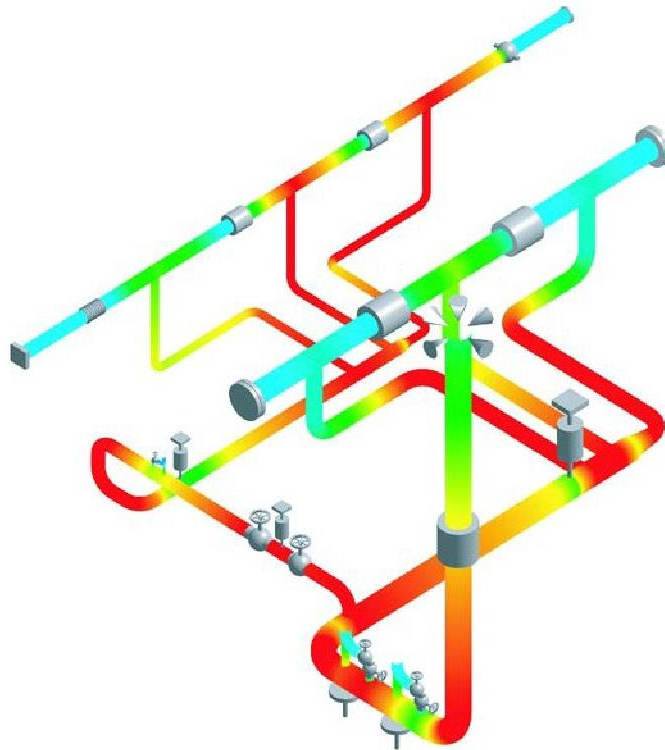


CAEPIPE™

Code Compliance Manual



From the CAdvantagE™ Library



SYSTEMS, INC.

the FASTEST Solutions for Piping Design and Analysis

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Table of Contents

PIPING CODE COMPLIANCE.....	1
ASME B31.1 (2020).....	1
ASME B31.1 (2018).....	1
ASME B31.1 (2016).....	11
ANSI B31.1 (1967)	21
ASME B31.3 (2018).....	24
ASME B31.3 (2016).....	35
ASME B31.3 (2014).....	46
ASME B31.4 (2019).....	55
ASME B31.4 (2016).....	63
ASME B31.4 (2012).....	71
ASME B31.5 (2016).....	78
ASME B31.8 (2018).....	83
ASME B31.8 (2016).....	93
ASME B31.8 (2012).....	103
ASME B31.9 (2017).....	112
ASME B31.9 (2014).....	120
ASME B31.12 (2019).....	128
ASME B31.12 (2014).....	139
ASME B31J (2017)	149
ASME CLASS 2 (1980)	166
ASME CLASS 2 (1986)	171
ASME CLASS 2 (1992)	176
ASME CLASS 2 (2015)	183
ASME CLASS 2 (2017)	191
ASME CLASS 3 (2017)	199
BS 806 (1986).....	207
IGEM (2012).....	211
EN 13480-3:2017/A2:2020	228
SS EN 13480-3:2017	240
SS EN 13480-3:2012	247
NORWEGIAN (1983).....	257
NORWEGIAN (1990).....	265
RCC-M (1985).....	276
CODETI (2013).....	281
CODETI (2006).....	295
STOOMWEZEN (1989)	307
SWEDISH (1978)	309
Z183 (1990).....	313
Z184 (1992).....	317
CSA Z662 (2019)	321
CSA Z662 (2015)	326
FRP STRESS	331
VON MISES STRESS	332
OPERATING STRESS FOR NDE/IMPACT TEST.....	338
THICKNESS AND SECTION MODULUS USED FOR B31.X CODES	342
ROTATING EQUIPMENT QUALIFICATION.....	346
API 610	347
ANSI/HI 9.6.2	360
NEMA SM-23.....	374
API 617	376

Table of Contents

FLANGE QUALIFICATION	378
PRESSURE DESIGN – EN 13480-3	396
LUG EVALUATION	405
ASME SECTION III, DIV 1 (2010)	406
EN 13480-3 (2017).....	416
NOZZLE EVALUATION.....	426
EN 13445-3:2019 - ALLOWABLE NOZZLE LOADS ON SPHERICAL SHELLS.....	427
EN 13445-3:2019 - ALLOWABLE NOZZLE LOADS ON CYLINDRICAL SHELLS.....	428
WRC 537 – SPHERICAL SHELLS	430
WRC 537 – CYLINDRICAL SHELLS.....	433
ASCE/SEI 7	438
EARTHQUAKE LOAD – ASCE/SEI 7-16	439
WIND LOAD – ASCE/SEI 7-16	442
EN1991-1-4 (2010)	449
WIND LOAD	450
INDEX.....	455

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Power Piping ASME B31.1 (2020)

Allowable Pressure

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

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

where

P_a = allowable pressure

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

t_a = available thickness for pressure design = $t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

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

t_n = nominal pipe thickness

D_o = outside diameter of pipe

d = inside diameter of pipe

I = 1.0 for straight pipes

$I = \frac{4(R/D_o)-1}{4(R/D_o)-2}$ for pipe bends / elbows

R = bend radius of pipe bend

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

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

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

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

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

Power Piping
ASME B31.1 (2020)

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

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

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

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

where

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

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

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

Sustained Stress

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

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

where

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

D_o = nominal outside diameter

t_n = nominal wall thickness

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

I_a = sustained longitudinal force index = 1.00

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

Power Piping
ASME B31.1 (2020)

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

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

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

Z = nominal section modulus = un-corroded section modulus

A_p = un-corroded nominal cross sectional area

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

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

Occasional Stress

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

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

where

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

I_a = occasional longitudinal force index = 1.00

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

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

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

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

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

Power Piping
ASME B31.1 (2020)

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

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

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

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

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

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

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

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

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

$$\left| \frac{P_o D_o}{4t_n} + \frac{I_a F_b}{A_p} \right| = \left| \frac{P_o D_o}{4t_n} + \frac{I_a F_b(sust)}{A_p} + \frac{I_a F_b(occa)}{A_p} \right|$$

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

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

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

where

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

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

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

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

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

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

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

where

F_c = axial force range due to reference displacement load range

A_p = un-corroded nominal cross sectional area

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

M_{ic} , M_{oc} , M_{tc} = in-plane, out-of-plane and torsional moment range respectively due to the reference displacement load range

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

Z = nominal section modulus = un-corroded section modulus

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

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

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

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

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

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

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

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

Note:

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

Power Piping
ASME B31.1 (2020)

Settlement Stress

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

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

where

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

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

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

A_p = un-corroded nominal cross sectional area

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

Z = nominal section modulus = un-corroded section modulus

S_C = allowable stress at the Reference Temperature in CAEPIPE

Power Piping
ASME B31.1 (2020)

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

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

Notes:

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

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

**Power Piping
ASME B31.1 (2020)**

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

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)										
		700	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) [see Note (a)]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Ferritic Steels (FS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
3	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77
4	Material Description that contains a string "CrMo"	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64
5	Material Types other than those stated in Sl. Nos. 1 to 3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

- (a) Based on Note 7 of Table 102.4.7-1 of ASME B31.1 (2020) code, $W = 1.0$ for Carbon Steel (CS).
- (b) For Austenitic Steels (including 800H and 800 HT), values up to 1500 deg F are as follows:

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

Power Piping
ASME B31.1 (2018)
[Superseded by ASME B31.1 (2020)]

Allowable Pressure

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

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

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

where

P_a = allowable pressure

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

t_a = available thickness for pressure design = $t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

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

t_n = nominal pipe thickness

D_o = outside diameter of pipe

d = inside diameter of pipe

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

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

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

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

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

Power Piping ASME B31.1 (2018)

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

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

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

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

where

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

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

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

Sustained Stress

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

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

where

P = maximum of CAEPIPE pressures P1 through P10

D_o = outside diameter

t_n = nominal wall thickness

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

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

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

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

Power Piping
ASME B31.1 (2018)

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),

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

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

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

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

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


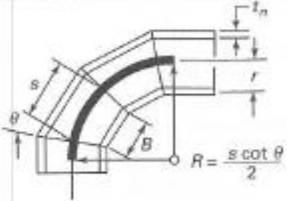
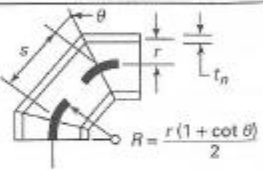
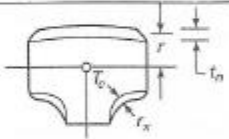
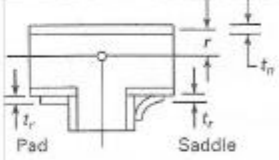
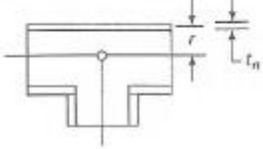
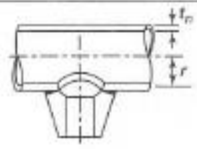
This is specified as an analysis option: “Use liberal allowable stresses”, in the menu Options->Analysis on the Code tab of CAEPIPE.

Note:

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

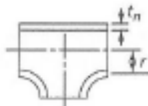
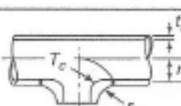
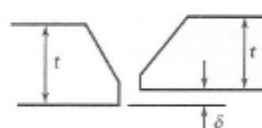
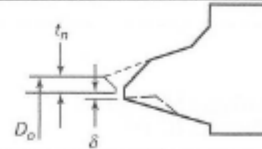
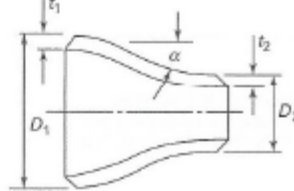
Power Piping
ASME B31.1 (2018)

Table D-1 Flexibility and Stress Intensification Factors

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

Power Piping
ASME B31.1 (2018)

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

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Illustration
Extruded outlet meeting the requirements of para. 104.3.1(g) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert [Notes (1), (2), (7)]	$\frac{3.1t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Description	Flexibility Factor, k	Stress Intensification Factor, i		Illustration
Branch connection [Notes (1), (10)]	1	For checking branch end $1.5 \left(\frac{R_m}{t_{nb}} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{t_{nb}}{t_m} \right) \left(\frac{r'_m}{r_p} \right)$		See Figure D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq \frac{1}{16}$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]		
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq \frac{1}{8}$ 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., $\delta_{max} \leq \frac{1}{16}$ in., and $\delta_{avg}/t \leq 0.33$	1	1.0		
Fillet welds	1	1.3 [Note (12)]		See Figures 127.4.4-1, 127.4.4-2, and 127.4.4-3
F tapered transition per para. 127.4.2(b) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_b}{t_n} + 3.6 \frac{\delta}{t_n}$		
Concentric reducer per ASME B16.9 [Notes (1), (13)]	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_2}{t_2} \right)^{1/2}$		

Power Piping ASME B31.1 (2018)

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

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

GENERAL NOTES:

- (a) The validity of the stress intensification and flexibility factor data in Table D-1 has been demonstrated for $D_o/t_n \leq 100$.
- (b) The designer may use the stress intensification and flexibility factors from ASME B31J instead of the stress intensification and flexibility factors herein. When using the stress intensification factors from ASME B31J, the maximum of the in-plane (i_i), out-plane (i_o), and torsional (i_t) stress intensification factors shall be used in calculating stresses in accordance with para. 104.8. Alternatively, stress intensification factors may be developed using ASME B31J, Nonmandatory Appendix A.

NOTES:

- (1) The following nomenclature applies to Table D-1:
 - B = length of miter segment at crotch, in. (mm)
 - D_1 = outside diameter of reducer on large end, in. (mm)
 - D_2 = outside diameter of reducer on small end, in. (mm)
 - D_o = outside diameter, in. (mm)
 - D_{ob} = outside diameter of branch, in. (mm)
 - R = bend radius of elbow or pipe bend, in. (mm)
 - r = mean radius of pipe, in. (mm) (matching pipe for tees)
 - r_e = external crotch radius of welded-in contour inserts and welding tees, in. (mm)
 - s = miter spacing at centerline, in. (mm)
 - T_c = crotch thickness of welded-in contour inserts and welding tees, in. (mm)
 - t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
 - t_r = reinforcement pad or saddle thickness, in. (mm)
 - α = reducer cone angle, deg
 - δ = mismatch, in. (mm)
 - θ = one-half angle between adjacent miter axes, deg
- (2) The flexibility factors, k , and stress intensification factors, i , in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Figure D-2 by entering with the characteristic, h , computed from the formulas given.
- (3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor, c , given below, which can be read directly from Figure D-3, entering with the computed h : one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.
- (4) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i . Values from the Table may be corrected by dividing k by

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

and dividing i by

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

- (6) Also includes single miter joints.
- (7) If $r_e \geq D_{ob}/8$ 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.
- (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.

Power Piping ASME B31.1 (2018)

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

NOTES (Cont'd):

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

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

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

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

(1) $0.002\theta d_0$

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

(g) $R_{in}/t_{nb} \leq 50$ and $r_m/R_{in} \leq 0.5$.

(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 Figure 127.4.4-3. For welds to socket welding flanges, the stress intensification factor is based on the weld geometry shown in Figure 127.4.4-2 and has been shown to envelop the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld, with no undercut, smoothly into the pipe wall, as shown in the concave fillet welds in Figure 127.4.4-1, illustrations (b) and (d), has been shown to improve the fatigue performance of the weld.

