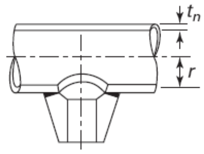
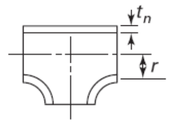
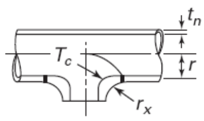
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r(1 + \tan\theta)$ $B \geq 6\ t_n$ $\theta \leq 22\frac{1}{2}$ 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	$\frac{0.9}{h^{2/3}}$	

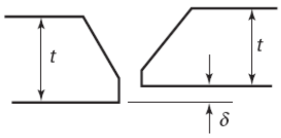
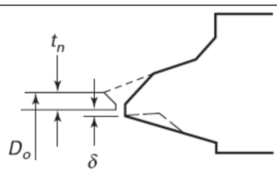
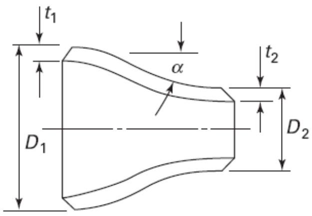
Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note (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

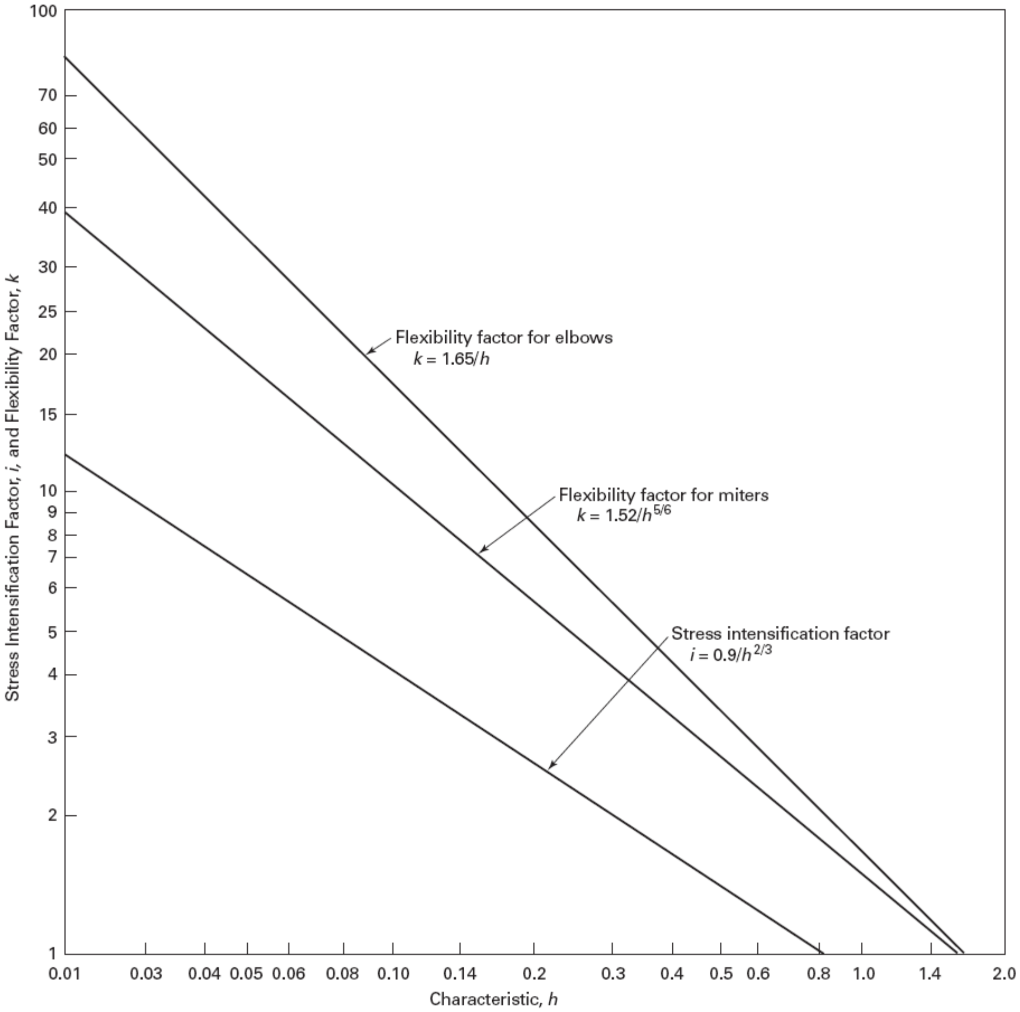
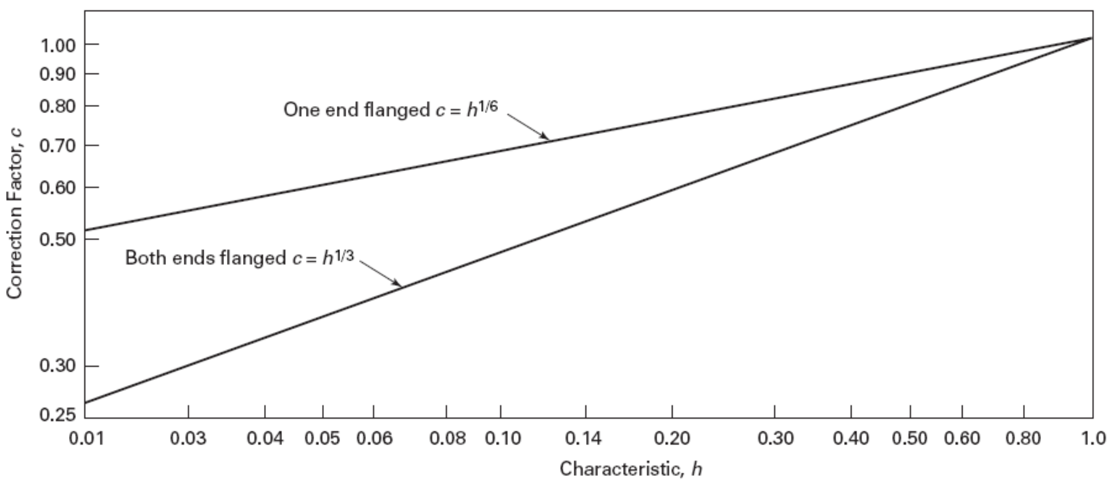


Chart D-2 Correction Factor, c



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 T_1 through T_{10} and T_{ref} in CAEPIPE).

With Material Type in CAEPIPE = CS [CrMo]

W = 1.0 with T_{max} <= 800^0 F (or 427^0 C)

W = 0.64 with T_{max} > 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 are linearly interpolated.

With Material Type in CAEPIPE = FS [CSEF (Subcritical)]

W = 1.0 with T_{max} <= 900^0 F (or 482^0 C)

W = 0.5 with T_{max} > 900^0 F (or 482^0 C)

With Material Type in CAEPIPE = AS or NA

W = 1.0 with T_{max} <= 950^0 F (or 510^0 C)

For T_{max} > 950^0 F (or 510^0 C), the values of W are taken as per Table 302.3.5.

W for intermediate temperatures are linearly interpolated.

