The *FASTEST* Solutions for Piping Design and Analysis.

Readme Supplement

CAEPIPE

Version 7.40

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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 × (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

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

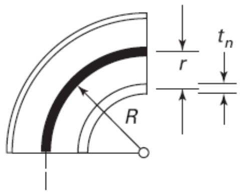
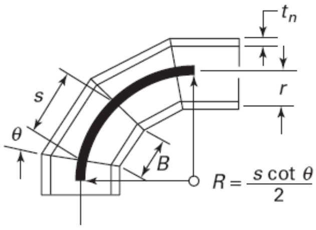
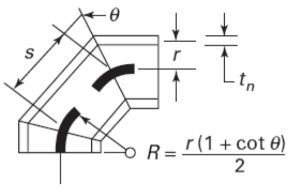
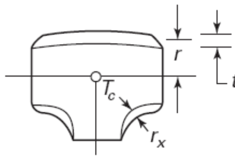
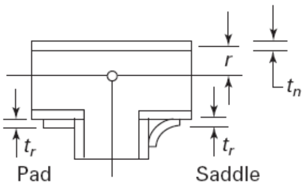
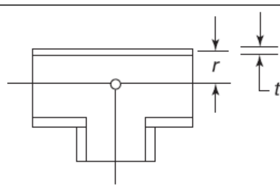
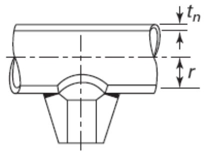
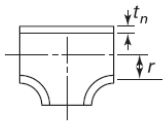
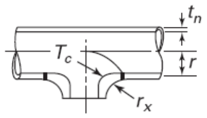
Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (5)] $s < r(1 + \tan \theta)$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

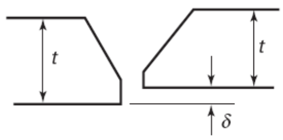
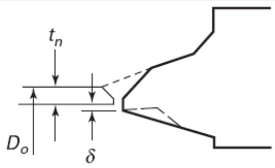
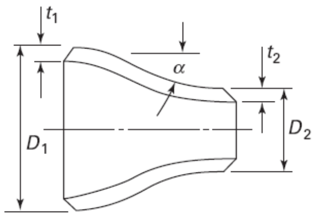
Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note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