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

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

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

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

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

Power Piping
ASME B31.1 (2018)

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

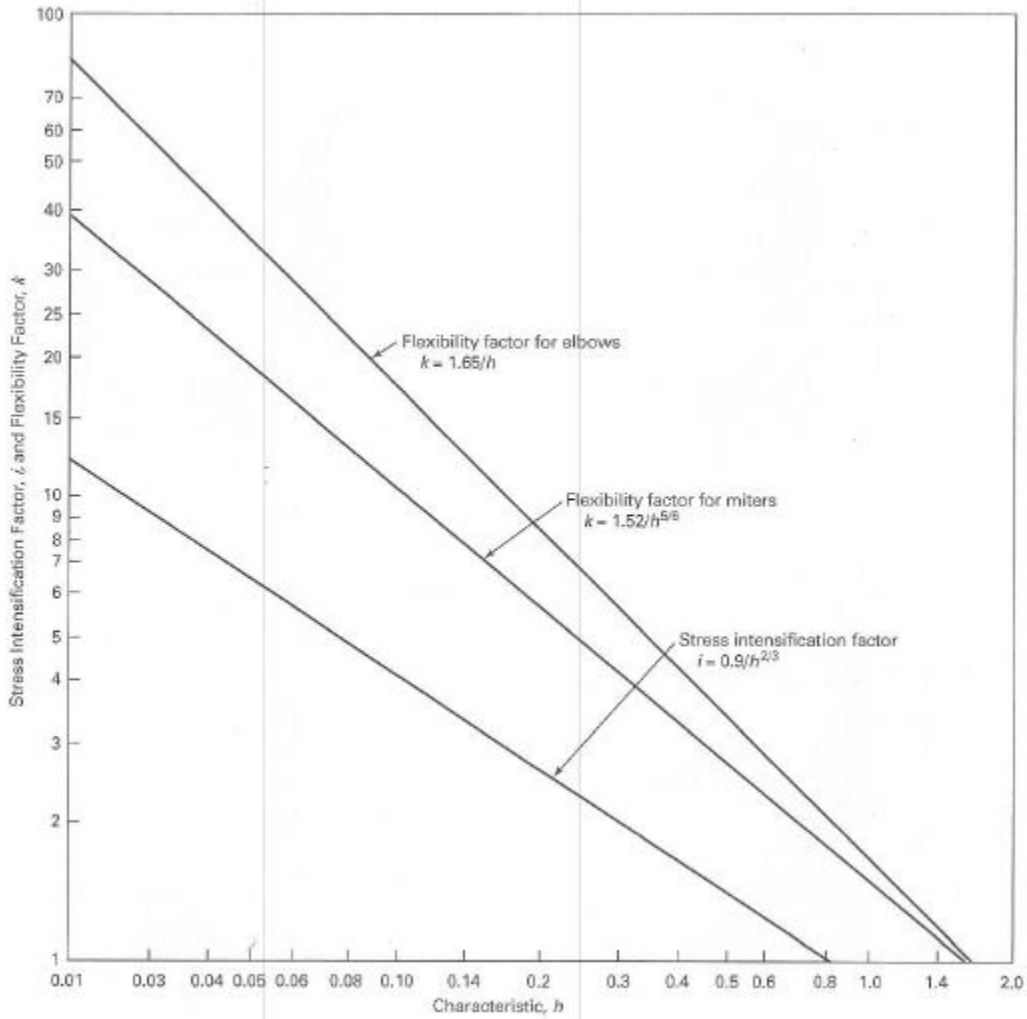
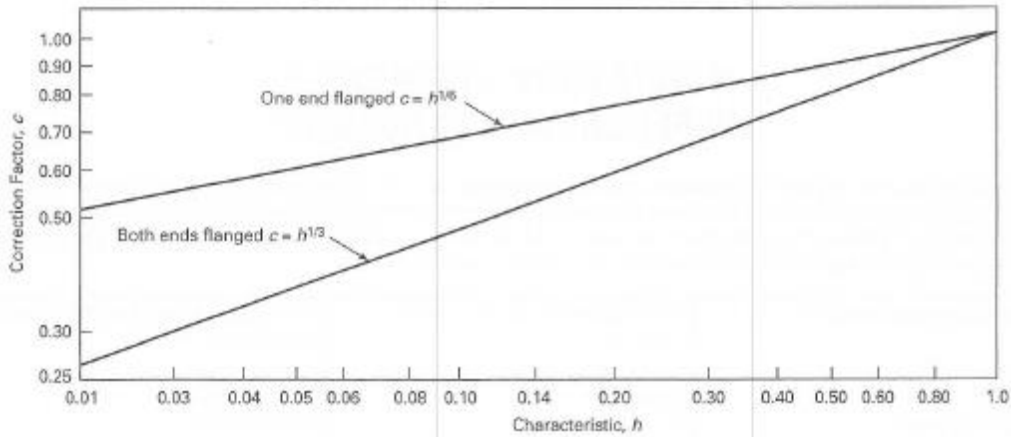


Figure D-3 Correction Factor, c



Power Piping
ASME B31.1 (2018)

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

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

Notes:

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

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

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

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

Power Piping
ASME B31.1 (2018)

Notes:

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

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

Power Piping
ASME B31.1 (2016)
[Superseded by ASME B31.1 (2018)]

Allowable Pressure

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

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

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

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

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

where

P_a = allowable pressure

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

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

t_a = available thickness for pressure design = $t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

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

t_n = nominal pipe thickness

D_o = outside diameter of pipe

d = inside diameter of pipe

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

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

Power Piping ASME B31.1 (2016)

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

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

Power Piping ASME B31.1 (2016)

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),

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

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

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

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

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

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

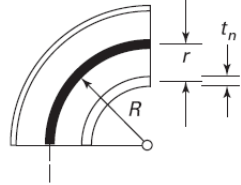
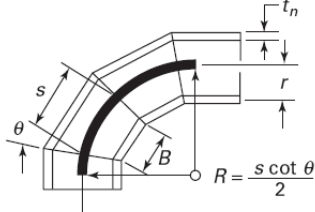
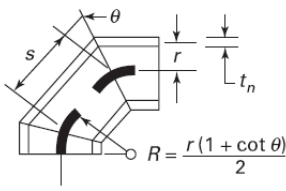
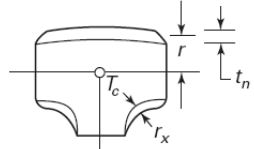
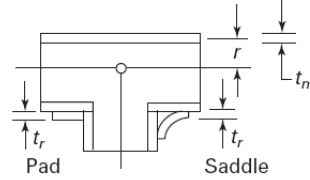
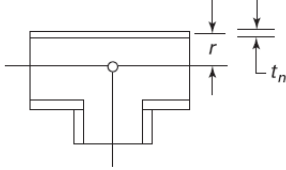
Note:

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

Power Piping
ASME B31.1 (2016)

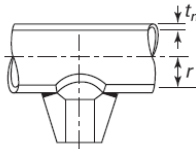
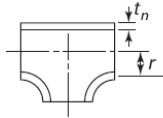
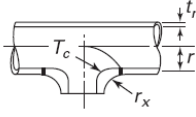
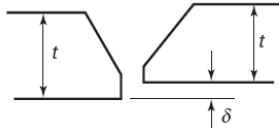
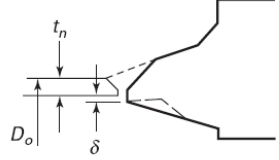
MANDATORY APPENDIX D

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)]	$\frac{(t_n + \frac{t_r}{2})^{5/2}}{r (t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (9)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

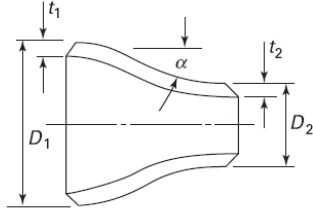
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Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

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 $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$		

Power Piping ASME B31.1 (2016)

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.

Power Piping

ASME B31.1 (2016)

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.

Power Piping ASME B31.1 (2016)

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

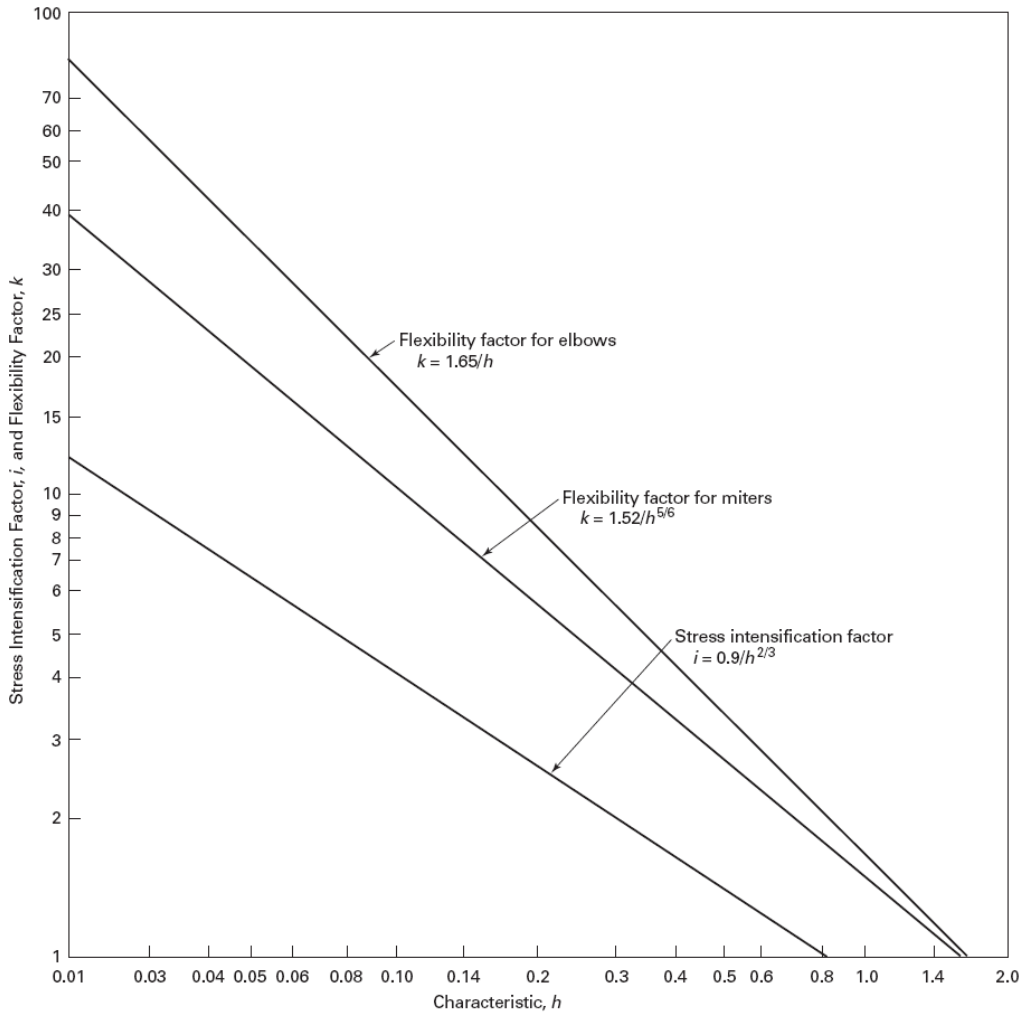
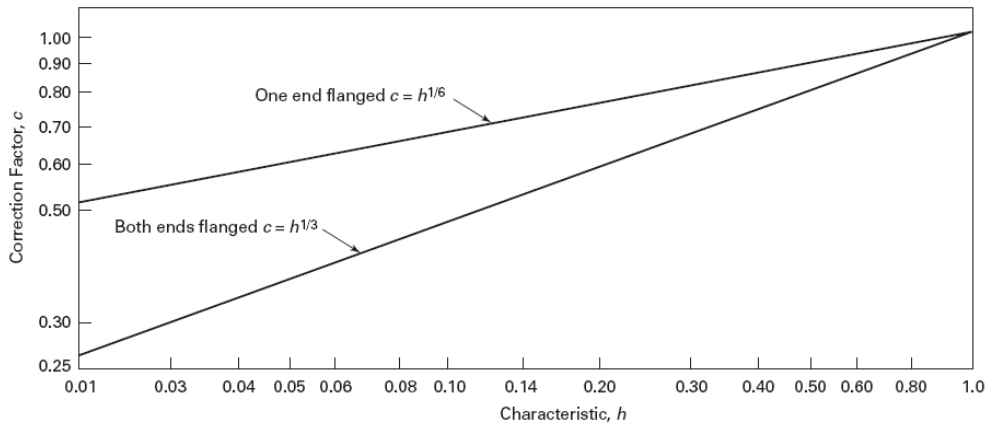


Chart D-2 Correction Factor, c



Power Piping
ASME B31.1 (2016)

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

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

Notes:

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

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

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

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

Power Piping
ASME B31.1 (2016)

Notes:

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

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

ANSI B31.1 (1967)

Allowable Pressure

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

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

where

P = allowable pressure

S = allowable stress

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical, corrosion, and erosion allowances

= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient from Table 104.1.2(a)2

Sustained Stress

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

$$S_L = \frac{PD}{4t_m} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \leq S_h$$

where

P = maximum pressure

D = outside diameter

t_m = minimum wall thickness

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 = section modulus

S_h = hot allowable stress

Occasional Stress

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

$$S_{LO} = S_L + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \leq 1.2S_h$$

Expansion Stress

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

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

where

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

$$S_t = \text{torsional stress} = M_t / 2Z$$

Z = un-corroded section modulus, for a branch, effective section modulus

$$S_A = f(1.25S_c + 0.25S_h)$$

S_c = allowable stress at cold temperature

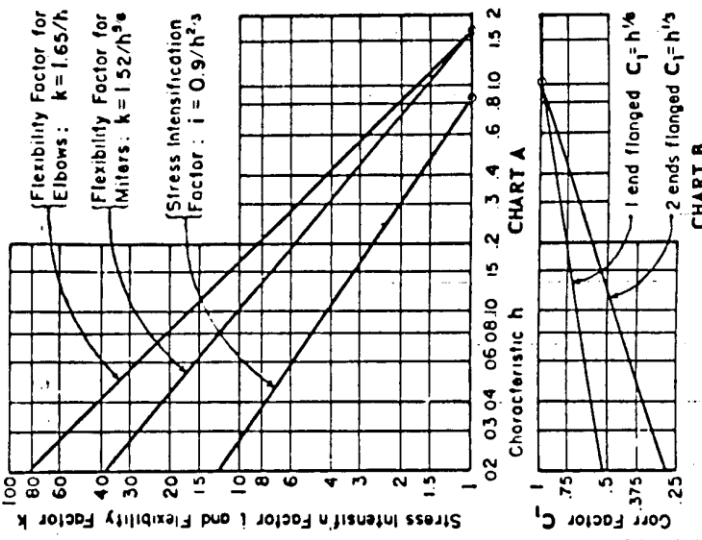
f = stress range reduction factor from Table 102.3.2(c).