With Material Type in CAEPIPE = SS

W = 1.0 with T_{max} <= 1500^0 F (or 816^0 C)

For Other Material Types in CAEPIPE

W = 1.0 with T_{max} <= 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

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

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

S_h = 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 <= 427^0 C or 800^0 F

$$S_{Lo} \le 1.33 S_h$$

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

$$S_{Lo} \le 0.9 W S_y$$

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 Austenetic stainless 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

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

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 listed in Appendix D of B31.3 (2012)

$F_a =$ range of axial forces due to displacement strains between any two thermal conditions being evaluated

$I_i =$ in-plane stress intensification factor

$I_o =$ out-of-plane stress intensification factor

$I_t =$ torsional stress intensification factor = 1.0

$M_i =$ in-plane bending moment

$M_o =$ out-of-plane bending moment

$M_t =$torsional moment

Z = uncorroded section modulus as per para. 319.3.5; for reduced outlets/branch connections, effective section modulus as per 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 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

$S_A = f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. 302.3.5(d).

This is specified as an analysis option “Use liberal allowable stresses”, in the menu Options->Analysis on the CAEPIPE 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 <= 371^0 C (700^0 F). <u>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.</u>
2. Refer Annexure C for the details of “Thickness” and the “Section Modulus” used for weight, pressure and stress calculations.

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Table D300[1] Flexibility Factor, *k*, and Stress Intensification Factor, *i*

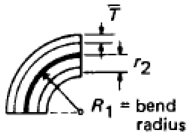
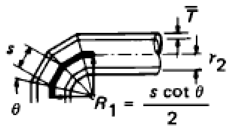
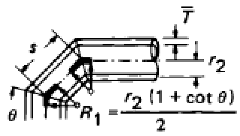
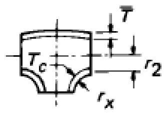
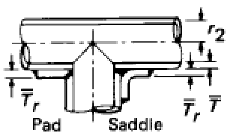
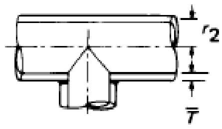
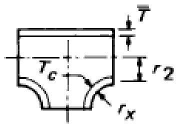
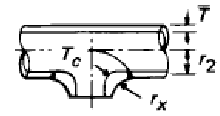
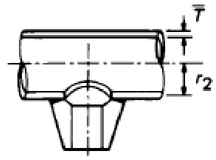
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (2), (4)-(7)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2\,(1 + \tan\theta)$ [Notes (2), (4), (5), (7)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2\,(1 + \tan\theta)$ [Notes (2), (4), (7)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (2), (4), (6), (8), (9)]	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 (2), (4), (9), (10), (11)]	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[1] Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd) (1

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (2), (4), (9), (11)]	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 (2), (4), (9)]	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 (2), (4), (8), (9)]	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 (2), (4), (11), (12)]	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 [Note (1)]
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 (13)]
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 (14)]	5	2.5

Table D300[1] Flexibility Factor, k, and Stress Intensification Factor, i (Cont'd)

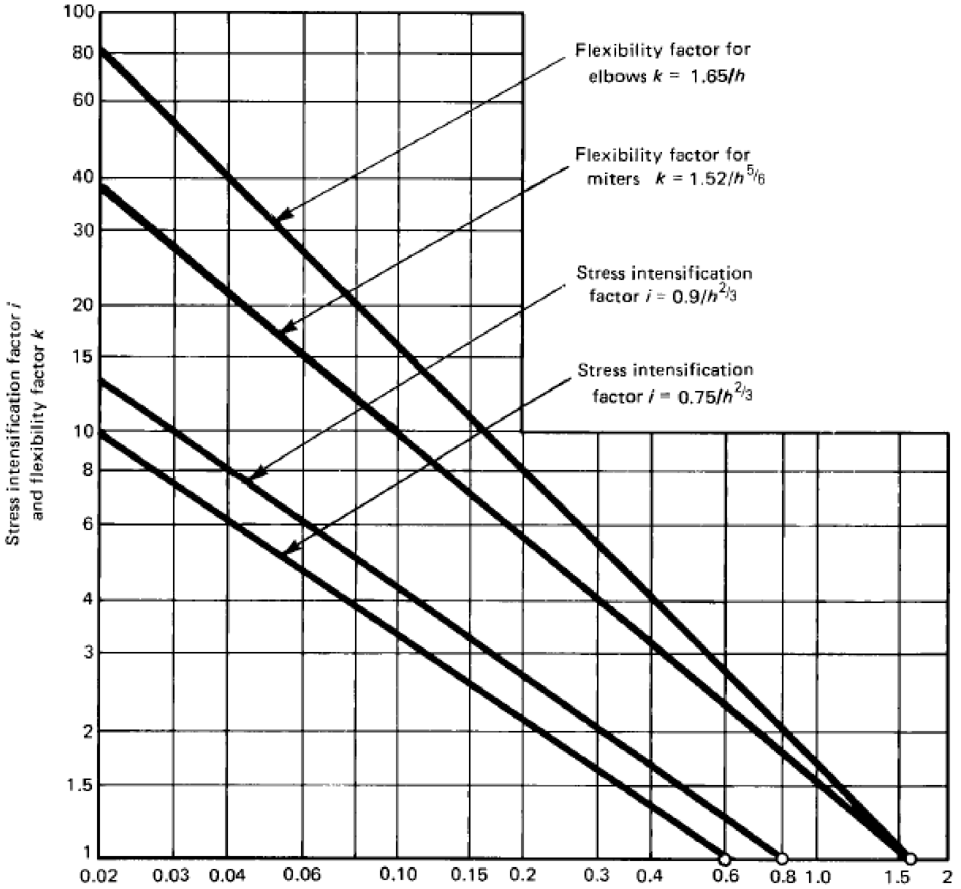


Chart A

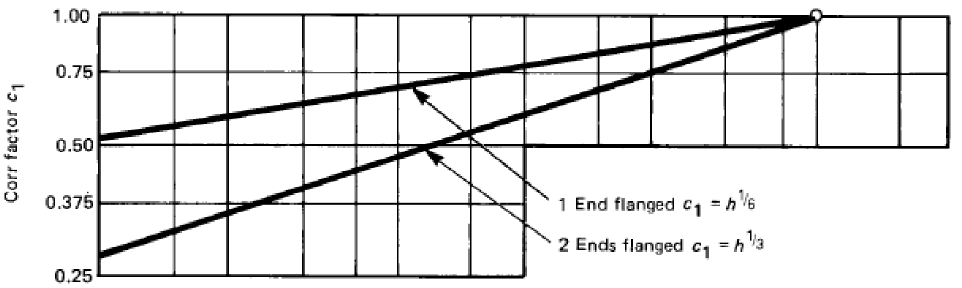


Chart B

NOTES:

(1) 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 $D/\overline{T} \leq 100$.

(2) The flexibility factor, k, in the Table 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.

(3) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.

(4) 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
$\overline{T}_c$ = crotch thickness of branch connections measured at the center of the crotch where shown in the sketches
$\overline{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

(5) 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.

(6) 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.

(7) 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.

(8) 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.

(9) 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.

(10) When $\overline{T}_r$ is $> 1\frac{1}{2}\ \overline{T}$, use $h = 4\ \overline{T}/r_2$.

(11) 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.

(12) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.

(13) 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 sketch (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.

