The *FASTEST* Solutions for Piping Design and Analysis.

Readme Supplement

CAEPIPE

Version 6.52

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Annexure A

ASME B31.3 (2010)

Code Compliance

ASME B31.3 (2010)

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)

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

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5 is implemented in CAEPIPE as follows. T_{max} below denotes maximum operating temperature (i.e., max of T1, T2 and T3 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)

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 from para 320.2.

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

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, P2 and P3

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

$A_p =$ corroded cross-sectional area of the pipe computed using t_s as per para. 320.1.

$I_a =$ sustained longitudinal force index = 1.0

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

R = axial force due to weight

I_t = sustained torsional moment index. In the absence of more applicable data, is taken as 1.00

$I_i =$ 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

$M_i =$ in-plane bending moment

$M_o =$ out-of-plane bending moment

$M_t =$ torsional bending moment

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

S_h = hot allowable stress

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).

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

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

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

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

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

Z_m = corroded section modulus; for reduced outlets, effective section modulus

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

S_y = yield strength at maximum temperature and

W = 1.0 for Austenetic stainless steel and 0.8 for all other materials

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. 319.4.4

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

where

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

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

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 = allowable stress at cold temperature

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), fm = 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 B 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*

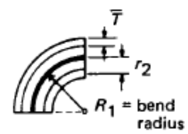
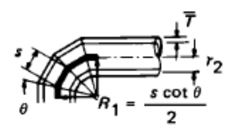
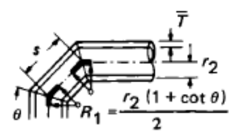
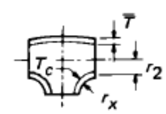
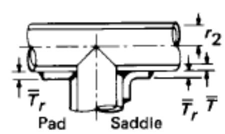
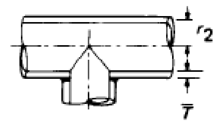
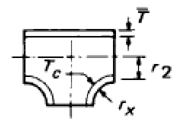
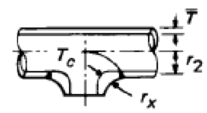
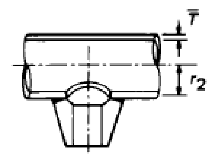
Description	Flexibility Factor, k	Stress Intensification Factor [Notes (2), (3)] Out-of-Plane, i_o	Stress Intensification Factor [Notes (2), (3)] In-Plane, i_i	Flexibility Characteristic, h	Sketch
Welding elbow or pipe bend [Notes (2), (4)-(7)]	$\frac{1.65}{h}$	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\bar{T}R_1}{r_2^2}$	
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	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{\overline{T}}{r_2}$	
Extruded welding tee with $r_x \geq 0.05\ D_b$, $T_c < 1.5\ \overline{T}$ [Notes (2), (4), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\left(1 + \frac{r_x}{r_2}\right)\frac{\overline{T}}{r_2}$	
Welded-in contour insert [Notes (2), (4), (8), (9)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$3.1\ \frac{\overline{T}}{r_2}$	
Branch welded-on fitting (integrally reinforced) [Notes (2), (4), (11), (12)]	1	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\ \frac{\overline{T}}{r_2}$	

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)

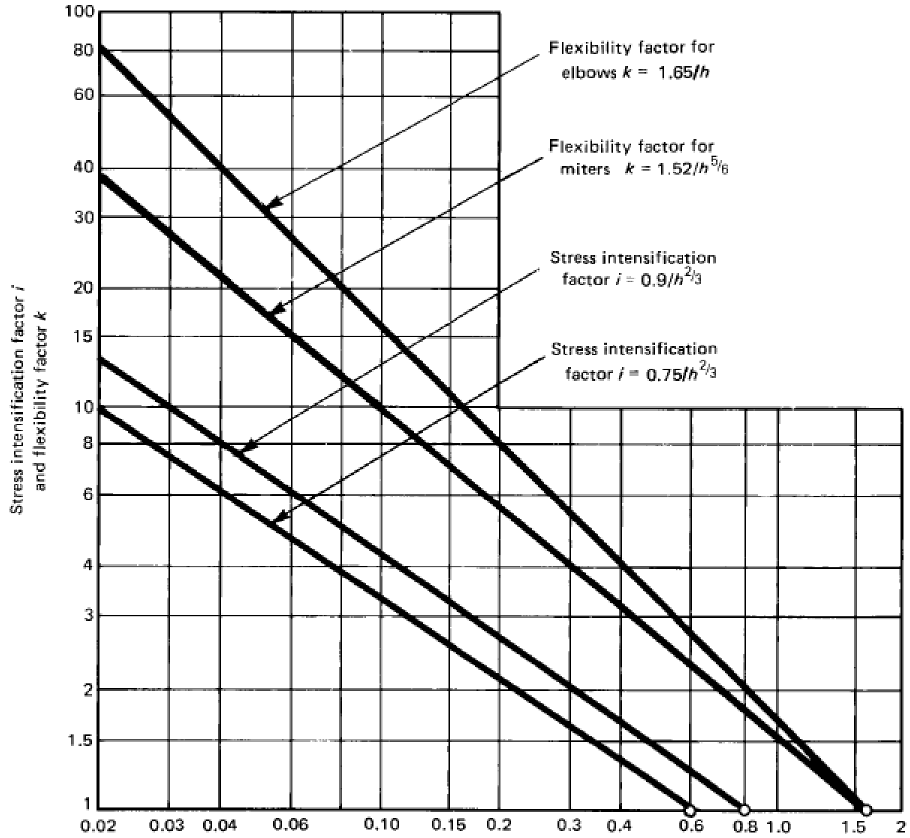


Chart A

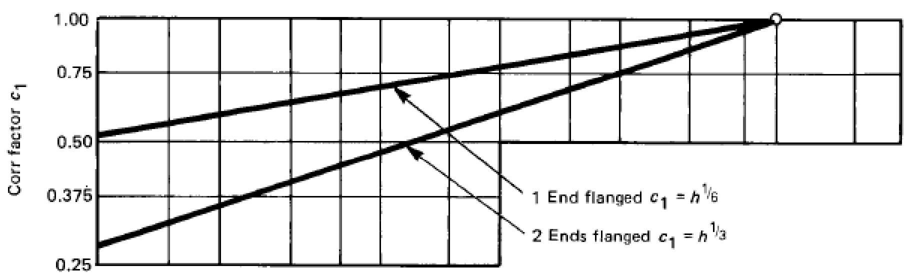


Chart B

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
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.

Annexure B

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 (2010)					
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 (2010)					
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 (2009)					
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 (2006)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness – Corrosion allowance	-	Nominal Thickness – Corrosion allowance

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
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
B31.8 (2007)					
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
B31.9 (2004)					
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