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

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

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

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS



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

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

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

r_2 = mean radius of matching pipe, inches
 \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting (see note 7), inches.
 \bar{T} = for tees, the nominal wall thickness of the matching pipe, inches.

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

One end flanged: $C_1 = \frac{1}{2}$
 Both ends flanged: $C_1 = \frac{1}{4}$

⁴Also includes single-miter joint.
⁵Factors shown apply to bending; flexibility factor for torsion equals 0.9.

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

⁷The 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.

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

Process Piping
ASME B31.3 (2018)

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with $I = 1.0$ for bends from paras. 304.1.2. and 304.2.1. respectively.

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

where

P_a = allowable pressure

S = allowable stress as provided in para. 302.3.1 (a) and as per Table A-1

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

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5. Refer to the Table listed at the end of this section for details on Weld strength reduction factor implemented in CAEPIPE.

t_a = available thickness for pressure design

$$= t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance "c"}$$

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

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

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

$$Y = \frac{d+2c}{D+d+2c}, \text{ valid for } t_a \geq D/6 \text{ for all material types.}$$

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

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

For widely spaced miter bends with $\theta \leq 22.5$ deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. 304.2.3 as

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

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

Process Piping
ASME B31.3 (2018)

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

where

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

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

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

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) from para. 320.2 and para. 302.3.5 (c).

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

where

$$S_a = \left[\frac{I_a F_a}{A_p} \right]_{\text{Sustained}} = \left[\frac{PD}{4t_s} + \frac{R}{A_p} \right]_{\text{Sustained}}$$

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

For branch (Leg 3 in Fig. 319.4.4B),

$$S_b = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_3} \right]_{\text{Sustained}}$$

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

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

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

I_a = longitudinal force index = 1.0

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

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

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

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

I_t = torsional moment index = 1.0

**Process Piping
ASME B31.3 (2018)**

- M_i = in-plane bending moment due to sustained loads e.g., pressure and weight
 M_o = out-of-plane bending moment due to sustained loads e.g., pressure and weight
 M_t = torsional moment due to sustained loads e.g., pressure and weight
 Z_m = corroded section modulus as per para. 320.1
 Z_3 = effective corroded section modulus (Z_e) when Appendix D of B31.3 is used to compute i_i and i_o (or corroded section modulus (Z_m) when B31J is used to compute i_i and i_o)
 S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref} , T_1 through T_{10})

Note:

i_i and i_o are taken from Appendix D of B31.3 (2018) or ASME B31J (2017), when the Analysis option “Use B31J for SIFs and Flexibility Factors” is Turned ON in CAEPIPE.

Sustained plus Occasional Stress

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

For temp $\leq 427^\circ\text{C}$ or 800°F

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

For temp $> 427^\circ\text{C}$ or 800°F

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

where

$S_{LO} = S_L + S_o$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) with applicable loads as per para. 302.3.6 (a).

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

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

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

For branch (Leg 3 in Fig. 319.4.4B)

$$S_{bo} = \left[\frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{Z_3} \right]_{Occasional}$$

Process Piping
ASME B31.3 (2018)

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

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

R = axial force due to occasional loads such as earthquake or wind

M_i = in-plane bending moment due to occasional loads such as earthquake or wind

M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind

M_t = torsional moment due to occasional loads such as earthquake or wind

S_y = yield strength at maximum temperature, i.e., max (T_{ref} , T_1 through T_{10})

W = 1.0 for Austenetic stainless steel and 0.8 for all other materials as per para. 302.3.6(a)

Z_m = corroded section modulus as per para. 320.1

Z_3 = effective corroded section modulus (Z_e) when Appendix D of B31.3 is used to compute i_i and i_o (or) corroded section modulus (Z_m) when B31J is used to compute i_i and i_o

Expansion Stress

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

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

where

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

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

For branch (Leg 3 in Fig. 319.4.4B)

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_3} \right]_{Expansion}$$

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

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D , as per para. 319.3.5.

i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ or i for other components as listed in Appendix D of B31.3 or as per B31J

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

i_i = in-plane stress intensification factor; shall not be less than 1.0

i_o = out-of-plane stress intensification factor; shall not be less than 1.0

i_t = torsional stress intensification factor as listed in Appendix D of B31.3 or as per B31J

Process Piping ASME B31.3 (2018)

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus as per para. 319.3.5 and para. 319.4.4 (a)

Z_3 = effective un-corroded section modulus (Z_c) when Appendix D of B31.3 is used to compute i_i and i_o (or) un-corroded section modulus (Z) when B31J is used to compute i_i and i_o

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)

f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$
where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)

N = equivalent number of full displacement cycles during expected service of piping (= Number of Thermal Cycles input into CAEPIPE through Options > Analysis > Temperature)

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

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

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

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

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

Notes:

1. As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures $\leq 371^\circ\text{C}$ (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence $f \leq 1.0$ for all materials including Ferrous materials.
2. Young’s modulus of elasticity corresponding to reference temperature (E_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).
3. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.
4. i_i and i_o are taken from Appendix D of B31.3 (2018) or ASME B31J (2017), when the Analysis option “Use B31J for SIFs and Flexibility Factors” is Turned ON in CAEPIPE.

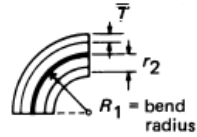
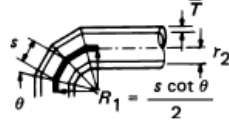
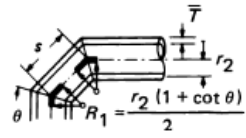
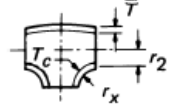
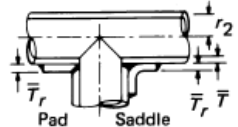
Notes on Material Library for B313-2018.mat supplied with CAEPIPE:

Material library for ASME B31.3 (2018) [B313-2018.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix A and Appendix C of ASME B31.3 (2018).

APPENDIX D FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

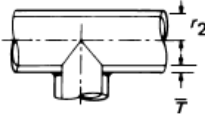
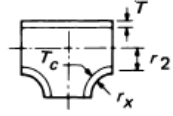
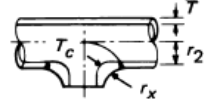
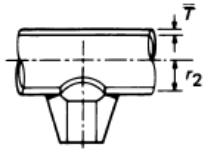
See Table D300.

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

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

Process Piping ASME B31.3 (2018)

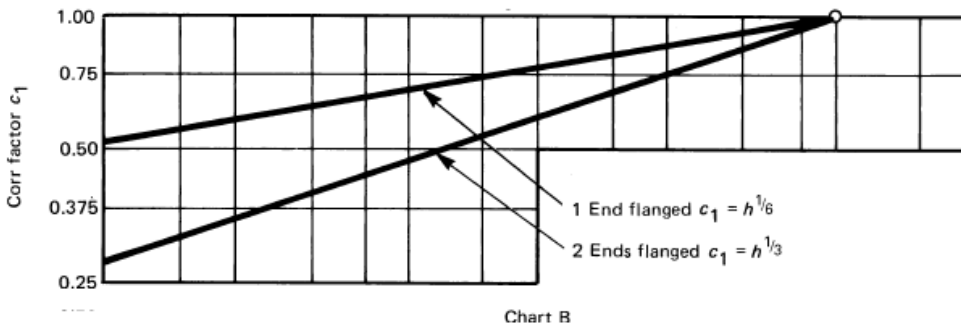
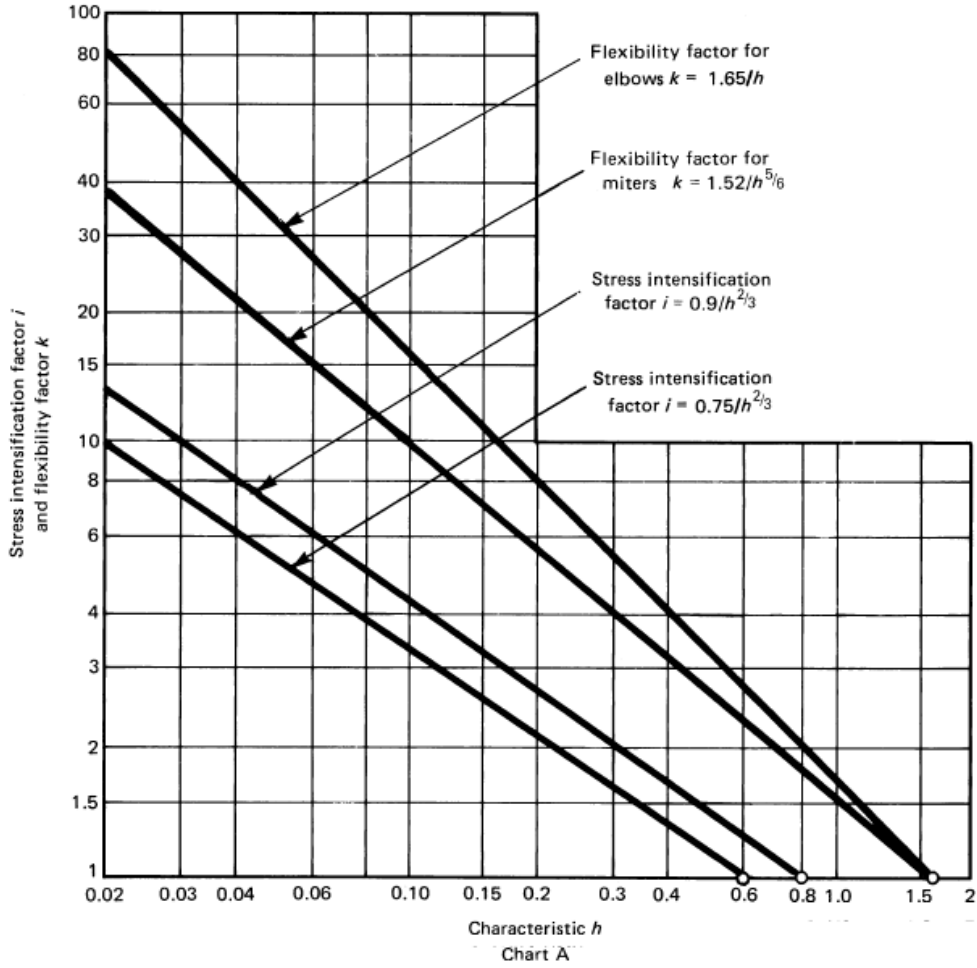
Table D300 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

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

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

Process Piping
ASME B31.3 (2018)

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



Process Piping ASME B31.3 (2018)

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

(14)

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

NOTES:

- (1) The flexibility factor, k , in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k , and stress intensification factors, i , shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.
- (2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.
- (3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:
 - D_b = outside diameter of branch
 - R_1 = bend radius of welding elbow or pipe bend
 - r_x = see definition in para. 304.3.4(c)
 - r_2 = mean radius of matching pipe
 - s = miter spacing at centerline
 - \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting
 - = for tees, the nominal wall thickness of the matching pipe
 - \bar{T}_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
 - \bar{T}_r = pad or saddle thickness
 - θ = one-half angle between adjacent miter axes
- (4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 , which can be read directly from Chart B, entering with the computed h .
- (5) The designer is cautioned that cast butt-welded 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

$$1 + 6 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3}$$

divide i by

$$1 + 3.25 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3}$$

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

- (7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5 \bar{T}$, a flexibility characteristic of $4.4 \bar{T}/r_2$ may be used.
- (8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.
- (9) When \bar{T}_r is $> 1\frac{1}{2} \bar{T}$, use $h = 4 \bar{T}/r_2$.
- (10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.
- (13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Process Piping
ASME B31.3 (2018)

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 304.1.1 of ASME B31.3 – 2018)

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

Process Piping
ASME B31.3 (2018)

Weld Strength Reduction Factors used in CAEPIPE to calculate the Allowable Design Pressure of components (extracted from Table 302.3.5 of ASME B31.3-2018)

Sl. No.	Material Type/Material Description	Weld Strength Reduction Factor for Temperature, Deg F (Deg C)														
		<=80 0 (427)	850 (454)	900 (482)	950 (510)	1000 (538)	1050 (566)	1100 (593)	1150 (621)	1200 (649)	1250 (677)	1300 (704)	1350 (732)	1400 (760)	1450 (788)	1500 (816)
1	Carbon Steel (CS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Material Description that contains a string "CrMo"	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.64	0.64	0.64	0.64	0.64	0.64
3	Ferritic Steels (FS) [CSEF & CSEF (N+T)]	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.77	0.77	0.77	0.77	0.77	0.77
4	Austenitic Steel (AS)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
5	Nickel Alloy (NA)	1.00	1.00	1.00	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55	0.5
6	Stainless Steel (SS)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7	Material Types other than those stated in Sl. Nos. 1 to 6	1.00	$W = 1 - 0.000909 (T_{max} - T_{cr})$ for $T_{max} > 800$ deg. F (or 427 deg. C) and ≤ 1500 deg. F (or 816 deg. C), where, T_{cr} is taken as 800 deg. F													

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with $I = 1.0$ for bends from paras. 304.1.2. and 304.2.1. respectively.