(14) 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.

$$P_i = \frac{2SEt_a}{D}$$

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)

$$S_L = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \le 0.75 Sy$$ 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)

$$S_{L(fc)} = \left|\frac{PD}{4t_n} + \frac{F_a}{A}\right|_{Sustained} + \left[\frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}\right]_{Sustained} \le 0.75 Sy$$ 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 $0.75 i_i$ 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

Z = uncorroded 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)

$$S_{Lo} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \le 0.8S_y$$ as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

$$S_{Lo} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{F_a}{A}\right|_{occasional} + \left[\frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \le 0.8S_y$$ 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

$$S_E = \sqrt{S_b^2 + 4S_t^2} \le S_A$$ as per Table 403.3.1-1 and para. 403.3.2

where

S_b = resultant bending stress = $\dfrac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$

S_t = torsional stress = $\dfrac{M_t}{2Z}$

M_t = torsional moment

Z = uncorroded 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 <= 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

$$
\begin{aligned}
S_L = \quad & \max(|S_p + S_x + S_B|, |S_p + S_x - S_B|)_{sustained} + \\
& \max(|S_p + S_x + S_B|, |S_p + S_x - S_B|)_{Occasional} + \\
& \max(|S_T|_{warmest}, |S_T|_{coldest}) \le 0.9 S_y
\end{aligned}
$$

where

Pressure stress = $S_p = \upsilon \dfrac{PD}{2t_n}$ 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) = $S_x = \dfrac{F_a}{A}$ and can be positive <u>or</u> 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 expansion stress = $S_T = E\alpha(T_i - T_o)$, which can be either 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 $0.75 i_i$ 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

F_a = axial force component for external loads

A = <u>nominal</u> cross-section area

Z = <u>uncorroded</u> 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

$\alpha =$ 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 Annexure B for the details of "Thickness" and the "Section Modulus" used for weight, pressure and stress calculations.

Table 402.1-1 Flexibility Factor, k, and Stress Intensification Factor, i

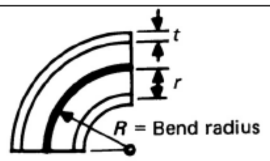
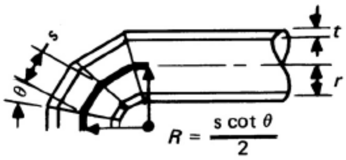
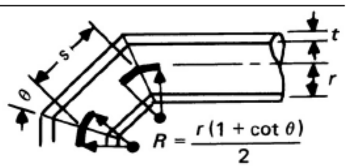
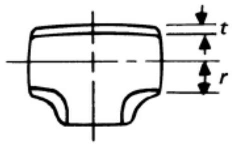
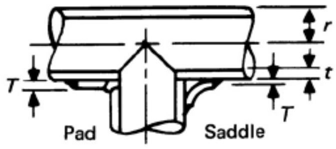
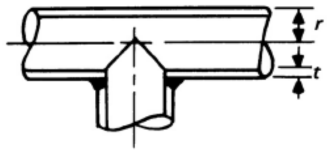
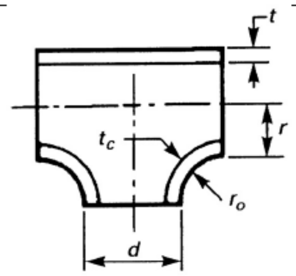
Description	Flexibility Factor, k	Stress Intensification Factor		Flexibility Characteristic, h	Sketch
		i_i [Note (1)]	i_o [Note (2)]		
Welding elbow, or pipe bend [Notes (3)–(7)]	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	$\frac{tR}{r^2}$	
Closely spaced miter bend, [Notes (3)–(5), 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

$$\text{Flexibility factor, } k\text{, by} \qquad 1 + 6\frac{P}{E_c}\left(\frac{r}{t}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$$

$$\text{Stress intensification factor, } i\text{, by} \qquad 1 + 3.25\frac{P}{E_c}\left(\frac{r}{t}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$$

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)

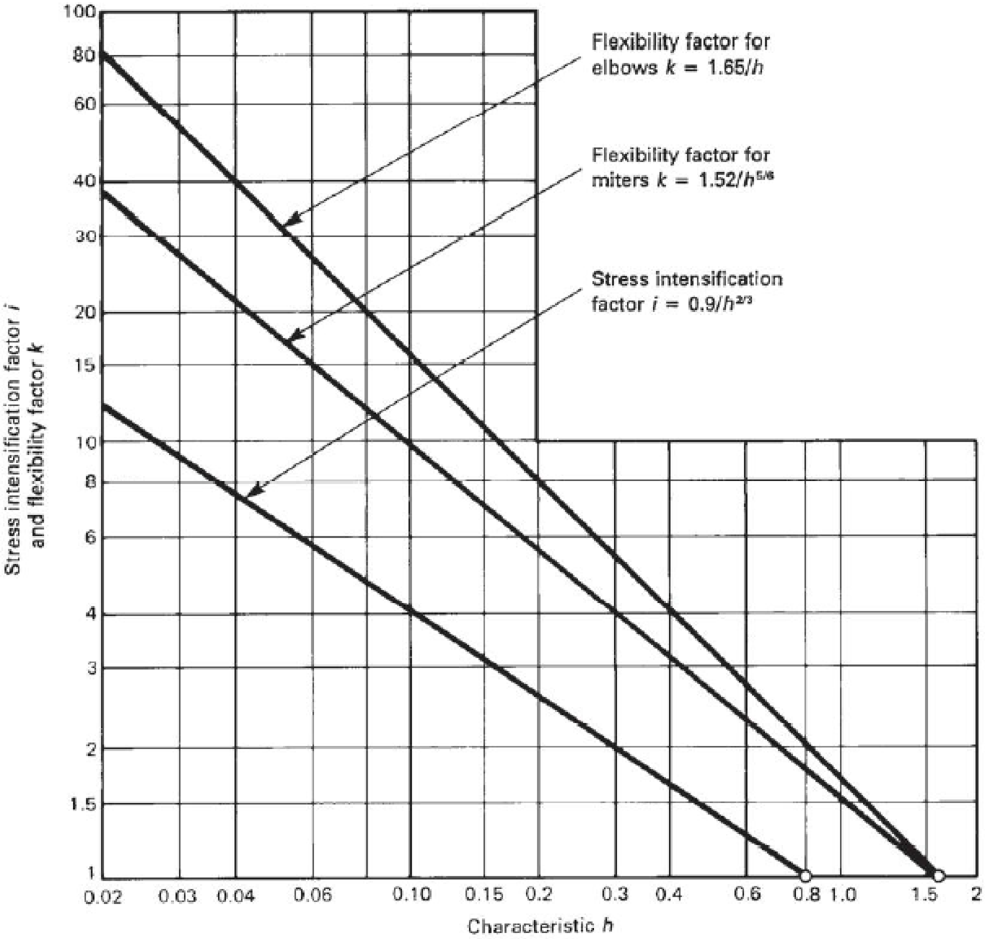


Chart A

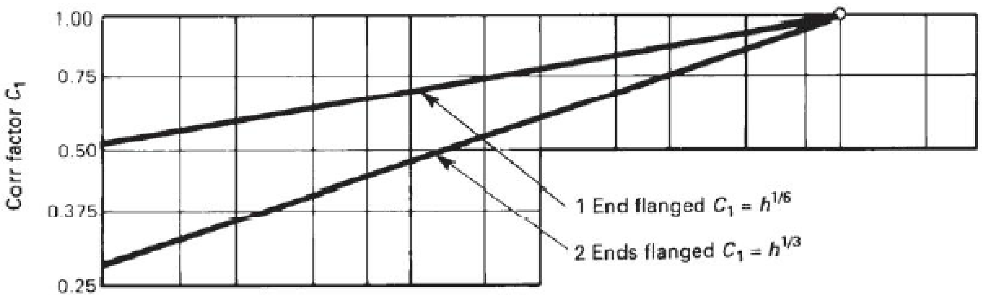


Chart B

Allowable Pressure

<u>For straight pipes and bends (including closely spaced and widely spaced miter bends),</u> 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 × (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 $4 \leq D/t_a < 6$

For Cast Iron, Y = 0.0

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.

$$S_{Lo} = \frac{P_{peak} D}{4t_c} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \right]_{sustained} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \right]_{occasional} \le 1.33 S_h$$

where

P_{peak} = peak pressure = (peak pressure factor) x P, where P is defined above

Expansion Stress (in uncorroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 519.4.5 and para. 519.3.5.