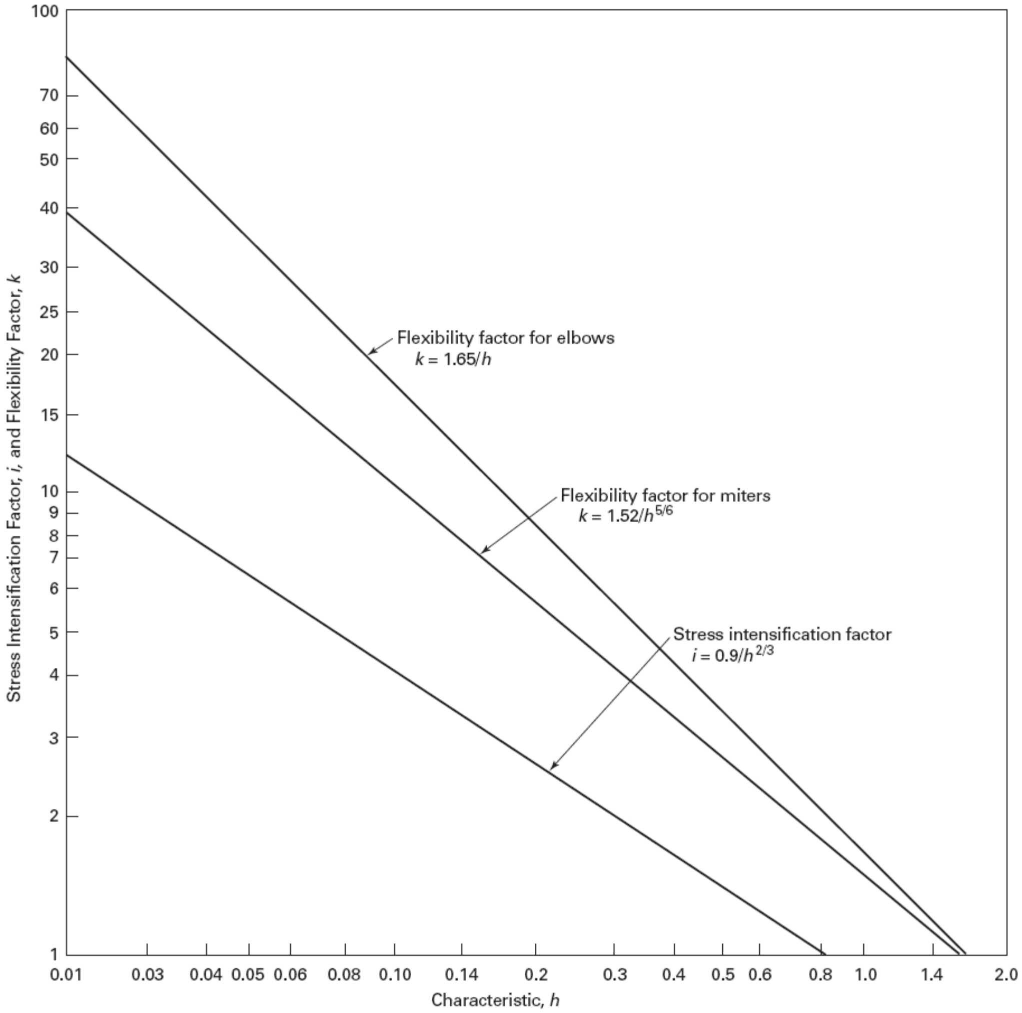
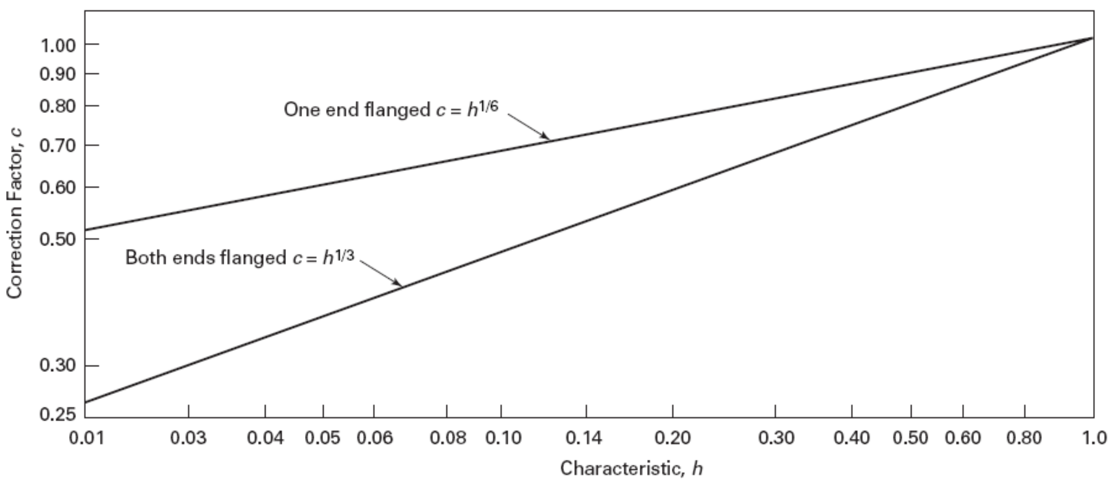


Chart D-2 Correction Factor, *c*



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

$Y = \dfrac{d+2c}{D+d+2c}$, 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 $0.75i_i$ shall not be less than 1.0

$I_o =$ out-of-plane stress intensification factor; the product of $0.75i_o$ 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

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

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

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

where

$S_{Lo} = S_L + S_O$, where S_L is computed as above, and

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

$$S_{ao} = \left[\frac{I_a F_a}{A_p}\right]_{occasional} = \left[\frac{(P_{peak} - P)D}{4t_s} + \frac{R}{A_p}\right]_{Occasional}$$

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

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

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)

$S_A = f(1.25 S_C + 0.25 S_h)$, 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). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f <= 1.0 for all materials including Ferrous materials.
2. Refer 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

See Table D300.