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

where

P_a = allowable pressure

S = allowable stress as provided in para. 302.3.1 (a) and as per Table A-1

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

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5 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 $T_{max} \leq 800^{\circ} \text{F}$ (or 427°C)

$W = 0.64$ with $T_{max} > 1200^{\circ} \text{F}$ (or 649°C) and

For $T_{max} > 800^{\circ} \text{F}$ (or 427°C) and $\leq 1200^{\circ} \text{F}$ (or 649°C), the values of W are taken from Table 302.3.5.

W for intermediate temperatures is linearly interpolated.

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

$W = 1.0$ with $T_{max} \leq 900^{\circ} \text{F}$ (or 482°C)

$W = 0.5$ with $T_{max} > 900^{\circ} \text{F}$ (or 482°C)

With Material Type in CAEPIPE = AS or NA

$W = 1.0$ with $T_{max} \leq 950^{\circ} \text{F}$ (or 510°C)

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

W for intermediate temperatures is linearly interpolated.

With Material Type in CAEPIPE = SS

$W = 1.0$ with $T_{max} \leq 1500^{\circ} \text{F}$ (or 816°C)

For Other Material Types in CAEPIPE

$W = 1.0$ with $T_{max} \leq 800^{\circ} \text{F}$ (or 427°C)

**Process Piping
ASME B31.3 (2016)**

$W = 1 - 0.000909 (T_{\max} - T_{cr})$ for $T_{\max} > 800^{\circ} \text{F}$ (or 427°C) and $\leq 1500^{\circ} \text{F}$ (or 810°C)

where, T_{cr} is taken as 800°F

t_a = available thickness for pressure design

$$= t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance "c"}$$

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

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

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

$$Y = \frac{d+2c}{D+d+2c}, \text{ valid for } t_a \geq D/6 \text{ for all material types.}$$

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

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

For widely spaced miter bends with $\theta \leq 22.5$ deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. 304.2.3 as

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

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

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

where

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

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

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

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) from para. 320.2 and para. 302.3.5 (c).

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

where

$$S_a = \left[\frac{I_a F_a}{A_p} \right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p} \right]_{Sustained}$$

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

For branch (Leg 3 in Fig. 319.4.4B),

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

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

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

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

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

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

I_a = longitudinal force index = 1.0

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

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

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

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

where i_i and i_o are taken from Appendix D of B31.3 (2016).

I_t = torsional moment index = 1.0

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

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

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

Z_m = corroded section modulus as per para. 320.1

Z_e = effective corroded section modulus for branch as per para. 320.2

Sustained plus Occasional Stress

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

For temp $\leq 427^\circ\text{C}$ or 800°F

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

For temp $> 427^\circ\text{C}$ or 800°F

$$S_{Lo} \leq 0.9WS_y$$

where

$S_{Lo} = S_L + S_o$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) with applicable loads.

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

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

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

For branch (Leg 3 in Fig. 319.4.4B)

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

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

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

R = axial force due to occasional loads such as earthquake or wind

M_i = in-plane bending moment due to occasional loads such as earthquake or wind

M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind

M_t = torsional moment due to occasional loads such as earthquake or wind

S_y = yield strength at maximum temperature, i.e., max (T_{ref} , T_1 through T_{10})

W = 1.0 for Austenitic stainless steel and 0.8 for all other materials as per para. 302.3.6(a)

Z_m = corroded section modulus as per para. 320.1

Z_e = effective corroded section modulus for branch as per para. 320.2

Process Piping
ASME B31.3 (2016)

Expansion Stress

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

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

where

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

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

For branch (Leg 3 in Fig. 319.4.4B)

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

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

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D , as per para. 319.3.5.

i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ or i for other components as listed in Appendix D of B31.3 (2016)

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

i_i = in-plane stress intensification factor; shall not be less than 1.0

i_o = out-of-plane stress intensification factor; shall not be less than 1.0

i_t = torsional stress intensification factor = 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus as per para. 319.3.5 and para. 319.4.4 (a)

Z_e = un-corroded effective section modulus as per para. 319.3.5 and para. 319.4.4 (c)

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)

f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$
where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)

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

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

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

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

Process Piping ASME B31.3 (2016)

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

Notes:

5. 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 $\leq 371^\circ\text{C}$ (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence $f \leq 1.0$ for all materials including Ferrous materials.
6. Young’s modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 319.4.4 (a).
7. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

Notes on Material Library for B313-2016.mat supplied with CAEPIPE:

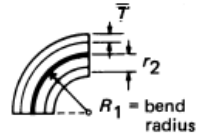
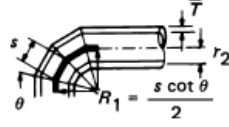
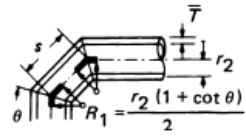
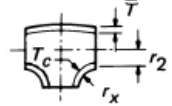
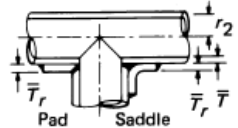
Material library for ASME B31.3 (2016) [B313-2016.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix A and Appendix C of ASME B31.3 (2016).

APPENDIX D

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

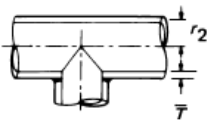
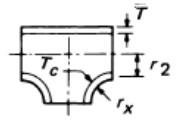
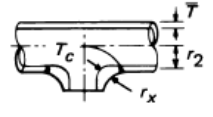
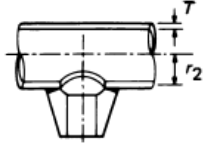
See Table D300.

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

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

Process Piping ASME B31.3 (2016)

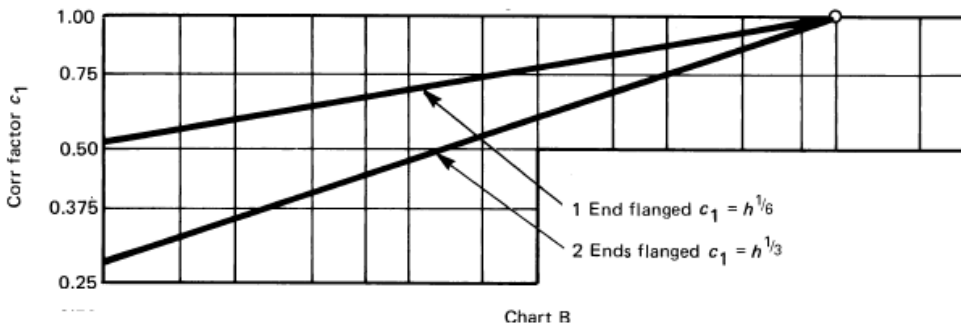
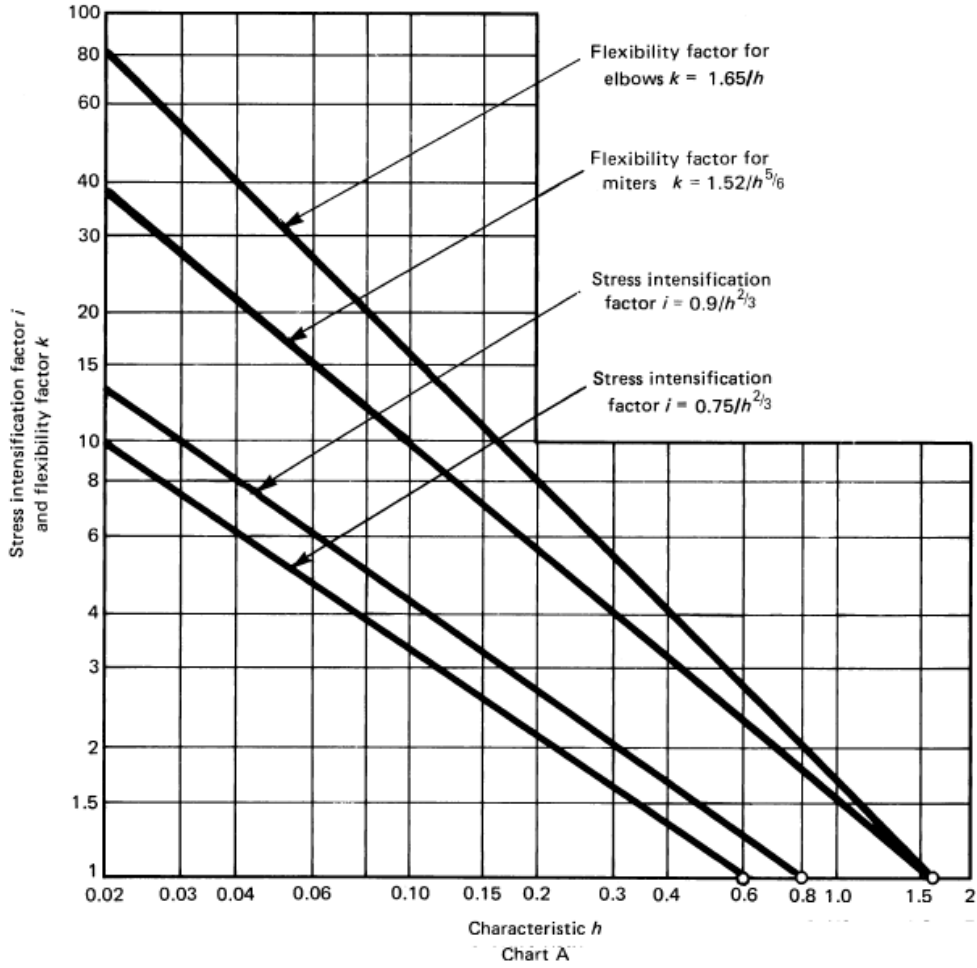
Table D300 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

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

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

Process Piping
ASME B31.3 (2016)

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



Power Piping ASME B31.3 (2016)

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

(14)

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

NOTES:

- (1) The flexibility factor, k , in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k , and stress intensification factors, i , shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.
- (2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.
- (3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:
 - D_b = outside diameter of branch
 - R_1 = bend radius of welding elbow or pipe bend
 - r_x = see definition in para. 304.3.4(c)
 - r_2 = mean radius of matching pipe
 - s = miter spacing at centerline
 - \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting
 - = for tees, the nominal wall thickness of the matching pipe
 - \bar{T}_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
 - \bar{T}_r = pad or saddle thickness
 - θ = one-half angle between adjacent miter axes
- (4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 , which can be read directly from Chart B, entering with the computed h .
- (5) The designer is cautioned that cast butt-welded 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

$$1 + 6 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3}$$

divide i by

$$1 + 3.25 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3}$$

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

- (7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5 \bar{T}$, a flexibility characteristic of $4.4 \bar{T}/r_2$ may be used.
- (8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.
- (9) When \bar{T}_r is $> 1\frac{1}{2} \bar{T}$, use $h = 4 \bar{T}/r_2$.
- (10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.
- (13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Process Piping
ASME B31.3 (2016)

Coefficient 'Y' used in CAEPIPE to compute Allowable Design Pressure of components (extracted from Table 304.1.1 of ASME B31.3 – 2016)

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

Process Piping
ASME B31.3 (2014)
[Superseded by ASME B31.3 (2016)]

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with $I = 1.0$ for bends from paras. 304.1.2. and 304.2.1. respectively.

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

where

P_a = allowable pressure

S = allowable stress as provided in para. 302.3.1 (a) and as per Table A-1

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

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e) and as per Table 302.3.5 is implemented in CAEPIPE as follows. T_{max} below denotes maximum operating temperature (i.e., max of T1 through T10 and Tref in CAEPIPE).

With Material Type in CAEPIPE = CS [CrMo]

$W = 1.0$ with $T_{max} \leq 800^{\circ} \text{F}$ (or 427°C)

$W = 0.64$ with $T_{max} > 1200^{\circ} \text{F}$ (or 649°C) and

For $T_{max} > 800^{\circ} \text{F}$ (or 427°C) and $\leq 1200^{\circ} \text{F}$ (or 649°C), the values of W are taken from Table 302.3.5.

W for intermediate temperatures is linearly interpolated.

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

$W = 1.0$ with $T_{max} \leq 900^{\circ} \text{F}$ (or 482°C)

$W = 0.5$ with $T_{max} > 900^{\circ} \text{F}$ (or 482°C)

With Material Type in CAEPIPE = AS or NA

$W = 1.0$ with $T_{max} \leq 950^{\circ} \text{F}$ (or 510°C)

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

W for intermediate temperatures is linearly interpolated.