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

where

$S_b =$ resultant bending stress = $\dfrac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$

$S_t =$ torsional stress = $\dfrac{M_t}{2Z}$

M_t = torsional moment

Z = uncorroded section modulus; for reduced outlets, effective section modulus

$S_A = f(1.25 S_{Cold} + 0.25 S_{hot})$ (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

$S_A = S_A + f\left(S_h - S_L\right)$

where, S_h = basic allowable stress at maximum of CAEPIPE input temperatures T_1, T_2 and T_3

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. Refer Annexure B for the details of “Thickness” and the “Section Modulus” used for weight, pressure and stress calculations.

Table 519.3.6 Illustration

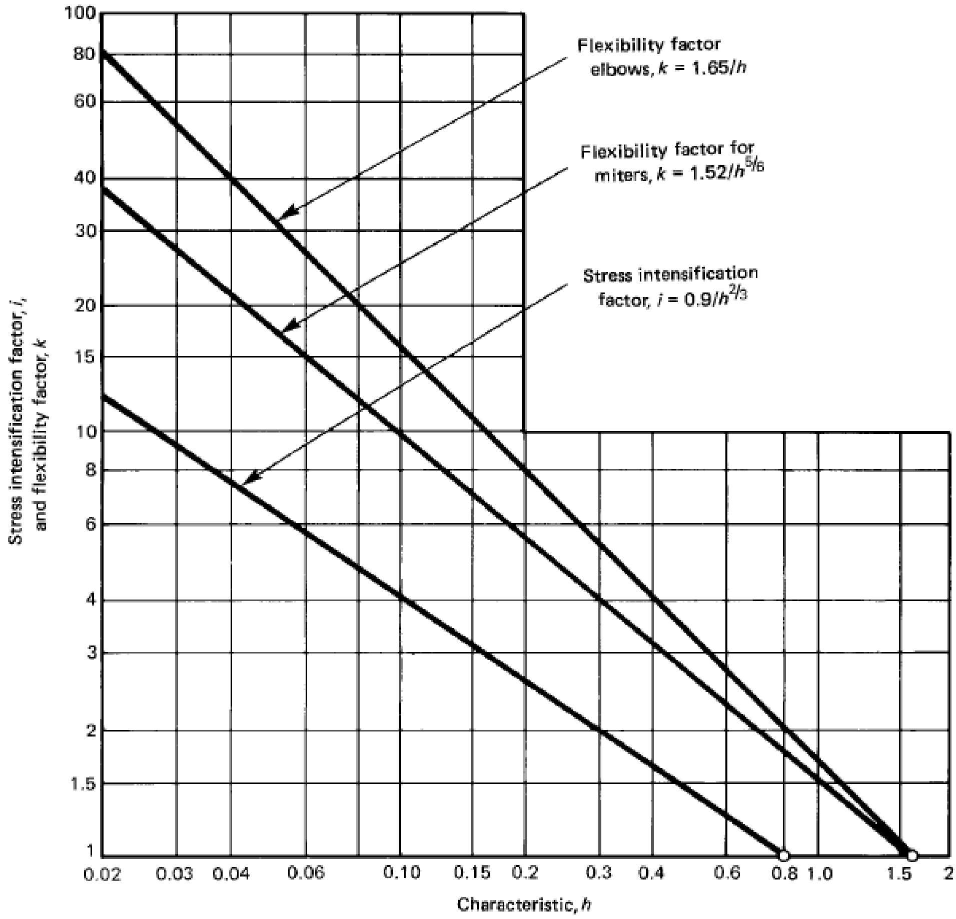


Chart A

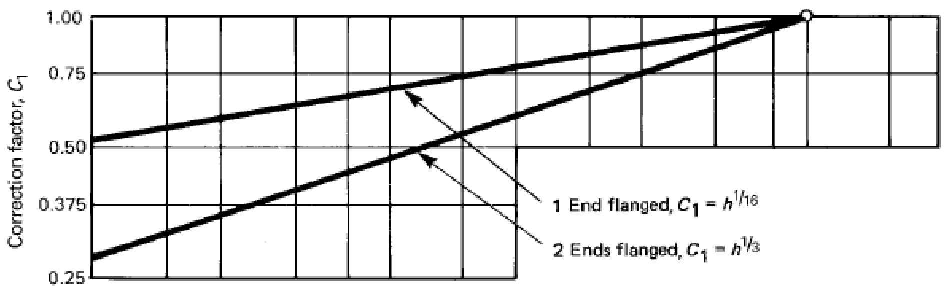


Chart B

Table 519.3.6 Flexibility Factor, k, and Stress Intensification Factor, i

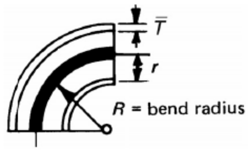
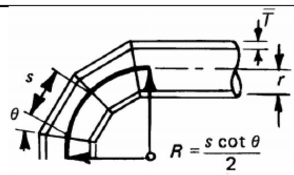
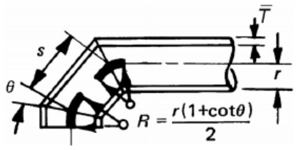
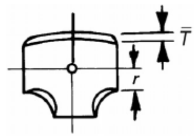
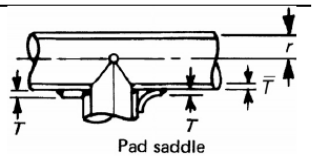
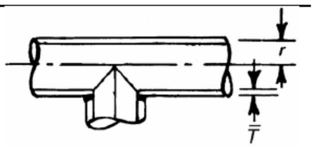
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor i_i [Note (1)]	Stress Intensification Factor i_o [Note (2)]	Illustration
Welding elbow or pipe bend [Notes (3)–(7)]	$\frac{\bar{T}R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Closely 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)]	$\frac{(\bar{T} + \frac{1}{2}T)^{5/2}}{\bar{t}^{3/2}r}$	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. 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 (required to compute Expansion Stress Allowable S_A):

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

$$S_{Lo} = S_L + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{occasional} + \left[\frac{\sqrt{(i_iM_i)^2 + (i_oM_o)^2}}{Z}\right]_{occasional} \le 0.75ST$$

For Fittings or Components

$$S_{Lo} = S_{L(fc)} + \left|\frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A}\right|_{Occasional} + \left[\frac{\sqrt{(0.75i_iM_i)^2 + (0.75i_oM_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \le 0.75ST$$

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 $0.75 i_i$ 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

Z = uncorroded 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 T10, 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.

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

where

$S_b =$ resultant bending stress = $\dfrac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$

$S_t =$ torsional stress = $\dfrac{M_t}{2Z}$

M_t = torsional moment

Z = uncorroded 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 <= 1.0 (from para. 833.8 (b)).