Table D300 Flexibility Factor, k, and Stress Intensification Factor, i

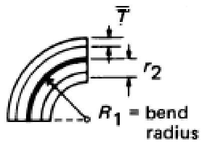
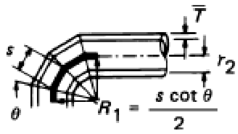
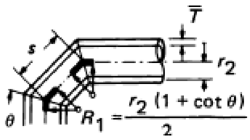
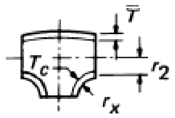
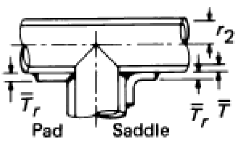
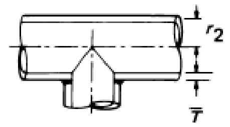
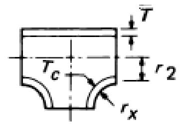
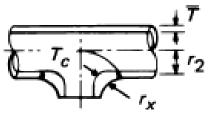
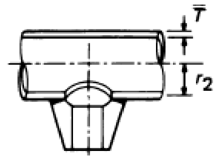
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (1), (3)–(6)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2 (1 + \tan\theta)$ [Notes (1), (3), (4), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot\theta}{2}\left(\frac{s\bar{T}}{r_2^2}\right)$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan\theta)$ [Notes (1), (3), (6)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot\theta}{2}\left(\frac{\bar{T}}{r_2}\right)$	
Welding tee in accordance with ASME B16.9 [Notes (1), (3), (5), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1 \frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1), (3), (8), (9), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2}\bar{T}_r)^{2.5}}{\bar{T}^{1.5} r_2}$	

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

Description	Flexibility Factor, k	Stress Intensification Factor [Notes (1), (2)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (1), (2)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Unreinforced fabricated tee [Notes (1), (3), (8), (10)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$, $T_c < 1.5\ \bar{T}$ [Notes (1), (3), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\bar{T}}{r_2}$	
Welded-in contour insert [Notes (1), (3), (7), (8)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4}i_o + \frac{1}{4}$	$3.1\ \frac{\bar{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (1), (3), (10), (11)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\ \frac{\bar{T}}{r_2}$	

Description	Flexibility Factor, k	Stress Intensification Factor, i
Butt welded joint, reducer, or weld neck flange	1	1.0
Double-welded slip-on flange	1	1.2
Fillet or socket weld	1	1.3 [Note (12)]
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6
Threaded pipe joint or threaded flange	1	2.3
Corrugated straight pipe, or corrugated or creased bend [Note (13)]	5	2.5