With Material Type in CAEPIPE = SS

$W = 1.0$ with $T_{max} \leq 1500^{\circ} \text{F}$ (or 816°C)

For Other Material Types in CAEPIPE

$W = 1.0$ with $T_{max} \leq 800^{\circ} \text{F}$ (or 427°C)

$W = 1 - 0.000909 (T_{max} - T_{cr})$ for $T_{max} > 800^{\circ} \text{F}$ (or 427°C) and $\leq 1500^{\circ} \text{F}$ (or 810°C)

Process Piping
ASME B31.3 (2014)

where, T_{cr} is taken as 800° F

t_a = available thickness for pressure design

$$= t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance "c"}$$

(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

$$Y = \frac{d+2c}{D+d+2c}, \text{ valid for } t_a \geq D/6$$

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

$$S_a = \left[\frac{I_a F_a}{A_p} \right]_{\text{Sustained}} = \left[\frac{PD}{4t_s} + \frac{R}{A_p} \right]_{\text{Sustained}}$$

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

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

Process Piping
ASME B31.3 (2014)

- 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_n = 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
 Z_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 $\leq 427^\circ\text{C}$ or 800°F

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

For temp $> 427^\circ\text{C}$ or 800°F

$$S_{Lo} \leq 0.9WS_y$$

where

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

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

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

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

Process Piping
ASME B31.3 (2014)

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

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 Austenitic 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

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

where

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

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

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

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D, as per para. 319.3.5.

i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ for other components as listed in Appendix D of B31.3 (2014)

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

i_i = in-plane stress intensification factor; shall not be less than 1.0

i_o = out-of-plane stress intensification factor; shall not be less than 1.0

i_t = torsional stress intensification factor = 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus as per para. 319.3.5; for reduced outlets/branch connections, effective section modulus as per para. 319.4.4 (a)

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. 302.3.5(d)

f = stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$
where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)

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

Process Piping ASME B31.3 (2014)

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

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

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

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

Notes:

1. As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures $\leq 371^\circ\text{C}$ (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence $f \leq 1.0$ for all materials including Ferrous materials.
2. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

APPENDIX D

FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

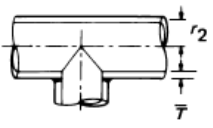
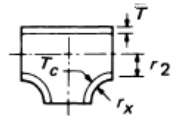
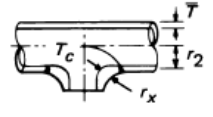
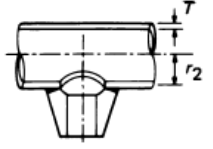
See Table D300.

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

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

Process Piping ASME B31.3 (2014)

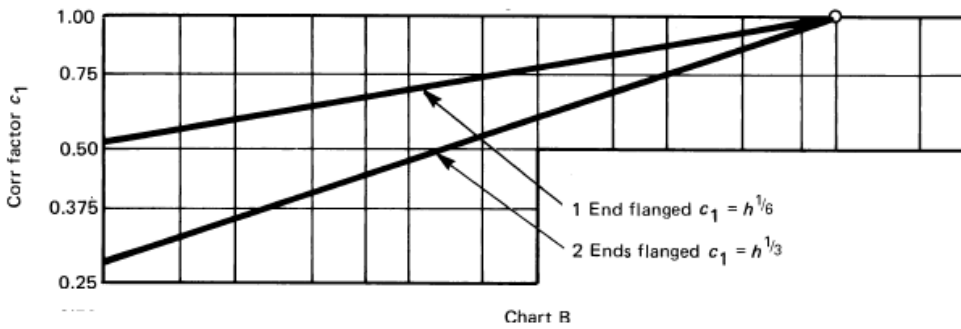
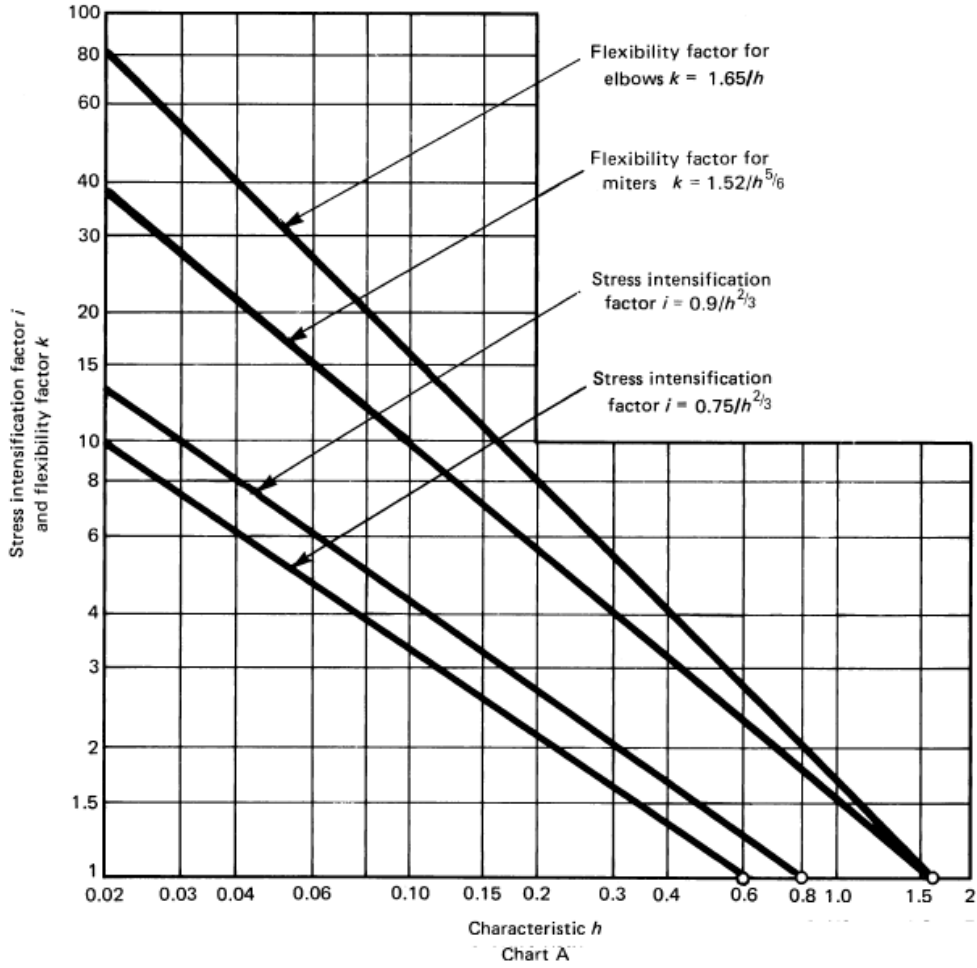
Table D300 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

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

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

Process Piping
ASME B31.3 (2014)

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



Process Piping ASME B31.3 (2014)

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

(14)

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

NOTES:

- (1) The flexibility factor, k , in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k , and stress intensification factors, i , shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.
- (2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.
- (3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:
 - D_b = outside diameter of branch
 - R_1 = bend radius of welding elbow or pipe bend
 - r_x = see definition in para. 304.3.4(c)
 - r_2 = mean radius of matching pipe
 - s = miter spacing at centerline
 - \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting
 - = for tees, the nominal wall thickness of the matching pipe
 - \bar{T}_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
 - \bar{T}_r = pad or saddle thickness
 - θ = one-half angle between adjacent miter axes
- (4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 , which can be read directly from Chart B, entering with the computed h .
- (5) The designer is cautioned that cast butt-welded 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

$$1 + 6 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3}$$

divide i by

$$1 + 3.25 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3}$$

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

- (7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5 \bar{T}$, a flexibility characteristic of $4.4 \bar{T}/r_2$ may be used.
- (8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.
- (9) When \bar{T}_r is $> 1\frac{1}{2} \bar{T}$, use $h = 4 \bar{T}/r_2$.
- (10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.
- (13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2019)

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 403.2.1.

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

where

P_i = allowable pressure

S = allowable stress = $F \times E \times S_y$

F = Design Factor = 0.72 as specified in para 403.2.1

S_y = specified minimum yield strength of pipe at Design Temperature input in CAEPIPE

E = weld joint factor as defined in Table 403.2.1-1

t_a = available thickness for pressure design

= $t_n \times (1 - \text{mill tolerance}/100) - \text{sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.}$

D = outside diameter

Stress due to Sustained Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor; for straight pipes, $i_i = 1.0$

i_o = out-of-plane stress intensification factor; for straight pipes, $i_o = 1.0$

For Fittings & Components.(as per para. 402.6.2)

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

as per Table 403.3.1-1

where

P = maximum operating pressure = max. of CAEPIPE input pressures P1 through P10
Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.

D = outside diameter

t_n = nominal thickness as per para. 402.1

i_i = in-plane stress intensification factor; the product $0.75 i_i$ 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

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2019)

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

F_a = axial force component for external loads

A = nominal cross-section area

S_y = specified minimum yield strength of pipe at maximum CAEPIPE temperature [i.e., at max (Tref, T1 through T10)]

Stress due to Sustained Loads + Occasional Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

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

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with $1.0 \leq$ peak pressure factor ≥ 1.1 as per para. 403.3.4

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.402.5.2

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.4

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

f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range Cycles, where $f \leq 1.2$ (from para. 403.3.2).

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2019)

$S_c = 0.67S_y$ at the lower of the installed temperature or minimum operating temperature
 $S_h = 0.67S_y$ at the higher of the installed temperature or maximum operating temperature
 S_y = specified minimum yield strength of pipe at maximum operating temperature [i.e., at max (T_{ref}, T1 through T10)]

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_{Lp} = S_E + \nu S_H + \frac{F_a}{A} + \frac{M}{Z}$$

$$S_{Ln} = S_E + \nu S_H + \frac{F_a}{A} - \frac{M}{Z}$$

As per para. 402.6.1, both positive and negative values of M/Z shall be considered for analysis.

Where

S_E = Thermal expansion stress = $E\alpha(T_i - T_o)$, which can either be positive or negative

S_H = circumferential (hoop) stress = $\frac{PD}{2t_n}$

ν = Poission's ratio = 0.3 as per para. 402.2.3

As per para. 402.6.1, S_H can be either positive or negative.

F_a = axial force, such as weight on a riser. As per para. 402.6.1, F_a can be positive or negative.

M = bending moment from Weight and other Sustained and Occasional loads

For Pipes

$$M = \sqrt{(i_i M_i)^2 + (i_o M_o)^2}$$

For Fittings & Components

$$M = \sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2}$$

where

P = PFO x max. pressure (P1 through P10) entered in CAEPIPE.

PFO = Peak Pressure Factor input. PFO = 1.0, if occasional loads are not present.

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment from Weight and other Sustained and Occasional loads

**Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2019)**

M_o = out-of-plane bending moment from Weight and other Sustained and Occasional loads

F_a = axial force component for Weight and other Sustained and Occasional loads

A = nominal cross-section area

Z = un-corroded section modulus; for reduced outlets, effective section modulus

S_y = specified minimum yield strength of pipe at maximum operating temperature [i.e., at max (T_{ref}, T1 through T10)]

T_i = installation temperature = T_{ref} in CAEPIPE

T_o = warmest or coldest operating temperature

α = coefficient of thermal expansion at T_o defined above

E = young's modulus at ambient (reference) temperature

Combining of Stresses (Restrained Piping)

The longitudinal and circumferential stresses are combined in accordance with the maximum shear stress theory as follows (by default in CAEPIPE).

$$S_{eq1} = 2\sqrt{[(S_{Lp} - S_H)/2]^2 + (S_t)^2} \quad S_{eq2} = 2\sqrt{[(S_{Ln} - S_H)/2]^2 + (S_t)^2}$$

where S_{Lp} and S_{Ln} are calculated as given above.

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 4 below):

$$S_{eq1} = \sqrt{(S_H)^2 - S_H S_{Lp} + (S_{Lp})^2 + 3(S_t)^2} \quad S_{eq2} = \sqrt{(S_H)^2 - S_H S_{Ln} + (S_{Ln})^2 + 3(S_t)^2}$$

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9S_y$$

where

S_{eq} = equivalent combined stress

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

M_t = torsional moment from Weight and other Sustained and Occasional loads

Notes:

1. Para. 402.6.2 of B31.4 (2019) states that “Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports”.

The above statement seems to imply that “elongation due to Bourdon effect” is to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).

On the other hand, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect as part of the results for Thermal Expansion (when “Solve Thermal Case” is opted) or as part of the Operating Case (when “Thermal = Operating – Sustained is opted).

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2019)

2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
4. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_314" with its value as "YES".
5. Stress Intensification Factors (SIFs) and Flexibility Factors (FFs) are computed using ASME B31.4 (2019) by default. When the option "Use B31J for SIFs and Flexibility Factors" is Turned ON, then CAEPIPE computes SIFs and FFs as per B31J (2017).

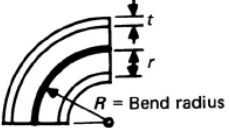
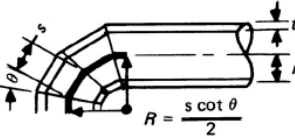
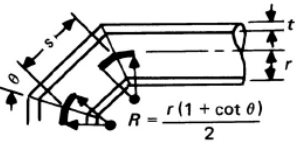
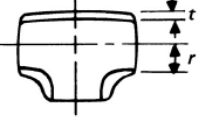
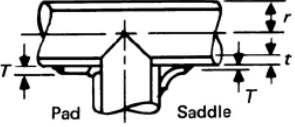
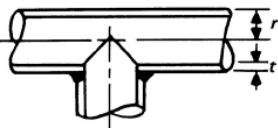
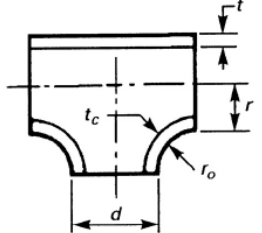
Notes on Material Library for B314-2019.mat supplied with CAEPIPE:

Material library for ASME B31.4 (2019) [B314-2019.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 402.2.1 of B31.4 (2019), Coefficient of Thermal Expansion for Carbon and low alloy high tensile steel are entered as $6.5E-6$ in./in./ $^{\circ}F$ for temperatures up to $250^{\circ}F$.
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy high tensile steel for temperatures up to $250^{\circ}F$ are entered by referring to the values provided in Table 832.5-1 of ASME B31.8 (2018).
3. **Yield Strength:** Yield Strength for Carbon and low alloy high tensile steel for temperatures up to $250^{\circ}F$ are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2018).
4. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in 3 and 0.3 respectively.