$S_c = 0.33 S_u T$ at the minimum installed or operating temperature

$S_h = 0.33 S_u T$ at the maximum installed or operating temperature

where

S_u = specified minimum <u>ultimate</u> 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)

$$\begin{aligned} S_L = \quad & \max(\left|S_p + S_x + S_B\right|, \left|S_p + S_x - S_B\right|)_{sustained} + \\ & \max(\left|S_p + S_x + S_B\right|, \left|S_p + S_x - S_B\right|)_{Occasional} + \\ & \max(\left|S_T\right|_{warmest}, \left|S_T\right|_{coldest}) \le 0.9ST \end{aligned}$$

where

Internal pressure stress = $S_p = 0.3\dfrac{PD}{2t_n}$

Stress due to axial loading (other than thermal expansion and pressure) = $S_X = \dfrac{R}{A}$, and may be positive or negative

Nominal bending stress S_B from Weight and / or other External loads for

<u>*For Pipes and Long Radius Bends*</u>

$$S_B = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$$

<u>*For other Fittings or 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 expansion stress = $S_T = E\alpha(T_i - T_o)$, and may be positive <u>or</u> negative

Where

P = maximum operating pressure = max(P_1 through P_{10})

D = nominal 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 = <u>corroded cross-sectional area</u> (i.e., after deducting for corrosion)

Z = <u>uncorroded section modulus</u>; 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

$\alpha =$ coefficient of thermal expansion at T_o defined above

Table E-1 Flexibility Factor, k, and Stress Intensification Factor, i

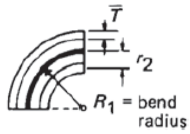
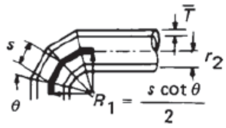
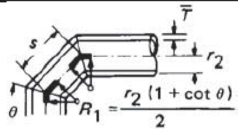
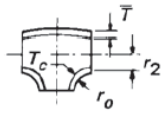
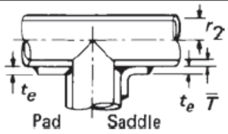
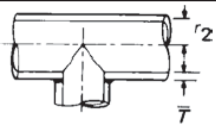
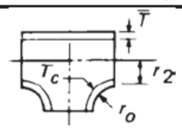
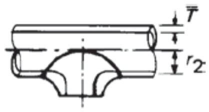
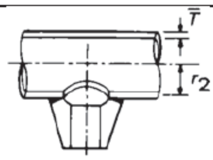
Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)] Out-plane, i_o	Stress Intensification Factor, i [Notes (1) and (2)] In-plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1)–(5)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T} R_1}{r_2^2}$	
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)

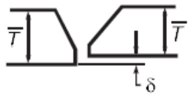
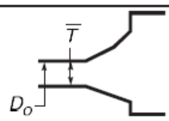
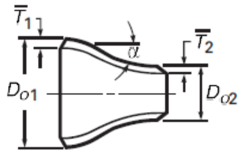
Description	Flexibility Factor, *k*	Stress Intensification Factor, *i*	Sketch
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/8$ 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), $\delta_{max.} \leq 1/16$ 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 $1.3 + 0.0036\dfrac{D_o}{\bar{T}} + 3.6\dfrac{\delta}{\bar{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\dfrac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
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)

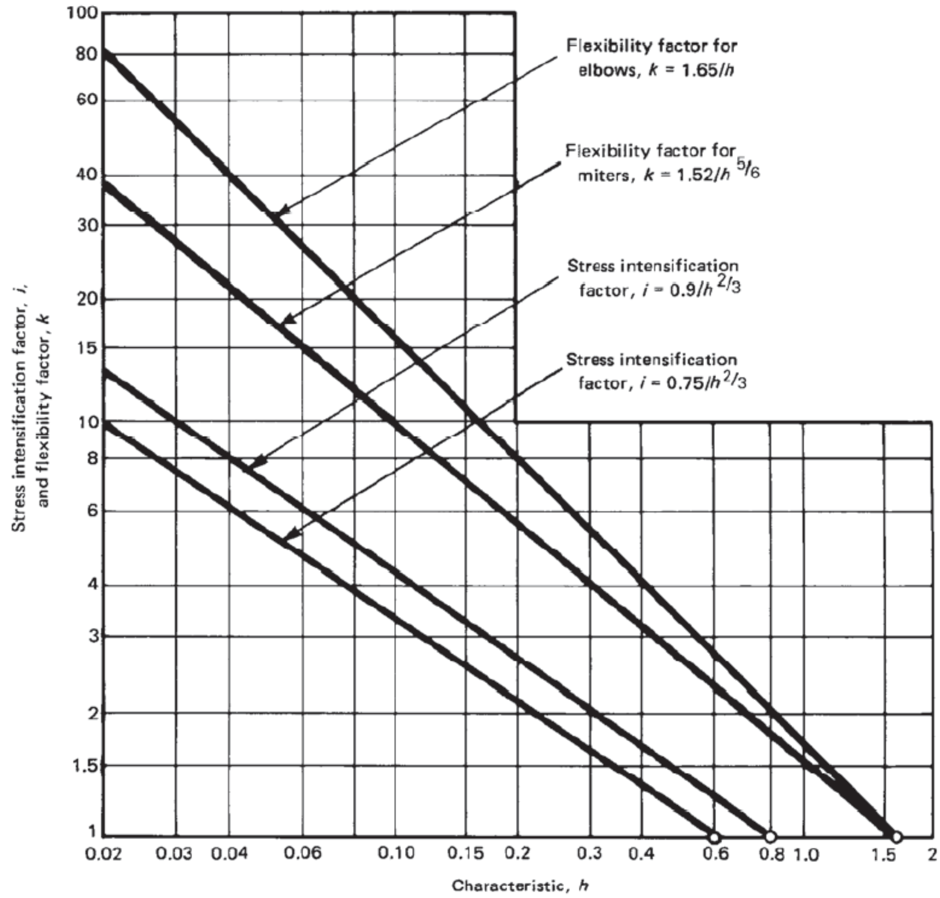


Chart A

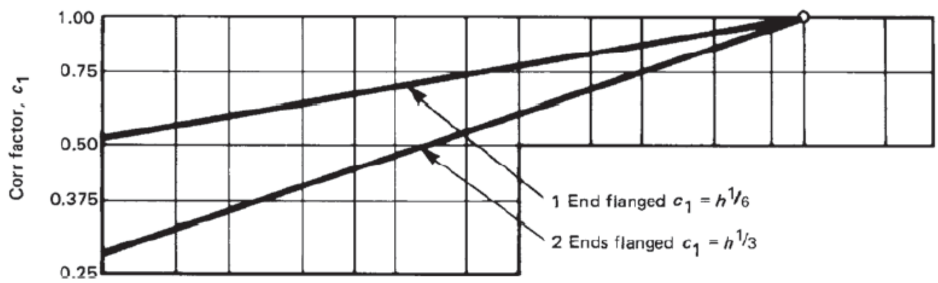


Chart B

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 $t_e > 1\frac{1}{2}\overline{T}$, use $h = 4.05\overline{T}/r_2$.

(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 $0.875\overline{T}$ 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

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 $D_o / D_i \leq 1.7$

$$P = \frac{2\,fze}{D_o - e}$$

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 x [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 = outside diameter

D_i = inside 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

$$t_f = \frac{(R/D - 0.25)}{(R/D - 0.50)}$$

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.

$$P = \min\left[\frac{fze^2}{r(e + 0.643\tan\theta\sqrt{re})}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] \text{ with } \theta \leq 22.5$$

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

$$P = \min\left[\frac{fze^2}{r(e + 0.643\tan\theta\sqrt{re})}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] \text{ with } \theta \leq 22.5$$

$$P = \frac{fze^2}{r(e + 1.25\tan\theta\sqrt{re})}$$ with θ > 22.5

Where

r = mean radius of pipe = (D - 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 P1, P2 and P3

D_o = outside diameter

e_n = nominal pipe thickness

$i =$ 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 = uncorroded section modulus; for reduced outlets / branch connections, effective section modulus

f_f = design (allowable) stress for flexibility analysis at the operating temperature under consideration (i.e., at T_i where i = 1 to 10)

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.

$$\sigma_2 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \le kf_f$$

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 by default.