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

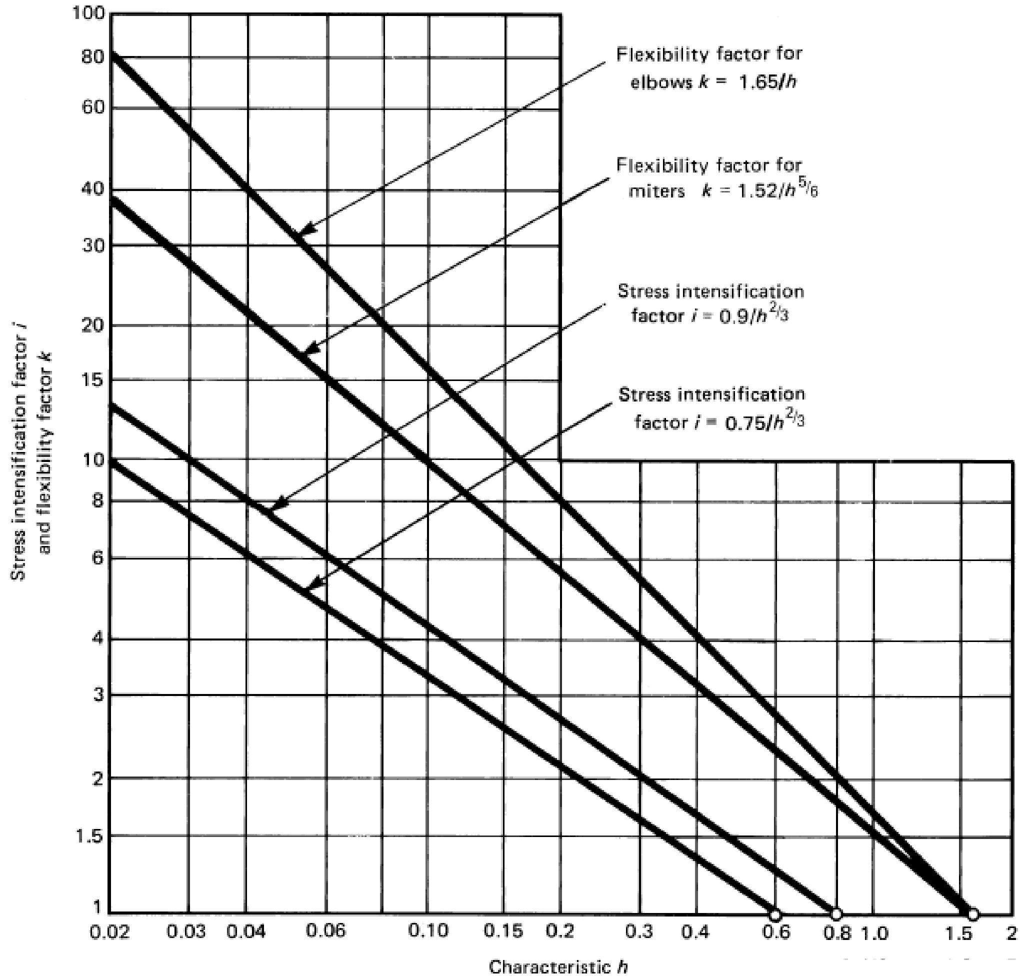


Chart A

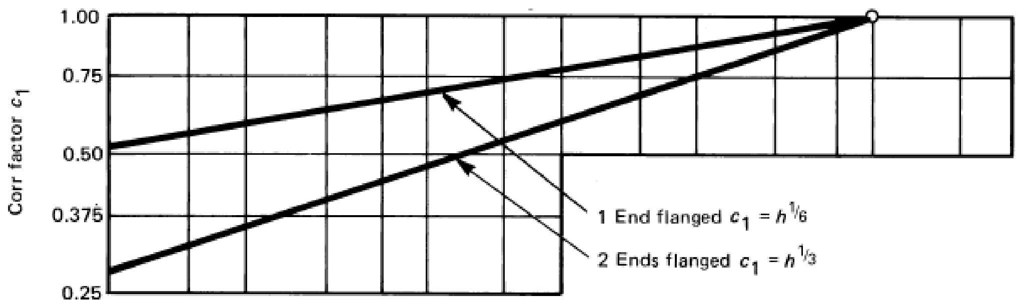


Chart B

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

GENERAL NOTE: Stress intensification and flexibility factor data in Table D300 are for use in the absence of more directly applicable data (see para. 319.3.6). Their validity has been demonstrated for $D/\overline{T} \leq 100$.

NOTES:

(1) The flexibility factor, k, in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k, and stress intensification factors, i, shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

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

(3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:

D_b = outside diameter of branch
R_1 = bend radius of welding elbow or pipe bend
r_x = see definition in para. 304.3.4(c)
r_2 = mean radius of matching pipe
s = miter spacing at centerline
$\overline{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting
= for tees, the nominal wall thickness of the matching pipe
T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
$\overline{T}_r$ = pad or saddle thickness
θ = one-half angle between adjacent miter axes

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

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

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i. To correct values from the Table, divide k by

$$1 + 6\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}$$

divide i by

$$1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

For consistency, use kPa and mm for SI metric, and psi and in. for U.S. customary notation.

(7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5\overline{T}$, a flexibility characteristic of $4.4\ \overline{T}/r_2$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

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

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

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

(12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.

(13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Annexure B

Weld Strength Reduction Factors built into CAEPIPE

(as given in Table 102.4.7 of ASME B31.1 – 2014)

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)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS) [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
4	Materials other than those stated from Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

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 (2014)					
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 (2014)					
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