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2019)

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	...	...	...

Pipeline Transportation Systems for Liquids and Slurries ASME B31.4 (2019)

Table 402.1-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor		Flexibility Characteristic, h	Sketch
		i_i [Note (1)]	i_o [Note (2)]		
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

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

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

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.

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2019)

Table 402.1-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

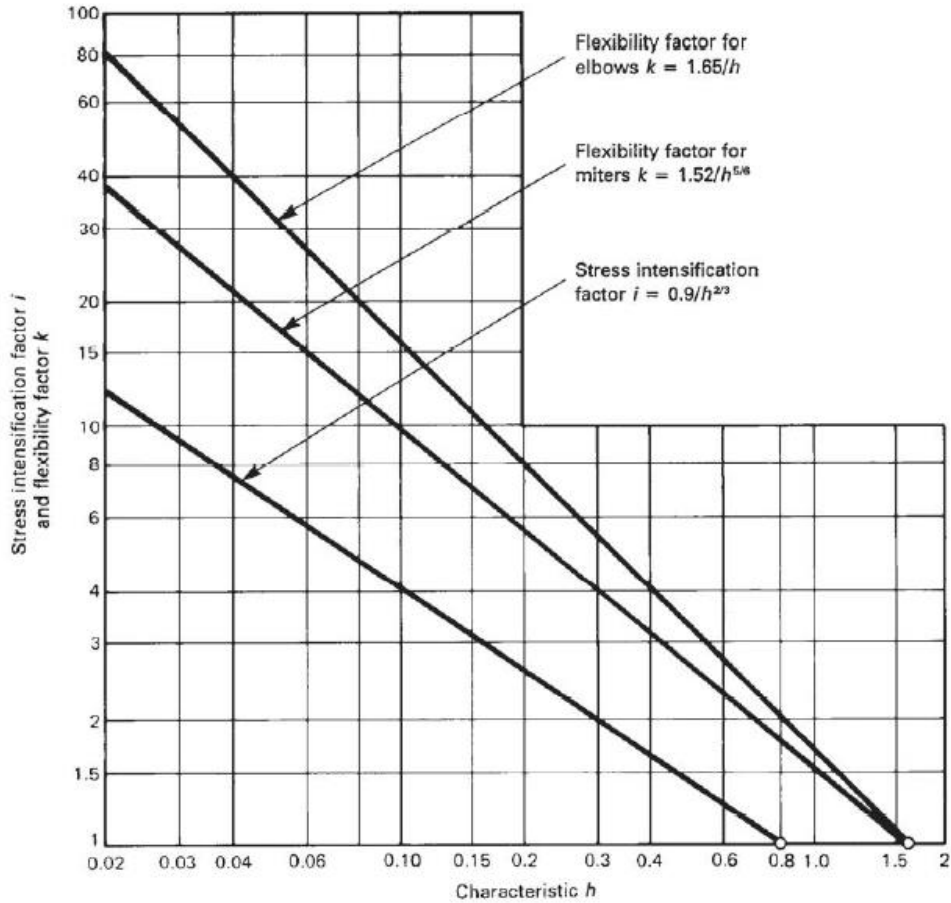


Chart A

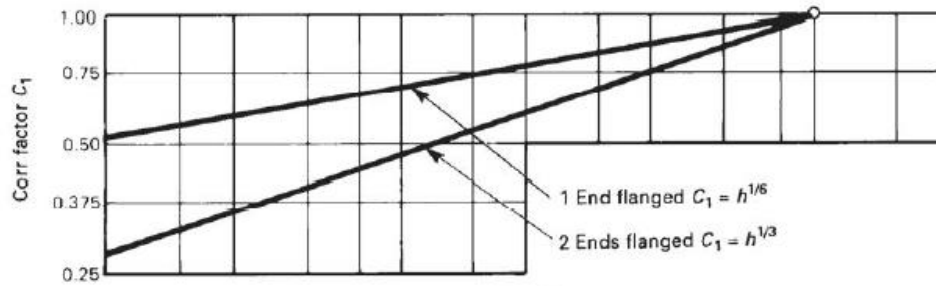


Chart B

**Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2016)
[Superseded by ASME B31.4 (2019)]**

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 403.2.1.

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

where

P_i = allowable pressure

S = allowable stress = 0.72 S_y , where S_y is specified minimum yield strength of pipe

E = weld joint factor as defined in Table 403.2.1-1

t_a = available thickness for pressure design

= $t_n \times (1 - \text{mill tolerance}/100) - \text{sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.}$

D = outside diameter

Stress due to Sustained Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor = 1.0 for pipes

i_o = out-of-plane stress intensification factor = 1.0 for pipes

For Fittings & Components (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

P = maximum operating pressure = max of CAEPIPE input pressures (P1 through P10). Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.

D = outside diameter

t_n = nominal thickness as per para. 402.1

i_i = in-plane stress intensification factor; the product $0.75 i_i$ 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

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2016)

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

F_a = axial force component for external loads

A = nominal cross-section area

S_y = specified minimum yield strength of pipe

Stress due to Sustained Loads + Occasional Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

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

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with $1.0 \leq$ peak pressure factor ≤ 1.1 as per para. 403.3.4

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.402.5.2

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.4

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

f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles

where $f \leq 1.2$ (from para. 403.3.2).

$S_C = 0.67S_y$ at the lower of the installed temperature or minimum operating temperature

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2016)

$S_h = 0.67S_y$ at the higher of the installed temperature or maximum operating temperature where

S_y = specified minimum yield strength of pipe

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_l) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_{Lp} = S_E + \nu S_H + \frac{F_a}{A} + \frac{M}{Z}$$

$$S_{Ln} = S_E + \nu S_H + \frac{F_a}{A} - \frac{M}{Z}$$

As per para. 402.6.1, both positive and negative values of M/Z shall be considered for analysis.

where

$$S_H = \text{circumferential (hoop) stress} = \frac{PD}{2t_n}$$

ν = Poission's ratio = 0.3 as per para. 402.2.3

As per para. 402.6.1, S_H can be either positive or negative.

F_a = axial force, such as weight on a riser. As per para. 402.6.1, F_a can be positive or negative.

M = bending moment from Weight and other External loads

For Pipes

$$M = \sqrt{(i_i M_i)^2 + (i_o M_o)^2}$$

For Fittings & Components

$$M = \sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2}$$

S_E = Thermal expansion stress = $E\alpha(T_i - T_o)$, which can be either be positive or negative

where

P = PFO x maximum pressure (P_1 through P_{10}) entered in CAEPIPE.

PFO = Peak Pressure Factor input. $PFO = 1.0$, if occasional loads are not present.

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment from Weight and other External loads

M_o = out-of-plane bending moment from Weight and other External loads

**Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2016)**

- F_a = axial force component for Weight and other External loads
 A = nominal cross-section area
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 S_y = specified minimum yield strength of pipe
 T_i = installation temperature = T_{ref} in CAEPIPE
 T_o = warmest or coldest operating temperature
 α = coefficient of thermal expansion at T_o defined above
 E = young's modulus at ambient (reference) temperature

Combining of Stresses

In restrained pipe, the longitudinal and circumferential stresses are combined in accordance with the maximum shear stress theory as follows (by default in CAEPIPE).

$$S_{eq1} = 2\sqrt{\left[\frac{(S_{Lp} - S_H)}{2}\right]^2 + (S_t)^2} \quad S_{eq2} = 2\sqrt{\left[\frac{(S_{Ln} - S_H)}{2}\right]^2 + (S_t)^2}$$

Where S_{Lp} and S_{Ln} are calculated as given above.

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 4 below):

$$S_{eq1} = \sqrt{(S_H)^2 - S_H S_{Lp} + (S_{Lp})^2 + 3(S_t)^2} \quad S_{eq2} = \sqrt{(S_H)^2 - S_H S_{Ln} + (S_{Ln})^2 + 3(S_t)^2}$$

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9S_y$$

where

S_{eq} = equivalent combined stress

S_t = torsional stress

Notes:

5. Para. 402.6.2 of B31.4 (2016) states that “Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports”.
The above statement seems to imply that “elongation due to Bourdon effect” is to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).
On the other hand, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect as part of the results for Thermal Expansion (when “Solve Thermal Case” is opted) or as part of the Operating Case (when “Thermal = Operating – Sustained is opted).
6. Young’s modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
7. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2016)

8. By default, CAEPIPE combines the stresses for restrained piping using the maximum shear stress theory as stated above. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name “DET_314” with its value as “YES”.

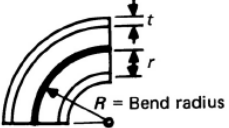
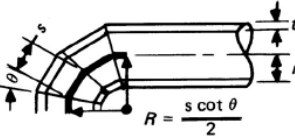
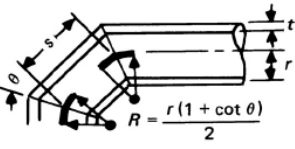
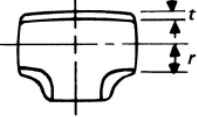
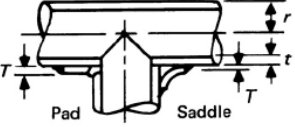
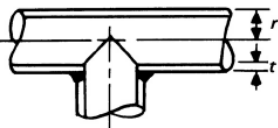
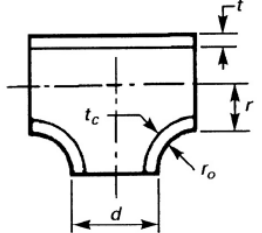
Notes on Material Library for B314-2016.mat supplied with CAEPIPE:

Material library for ASME B31.4 (2016) [B314-2016.mat] has been created and supplied with CAEPIPE as mentioned below.

9. **Coefficient of Thermal Expansion:** As stated in para. 402.2.1 of B31.4 (2016), Coefficient of Thermal Expansion for Carbon and low alloy high tensile steel are entered as $6.5E-6$ in./in./ $^{\circ}F$ for temperatures up to $250^{\circ}F$.
10. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy high tensile steel for temperatures up to $250^{\circ}F$ are entered by referring to the values provided in Table 832.5-1 of ASME B31.8 (2016).
11. **Yield Strength:** Yield Strength for Carbon and low alloy high tensile steel for temperatures up to $250^{\circ}F$ are entered by referring to the values specified in Mandatory Appendix D titled “Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems” of ASME B31.8 (2016).
12. **Density and Poisson’s ratio:** Density and Poisson’s ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in³ and 0.3 respectively.
13. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy high tensile steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2016).

Pipeline Transportation Systems for
Liquids and Slurries
ASME B31.4 (2016)

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	...	...	...

Pipeline Transportation Systems for Liquids and Slurries ASME B31.4 (2016)

Table 402.1-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor		Flexibility Characteristic, h	Sketch
		i_i [Note (1)]	i_o [Note (2)]		
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

$$\text{Flexibility factor, } k, \text{ by } 1 + 6 \frac{P}{E_c} \left(\frac{r}{t}\right)^{7/3} \left(\frac{R}{r}\right)^{2/3}$$

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

where

- E_c = cold modulus of elasticity
- P = gage pressure

- (8) Also includes single miter joint.
- (9) When $T > 1\frac{1}{2}t$, use $h = 4.05 t/r$.
- (10) Radius of curvature of external contoured portion of outlet measured in the plane containing the axes of the run and branch. This is subject to the following limitations:
 - (a) minimum radius, r_o : the lesser of $0.05d$ or 38 mm (1.5 in.)
 - (b) maximum radius, r_o shall not exceed
 - (1) for branches DN 200 (NPS 8) and larger, $0.10d + 13$ mm (0.50 in.)
 - (2) for branches less than DN 200 (NPS 8), 32 mm (1.25 in.)
 - (c) when the external contour contains more than one radius, the radius on any arc sector of approximately 45 deg shall meet the requirements of (a) and (b) above
 - (d) machining shall not be employed in order to meet the above requirements
- (11) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2016)