User can modify this value through CAEPIPE menu Options > Analysis > Code > Occasional load factor.

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 = uncorroded section modulus; for reduced outlets / branch connections, effective section modulus

$$f_a = U(1.25 f_C + 0.25 f_h)\frac{E_h}{E_c}$$

$U =$ cyclic stress range reduction factor taken from table 12.1.3-1

f_C = basic allowable stress at minimum metal temperature consistent with the loading under consideration

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration

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

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

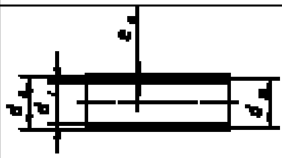
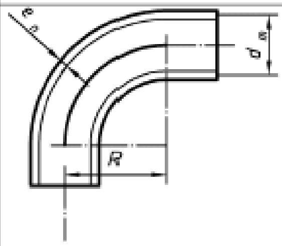
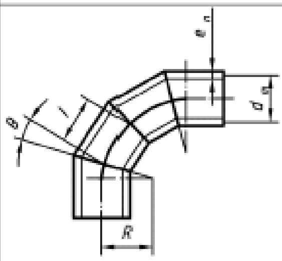
For piping operating within the creep range, the stress, σ_5, due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-1) below.

$$\sigma_5 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_C}{3Z} \leq f_{cr}$$

where

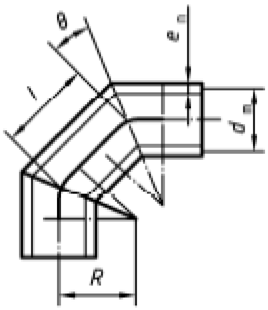
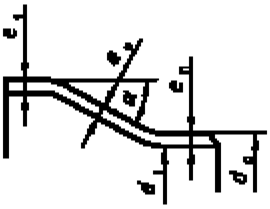
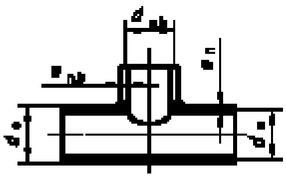
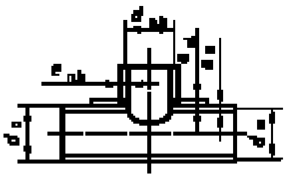
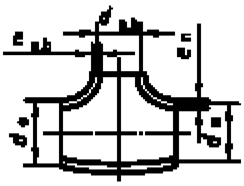
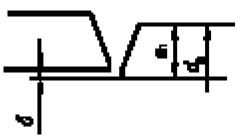
f_{cr} = allowable creep stress value

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 h l]	$\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$
3	Closely spaced mitre bend $l < r(1+\tan\theta)$ $(l = 2R\tan\theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{l\cot\theta}{2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ [b c h l]	

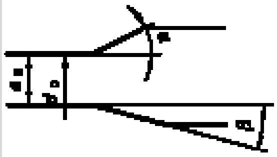
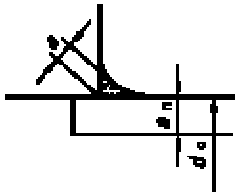
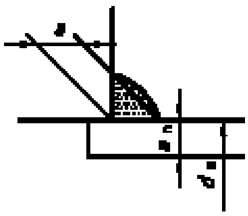
(to be continued)

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 $l \geq r\,(1 + \tan\theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{d_m(1+\cot\theta)}{4}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$ [b,h,l]	
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]	
6	tee with welded-on, welded-in or extruded nozzle		$\frac{2e_n}{d_m}$	1	$\frac{0{,}9}{h^{2/3}}$ [b,e,g]	Header $\frac{\pi}{32}\frac{d_o^4 - d_i^4}{d_o}$
7	as above, however, with additional reinforcing ring		$\frac{2(e_n + 0{,}5e_{pl})^{5/2}}{d_m e_n^{3/2}}$ with $e_{pl} \leq e_n$	1	$\frac{0{,}9}{h^{2/3}}$ [b,e,g]	Nozzle $\frac{\pi}{4} d_{m,b}^2\, e_x$
8	forged welded-in tee with e_n and $e_{n,b}$ as connecting wall thickness		$\frac{8{,}8e_n}{d_m}$	1	$\frac{0{,}9}{h^{2/3}}$ [b,g]	with e_x as smaller value of $e_{x1} = e_n$ and $e_{x2} = i\, e_{n,b}$ resp.
9	butt weld		$e_n \geq 5$ mm and $\delta \leq 0{,}1\ e_n$ [f] $e_n < 5$ mm and $\delta > 0{,}1\ e_n$ [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, not applicable for instance for configurations according to Figure 8.4.3-5.

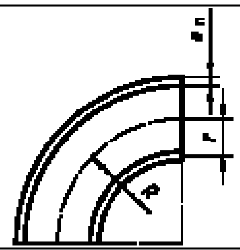
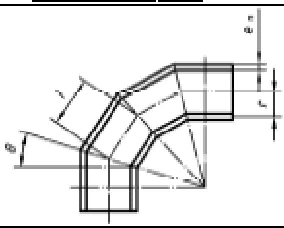
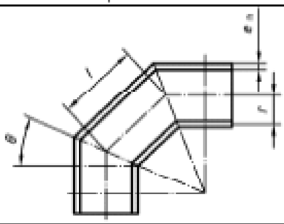
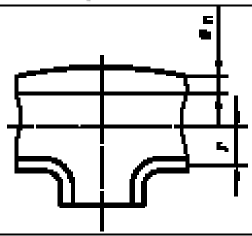
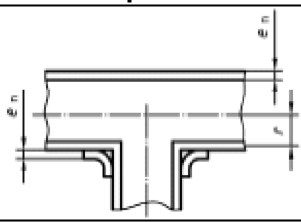
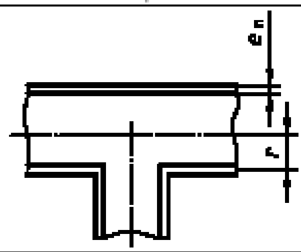
[h] If the pressure is likely to correct ovality (large diameter, small thickness), the factor i shall be divided by:

$1 + 3{,}25\left(\dfrac{p_o}{E_c}\right)\left(\dfrac{d_m}{2e_n}\right)^{5/2}\left(\dfrac{2R}{d_m}\right)^{2/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20 °C).

[i] If the pressure is likely to correct ovality (large diameter, small thickness), the factor k shall be divided by:

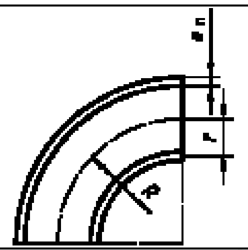
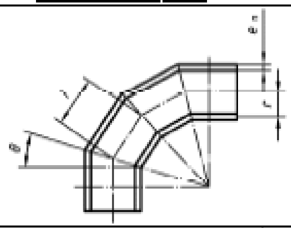
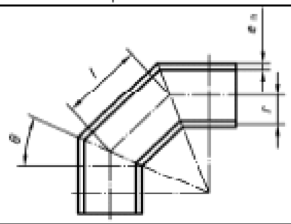
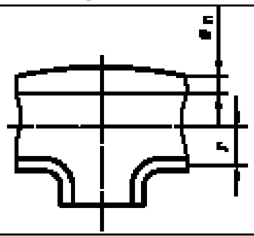
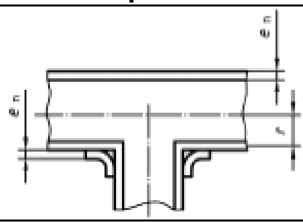
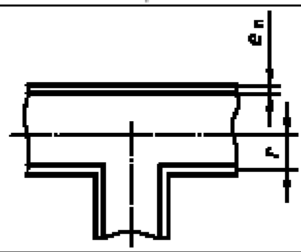
$1 + 6\left(\dfrac{p_o}{E_c}\right)\left(\dfrac{d_m}{2e_n}\right)^{7/3}\left(\dfrac{2R}{d_m}\right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20 °C).