Table 402.1-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

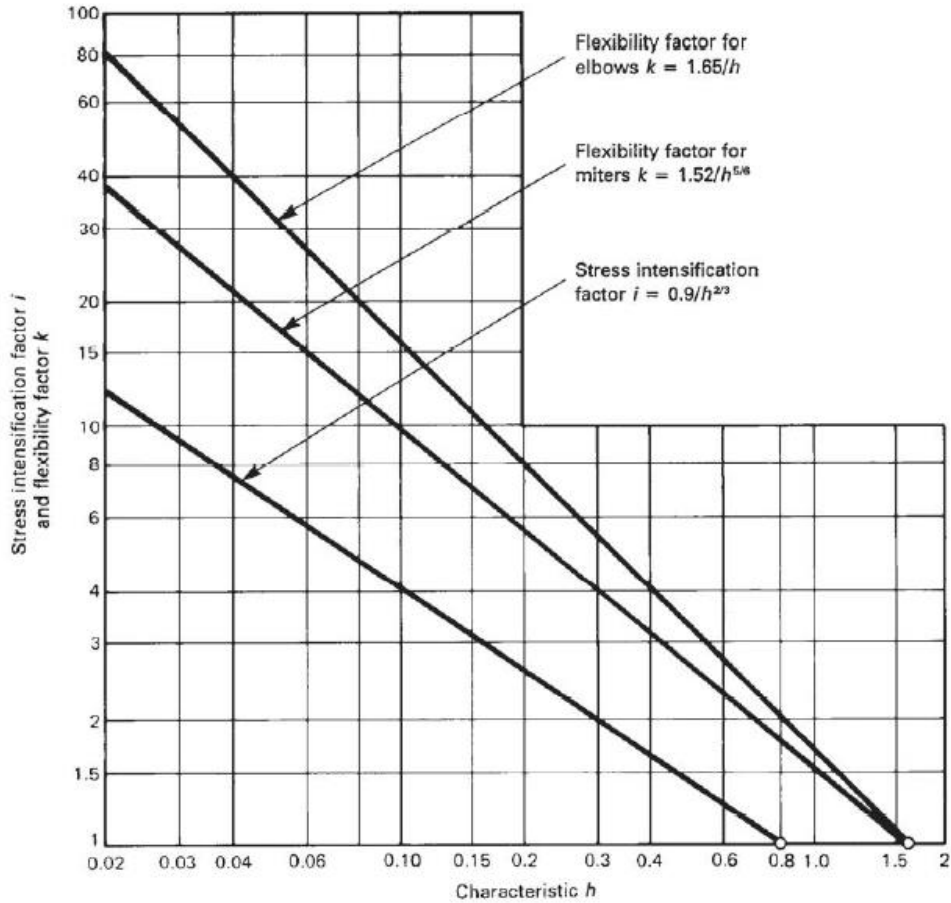


Chart A

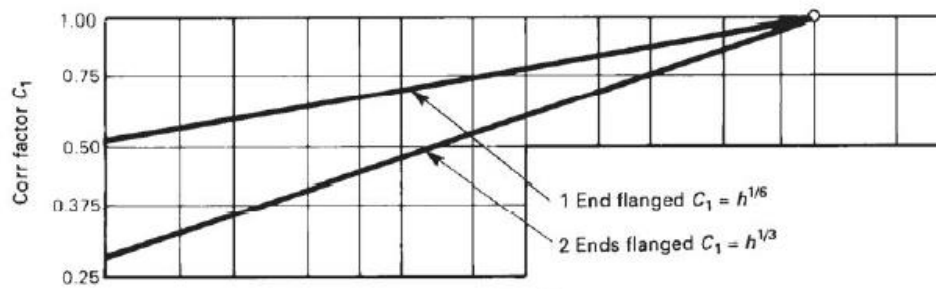


Chart B

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

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

= $t_n \times (1 - \text{mill tolerance}/100) - \text{sum of allowances, as per para. 403.2.1, for corrosion, threading, grooving and erosion.}$

D = outside diameter

Stress due to Sustained Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

i_i = in-plane stress intensification factor = 1.0 for pipes

i_o = out-of-plane stress intensification factor = 1.0 for pipes

For Fittings & Components (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

P = maximum operating pressure = max of CAEPIPE input pressures (P1 through P10). Due considerations shall be given as per para. 401.2.2.2 while inputting pressure values in CAEPIPE.

D = outside diameter

t_n = nominal thickness as per para. 402.1

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

- i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
 M_i = in-plane bending moment
 M_o = out-of-plane bending moment
 M_t = torsional moment
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 F_a = axial force component for external loads
 A = nominal cross-section area
 S_y = specified minimum yield strength of pipe

Stress due to Sustained Loads + Occasional Loads (Unrestrained Piping)

For Pipes (as per para. 402.6.2)

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

as per Table 403.3.1-1

For Fittings & Components (as per para. 402.6.2)

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

as per Table 403.3.1-1

where

P_{peak} = peak pressure = (peak pressure factor x P) where P = maximum operating pressure, as defined above with $1.0 \leq$ peak pressure factor ≥ 1.1 as per para. 403.3.4

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.402.5.2

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.4

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

f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

where $f \leq 1.2$ (from para. 403.3.2).

$S_c = 0.67S_y$ at the lower of the installed temperature or minimum operating temperature
 $= 0.67S_y$ at the higher of the installed temperature or maximum operating temperature
 where

S_c = specified minimum yield strength of pipe

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from para. 402.6.1

$$S_L = \max(|S_p + S_x + S_B|, |S_p + S_x - S_B|)_{sustained} + \max(|S_p + S_x + S_B|, |S_p + S_x - S_B|)_{occasional} + \max(|S_T|_{warmest}, |S_T|_{coldest}) \leq 0.9S_y$$

where

Pressure stress = $S_p = v \frac{PD}{2t_n}$ where $v = 0.3$ as per para. 402.2.3 and can be either positive or negative

Stress due to axial loading (other than temperature and pressure) = $S_x = \frac{F_a}{A}$

and can be positive or negative.

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

For Pipes

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

For Fittings & Components

$$S_B = \frac{\sqrt{(0.75 i_i M_i)^2 + (0.75 i_o M_o)^2 + (M_t)^2}}{Z}$$

Thermal expansion stress $S_T = E\alpha(T_i - T_o)$, which can either be positive or negative

where

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

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

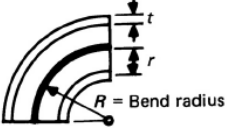
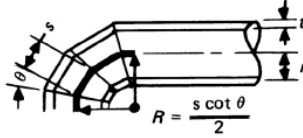
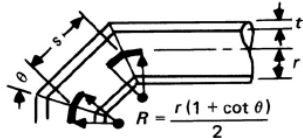
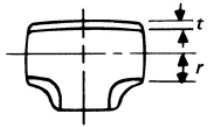
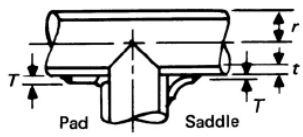
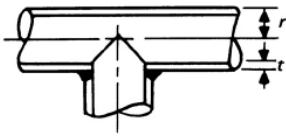
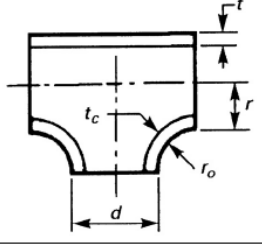
- F_a = axial force component for external loads
 A = nominal cross-section area
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 S_y = specified minimum yield strength of pipe
 T_i = installation temperature = T_{ref} in CAEPIPE
 T_o = warmest or coldest operating temperature
 α = coefficient of thermal expansion at T_o defined above
 E = young's modulus at ambient (reference) temperature

Note:

1. Para. 402.6.2 of B31.4 (2012) states that “Longitudinal stress from pressure in an unrestrained line should include consideration of bending stress or axial stress that may be caused by elongation of the pipe due to internal pressure and result in stress at bends and at connections and produce additional loads on equipment and on supports”.
The above statement seems to imply that “elongation of pipe and opening of bends due to Bourdon effect” are to be included in the Sustained load case (and hence in Operating case and Sustained plus Occasional load case).
On the other hand, since the deformation due to Bourdon effect is being constrained by piping supports, CAEPIPE includes the Bourdon effect as part of the results for Thermal Expansion (when “Solve Thermal Case” is opted) or as part of the Operating Case (when “Thermal = Operating – Sustained is opted).
2. Young's modulus of elasticity corresponding to reference temperature (T_{ref}) is used to form the stiffness matrix in accordance with para. 402.2.2.
3. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

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	...	...	...

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

Table 402.1-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor		Flexibility Characteristic, h	Sketch
		i_i [Note (1)]	i_o [Note (2)]		
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

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

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

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.

Pipeline Transportation Systems for
Liquid Hydrocarbons and Other Liquids
ASME B31.4 (2012)
[Superseded by ASME B31.4 (2016)]

Table 402.1-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

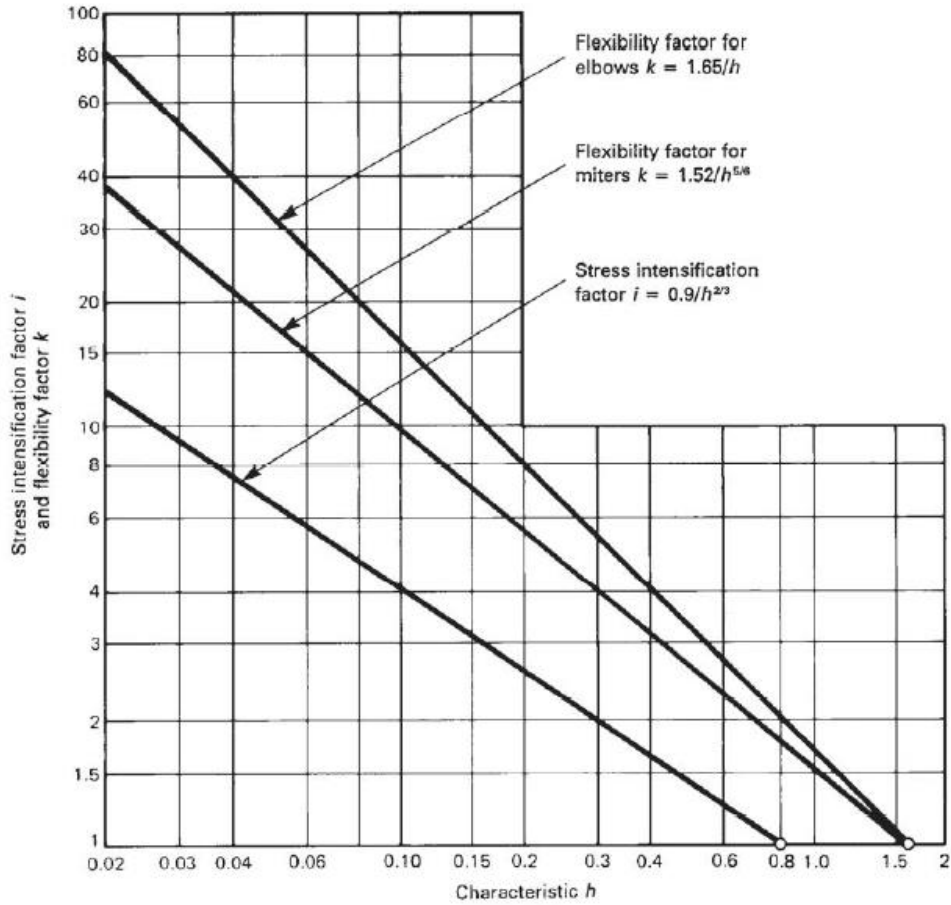


Chart A

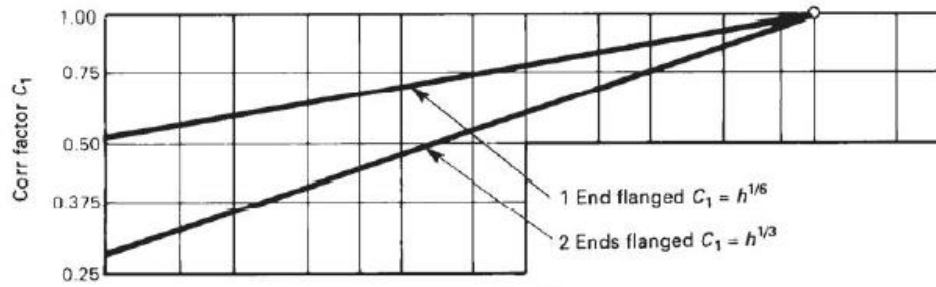


Chart B

Refrigeration Piping and Heat Transfer Components ASME B31.5 (2016)

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 504.1.2.

$$P = \frac{2SEt_a}{D - 2Yt_a}$$

where

P = allowable pressure

S = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

E = longitudinal or spiral joint factor (input as material property) from para. 502.3.1 and Table 502.3.1

Table 502.3.1 provides maximum allowable hoop stress values (SE) as a function of metal temperature and includes Longitudinal or Spiral Joint Factor (E) for various materials. Divide SE value by E value provided in Table 502.3.1 to obtain basic allowable stress S . For materials where E is not given explicitly in Table 502.3.1, use $E = 1.0$.

Hence, SE in the above formula for allowable pressure P is the allowable hoop stress per para. 502.3.1 and Table 502.3.1.

t_a = available thickness for pressure design (as per para. 504.1.1)

= $t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

(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,

$$Y = 0.4 \text{ for } D/t_a \geq 6 \text{ and } Y = \frac{d}{d+D}, \text{ for } 4 \leq D/t_a < 6$$

$Y = 0.0$ for Cast Iron

Sustained Stress (in corroded condition)

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 502.3.2(d). Also, refer to Note 1 below.

$$S_L = \frac{PD}{4t_c} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_c} \leq S_h$$

where

P = maximum of CAEPIPE input pressures P_1 through P_{10}

D = outside diameter

t_c = nominal thickness – corrosion allowance, as per para. 502.3.2 (d)

i_i = in-plane stress intensification factor

i_o = out-of-plane stress intensification factor

M_i = in-plane bending moment

Refrigeration Piping and Heat Transfer Components
ASME B31.5 (2016)

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.