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 $l < r\,(1 + \tan\theta)$ $(l = 2\,R\tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ 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 l	$0{,}75 i_o + 0{,}25$ a e f g l	$\frac{4{,}4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0{,}9}{h^{2/3}}$ a d e l	$0{,}75 i_o + 0{,}25$ a d e l	$\frac{(e_n + 0{,}5 e_r)^{5/2}}{r\left(e_n{}^{3/2}\right)}$	
Unreinforced fabricated tee	$\frac{0{,}9}{h^{2/3}}$ a d e l	$0{,}75 i_o + 0{,}25$ a d e l	$\frac{e_n}{r}$	

(to be continued)

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 $l < r\,(1 + \tan\theta)$ $(l = 2\,R\,\tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ 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 l	$0{,}75 i_o + 0{,}25$ a e f g l	$\frac{4{,}4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0{,}9}{h^{2/3}}$ a d e l	$0{,}75 i_o + 0{,}25$ a d e l	$\frac{(e_n + 0{,}5 e_r)^{5/2}}{r\,(e_n)^{3/2}}$	
Unreinforced fabricated tee	$\frac{0{,}9}{h^{2/3}}$ a d e l	$0{,}75 i_o + 0{,}25$ a d e l	$\frac{e_n}{r}$	

(to be continued)

Table H.3 (*continued*)

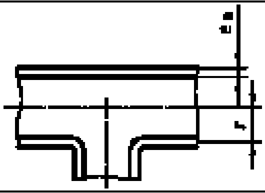
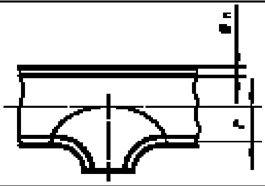
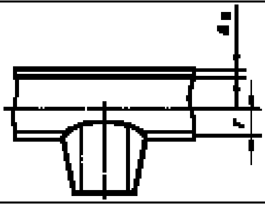
Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Extruded welding tee	$\dfrac{0{,}9}{h^{2/3}}$ [a,e,l]	$0{,}75 i_o + 0{,}25$ [a,e,l]	$\left(1+\dfrac{r_1}{r}\right)\dfrac{e_n}{r}$	
Welded in contour insert	$\dfrac{0{,}9}{h^{2/3}}$ [a,e,f,g,l]	$0{,}75 i_o + 0{,}25$ [a,e,f,g,l]	$\dfrac{4{,}4 e_n}{r}$	
Branch welded on fitting (integrally reinforced)	$\dfrac{0{,}9}{h^{2/3}}$ [a,d,f,h]	$0{,}75 i_o + 0{,}25$ [a,d,f,h]	$\dfrac{3{,}3 e_n}{r}$	

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:

$1 + 3{,}25\left(\dfrac{p_o}{E_c}\right)\left(\dfrac{r}{e_n}\right)^{5/2}\left(\dfrac{R}{r}\right)^{2/3}$, 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 $\dfrac{e_n}{r}$.

[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:

$1+6\left(\dfrac{p_o}{E_c}\right)\left(\dfrac{r}{e_n}\right)^{7/3}\left(\dfrac{R}{r}\right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

ANSI/API Standard 610
Tenth Edition, October 2004

ISO 13709: 2003, (Identical) Centrifugal pumps for petroleum, petrochemical and natural gas industries

API 610 (Tenth Edition, 2004) / ISO 13709 for Pumps

The allowable nozzle forces and moments for pumps are taken from Table 4 of the tenth 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

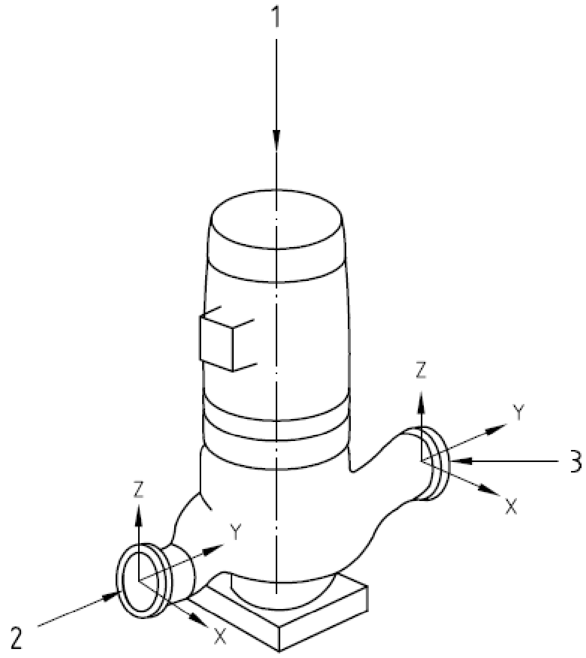
Table 4 — Nozzle loadings (*continued*)

	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.

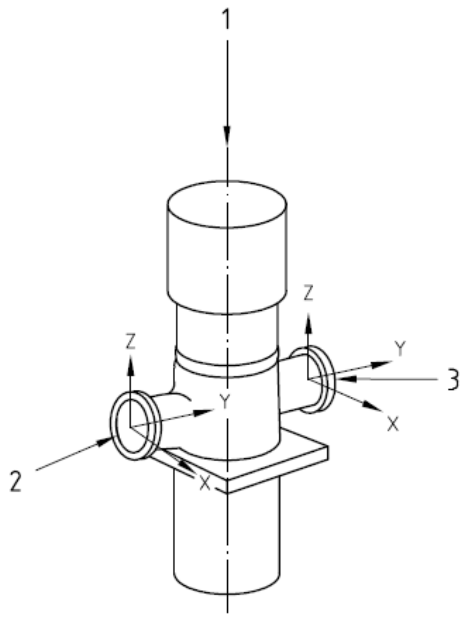
The coordinate systems and nozzle orientations for various pump configurations are shown next.



Key

1 shaft centreline
2 discharge
3 suction

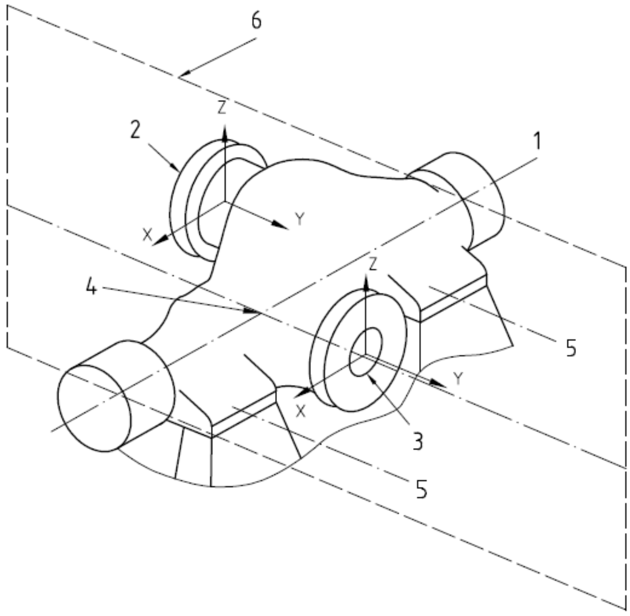
Figure 20 — Coordinate system for the forces and moments in Table 4 — Vertical in-line pumps



Key

1 shaft centreline
2 discharge
3 suction

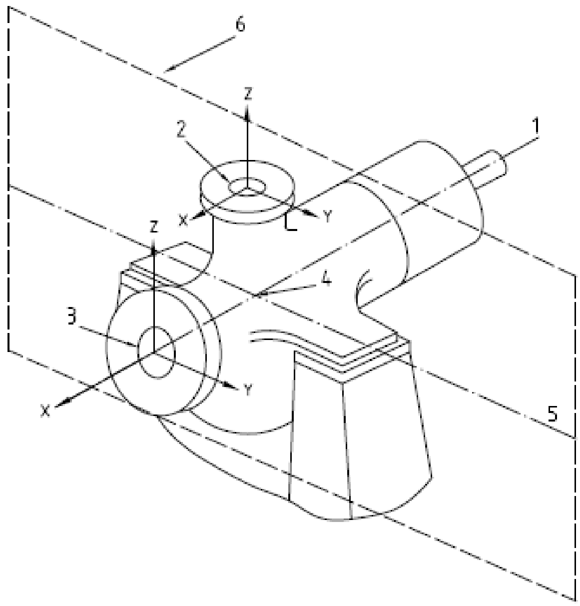
Figure 21 — Coordinate system for the forces and moments in Table 4 — Vertically suspended double-casing pumps



Key

1 shaft centreline
2 discharge nozzle
3 suction nozzle
4 centre of pump
5 pedestal centreline
6 vertical plane

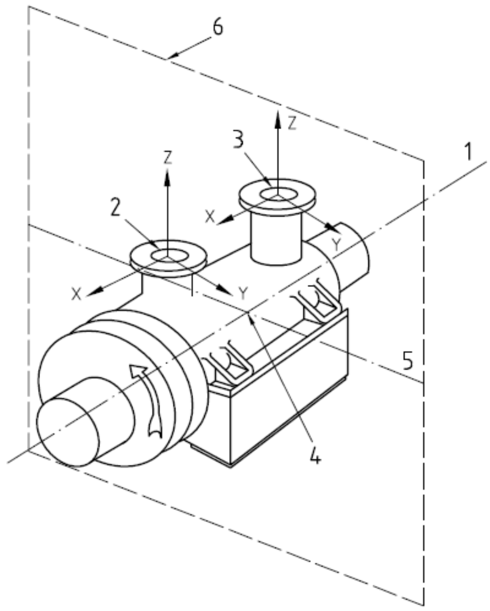
Figure 22 — Coordinate system for the forces and moments in Table 4 — Horizontal pumps with side suction and side discharge nozzles



Key

1 shaft centreline
2 discharge nozzle
3 suction nozzle
4 centre of pump
5 pedestal centreline
6 vertical plane

Figure 23 — Coordinate system for the forces and moments in Table 4 — Horizontal pumps with end suction and top discharge nozzles



Key

1 shaft centreline
2 discharge nozzle
3 suction nozzle
4 centre of pump
5 pedestal centreline
6 vertical plane

Figure 24 — Coordinate system for the forces and moments in Table 4 — 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 4 limit casing distortion to one-half the pump vendor's design criterion (see 5.3.3) 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 4 are also acceptable without consultation with the pump vendor if the conditions specified in F.1.2 a) through F.1.2 c) below are satisfied. Satisfying these conditions ensures that any pump casing distortion will be within the vendor's design criteria (see 5.3.3) and that the displacement of the pump shaft will be 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 4 (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 below.

$$[F_{RSA} / (1,5 \times F_{RST4})] + [M_{RSA} / (1,5 \times M_{RST4})] \leqslant 2 \quad \text{(F.1)}$$

$$[F_{RDA} / (1,5 \times F_{RDT4})] + [M_{RDA} / (1,5 \times M_{RDT4})] \leqslant 2 \quad \text{(F.2)}$$

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 Equation (F.3), Equation (F.4) and Equation (F.5) (the sign convention shown in Figure 20 through Figure 24 and the right-hand rule should be used in evaluating these equations).

$$F_{RCA} < 1,5\ (F_{RST4} + F_{RDT4}) \quad \text{(F.3)}$$

$$|\, M_{YCA} \,| < 2,0\ (M_{YST4} + M_{YDT4}) \quad \text{(F.4)}$$

$$M_{RCA} < 1,5\ (M_{RST4} + M_{RDT4}) \quad \text{(F.5)}$$

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.

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:

$$\sigma_p = (\sigma/2) + (\sigma^2/4 + \tau^2)^{0,5} < 41 \tag{F.6}$$

$$\sigma_l = [1{,}27 \times F_Y / (D_o^2 - D_i^2)] + [10\,200 \times D_o (M_X^2 + M_Z^2)^{0,5}] / (D_o^4 - D_i^4) \tag{F.7}$$

$$\tau = [1{,}27 \times (F_X^2 + F_Z^2)^{0,5}] / (D_o^2 - D_i^2) + [5\,100 \times D_o (|M_Y|)] / (D_o^4 - D_i^4) \tag{F.8}$$

For USC units, the following equations apply:

$$\sigma_p = (\sigma/2) + (\sigma^2/4 + \tau^2)^{0,5} < 5\,950 \tag{F.9}$$

$$\sigma_l = [1{,}27 \times F_Y / (D_o^2 - D_i^2)] + [122 \times D_o (M_X^2 + M_Z^2)^{0,5}] / (D_o^4 - D_i^4) \tag{F.10}$$

$$\tau = [1{,}27 \times (F_X^2 + F_Z^2)^{0,5}] / (D_o^2 - D_i^2) + [61 \times D_o (|M_Y|)] / (D_o^4 - D_i^4) \tag{F.11}$$

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.

Annexure B

Weld Strength Reduction Factors built into CAEPIPE

(as given in Table 102.4.7 of ASME B31.1 – 2012)

Weld Strength Reduction Factors applied for calculating the Allowable Design Pressure of components (extracted from Table 102.4.7 of ASME B31.1-2012).

Sl. No.	Steel Group	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700	750	800	850	900	950	1000	1050	1100	1150	1200
		(371)	(399)	(427)	(454)	(482)	(510)	(538)	(566)	(593)	(621)	(649)
1	Carbon Steel (CS) with Max. Temp in CAEPIPE is <= 800 [see note 1 below]	1.00	0.95	0.91	NP	NP	NP	NP	NP	NP	NP	NP
2	Carbon Steel (CS) with Max. Temp in CAEPIPE > 800	-	-	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64
3	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
4	Austenitic Steel (AS) [contd. in note 2 below]	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
5	Materials other than those stated from Sl. Nos. 1 to 4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

1. NP = Not permitted
2. 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

Annexure C

Thickness and Section Modulus used in Weight, Pressure and Stress Calculations for ASME B31.x Codes

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
B31.1 (2012)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus
B31.3 (2012)					
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	Uncorroded Section Modulus; For Branch, effective section modulus	*Corroded* Section Modulus; For Branch, effective section modulus
B31.4 (2012)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch effective section modulus
B31.5 (2013)					
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	Uncorroded Section Modulus; For Branch, effective section modulus	Corroded Section Modulus; For Branch, effective section modulus

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
B31.8 (2012)					
Pipe Thickness used	Nominal Thk.	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus
B31.9 (2008)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus

Note:

1. Corrosion allowance includes thickness required for threading, grooving, erosion, corrosion etc.
2. Uncorroded 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