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

where

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

Expansion Stress (in un-corroded condition)

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

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

S_A = $f(1.25S_{cold} + 0.25S_{hot})$ (see para. 502.3.2 (c))

f = stress range reduction factor from Figure 502.3.2

S_{cold} = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis

S_{hot} = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis

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

$$S_A = S_A + f(S_h - S_L)$$

where, S_h = basic allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

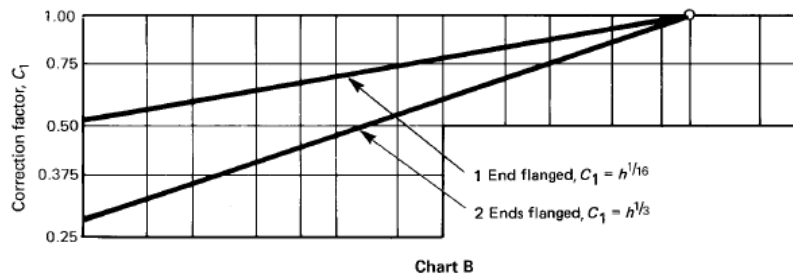
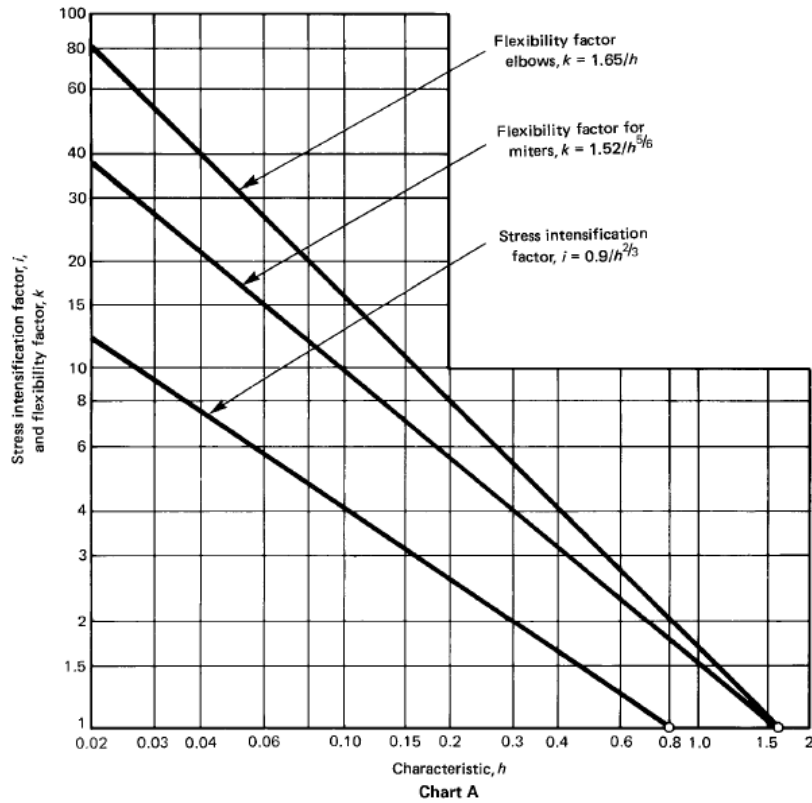
This is specified as an analysis option: "Use liberal allowable stresses", in the CAEPIPE menu Options->Analysis on the Code tab.

Refrigeration Piping and Heat Transfer Components ASME B31.5 (2016)

Notes:

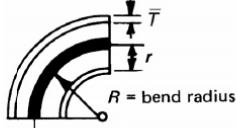
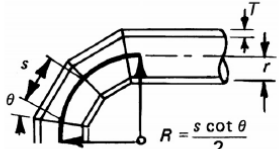
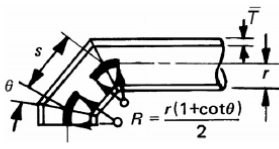
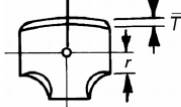
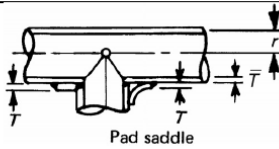
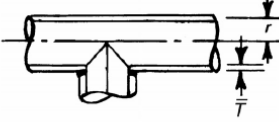
1. As per para. 502.3.2 (d), the pressure stress should be calculated using the formula $Pd^2/(D^2 - d^2)$, where d is the internal diameter = $D - 2t_c$. This can be selected through Options > Analysis > Pressure.
2. As per para. 519.4.5(a), Bending and torsional stress shall be computed using the as-installed modulus of elasticity, i.e., E_c at installation temperature. Hence, "Use modulus at reference temperature" (available through CAEPIPE Layout > Options > Analysis > Temperature) is set as "default" and is disabled for user to modify.
3. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".

Table 519.3.6 Illustration



Refrigeration Piping and Heat Transfer Components ASME B31.5 (2016)

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

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor		Illustration
			i_i [Note (1)]	i_o [Note (2)]	
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)], $s < r(1 + \tan \theta)$	$\frac{\bar{T}s}{r^2} \left(\frac{\cot \theta}{2} \right)$	$\frac{1.52}{h^{3/4}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan \theta)$	$\frac{\bar{T}}{r} \left(\frac{1 + \cot \theta}{2} \right)$	$\frac{1.52}{h^{3/4}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.75}{h^{2/3}}$	
Welding tee ASME B16.9 [Notes (3) and (4)]	$4.4 \frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)]	$\frac{(\bar{T} + 1/2 T)^{3/2}}{t^{3/2} r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (3) and (4)]	$\frac{\bar{T}}{r}$	1	$0.75i_o + 0.25$	$\frac{0.9}{h^{2/3}}$	
Butt welded joint, reducer, or welding neck flange	...	1	1.0	1.0	...
Double-welded slip-on flange	...	1	1.2	1.2	...

Refrigeration Piping and Heat Transfer Components ASME B31.5 (2016)

Table 519.3.6 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor		Illustration
			i_i [Note (1)]	i_o [Note (2)]	
Fillet welded joint (single-welded), socket welded flange, or single-welded slip-on flange	...	1	1.3	1.3	...
Lap flange (with ASME B16.9 lap-joint stub)	...	1	1.6	1.6	...
Threaded pipe joint or threaded flange	...	1	2.3	2.3	...
Corrugated straight pipe, or corrugated or creased bend [Note (10)]	...	5	2.5	2.5	...

GENERAL NOTE: For reference, see Table 519.3.6 Illustration on page 41.

NOTES:

- (1) In-plane.
- (2) Out-plane.
- (3) For fittings and miter bends the flexibility factors, k , and stress intensification factors, i , in the Table apply to bending in any plane and shall not be less than unity; factors for torsion equal unity.
- (4) Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows and to the intersection point for tees. The values of k and i can be read directly from Chart A by entering with the characteristic, h , computed from the equations given where
 - R = bend radius of welding elbow or pipe bend, in. (mm)
 - r = mean radius of matching pipe, in. (mm)
 - s = miter spacing at centerline, in. (mm)
 - T = pad or saddle thickness, in. (mm)
 - \bar{T} = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; matching pipe for welding tees; run or header for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter).
 - θ = one-half angle between adjacent miter axes, deg
- (5) Where flanges are attached to one or both ends, the values of k and T in the Table shall be corrected by the factors C_1 given below, which can be read directly from Chart B; entering with the computed h : one end flanged, $h^{1/2} \geq 1$; 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

$$1 + 6 \frac{P}{E_c} \left(\frac{r}{T} \right)^{1/2} \left(\frac{R}{r} \right)^{1/2}$$

- (b) stress intensification factor, i , by

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

where

E_c = cold modulus of elasticity, ksi (MPa)
 P = internal design pressure, psi (kPa)

- (8) Also includes single-miter joint.
- (9) When $T > 1.5\bar{T}$, use $h = 4.05 \bar{T}/r$.
- (10) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2018)

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

When $D/t_n < 30$, then

$$P = \frac{2SEt_nFT}{D - t_n}$$

where

P = allowable pressure

S = specified minimum yield strength from para. 841.1.1 (a) and para. 817.1.3 (h)

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)

t_n = nominal pipe thickness

D = outside diameter

F = construction type design factor, obtained from Table 841.1.6-1

T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Stress due to Sustained and Occasional Loads (Unrestrained Piping)

The sum of longitudinal pressure stress due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the “include axial force in stress calculations” option is turned ON by default for ANSI B31.8 in CAEPIPE.

Sustained Stress S_L :

For Pipes and Long Radius Bends

$$S_L = \left[\frac{PD}{4t_n} + \frac{R}{A} \right]_{\text{Sustained}} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z} \right]_{\text{Sustained}} \leq 0.75ST$$

For other Fittings and Components.

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

Sustained + Occasional Stress S_{LO} :

For Pipes and Long Radius Bends

$$S_{LO} = S_L + \left[\frac{(P_{\text{peak}} - P)D}{4t_n} + \frac{R}{A} \right]_{\text{occasional}} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z} \right]_{\text{occasional}} \leq 0.75ST$$

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2018)

For Fittings and Components

$$S_{LO} = S_{L(f_c)} + \left| \frac{(P_{peak} - P)D}{4t_n} + \frac{R}{A} \right|_{occasional} + \left[\frac{\sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2 + (M_t)^2}}{Z} \right]_{occasional} \leq 0.75ST$$

where

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

P_{peak} = Peak pressure factor x P

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

R = axial force component for external loads (other than thermal expansion and pressure)

A = un-corroded cross-section area

S = specified minimum yield strength from para. 841.1.1(a)

T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10} , T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with para. 832.3(g).

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.

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

f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles

where $f \leq 1.0$ (from para. 833.8 (b)).

S_L = sustained stress computed as per equation given above

S_C = 0.33SuT at the minimum installed or operating temperature

S_h = 0.33SuT at the maximum installed or operating temperature

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2018)

where

S_u = specified minimum ultimate tensile strength = $1.5 S_y$ (assumed), and

S_y = specified minimum yield strength as per para. 841.1.1(a)

T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [$=\min(T_1$ through $T_{10}, T_{reb})$] is used to form the stiffness matrix for Expansion load calculations in accordance with para. 832.4(b).

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per 833.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.

where

$$S_p = 0.3S_H = 0.3 \frac{PD}{2t_n} = \text{longitudinal stress due to internal pressure in restrained pipeline}$$

S_H = hoop stress

S_T = longitudinal stress due to thermal expansion in restrained pipeline = $E\alpha(T_i - T_o)$ (see Note 1 below)

S_X = stress due to axial loading (other than thermal expansion and pressure) = $\frac{R}{A}$

S_B = nominal bending stress due to weight and other external loads (other than thermal expansion)

For Pipes and Long Radius Bends

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

For other Fittings and Components.

$$S_B = \frac{\sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2 + (M_t)^2}}{Z}$$

As per para 833.3(a), note that S_B, S_L, S_T or S_X can be positive or negative where

P = maximum operating pressure = max(P1 through P10)

D = outside diameter

t_n = nominal thickness

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2018)

- i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
 i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
 M_i = in-plane bending moment
 M_o = out-of-plane bending moment
 M_t = torsional moment
 R = axial force component for external loads (other than thermal expansion and pressure)
 A = un-corroded cross-sectional area (i.e., before deducting for corrosion)
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
 T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
 E = Young's modulus at ambient temperature = T_{ref} in CAEPIPE
 T_i = installation temperature = T_{ref} in CAEPIPE
 T_o = warmest or coldest operating temperature
 α = coefficient of thermal expansion at T_o in CAEPIPE

Note 1:

If there are more than one thermal load, for example T1 and T2, then CAEPIPE calculates longitudinal stress due to thermal expansion from T1 to T2 in restrained pipeline as follows.

$$E\alpha(T_n - T_m) = E\alpha_n(T_n - T_{ref}) - E\alpha_m(T_m - T_{ref}), \text{ where } n = 1 \text{ and } m = 2$$

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE.

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where

S_{eq} = equivalent combined stress

Gas Transmission and Distribution Piping Systems ASME B31.8 (2018)

Notes:

4. Young's modulus of elasticity corresponding to the lowest operating temperature [$=\min(T_1 \text{ through } T_{10}, T_{ref})$] is used to form the stiffness matrix in accordance with para. 832.4(b).
5. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
6. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_318" with its value as "YES".

Notes on Material Library for B318-2018.mat supplied with CAEPIPE:


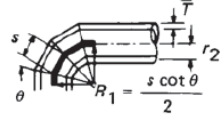
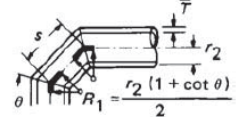
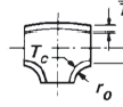
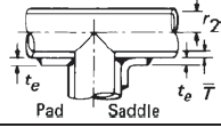
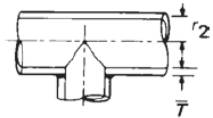
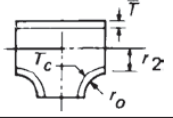
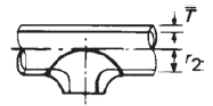
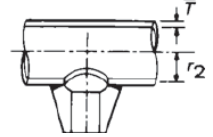
Material library for ASME B31.8 (2018) [B318-2018.mat] has been created and supplied with CAEPIPE as mentioned below.

7. **Coefficient of Thermal Expansion:** As stated in para. 832.2 of B31.8 (2018), Coefficient of Thermal Expansion for Carbon and low alloy steel are entered by referring to the values given in Table 832.2-1 of ASME B31.8 (2018).
8. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy steel are entered by referring to the values given in Table 832.5-1 of ASME B31.8 (2018).
9. **Yield Strength:** Yield Strength for Carbon and low alloy steel are entered by referring to the values specified in Mandatory Appendix D titled "Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems" of ASME B31.8 (2018).
10. **Density and Poisson's ratio:** Density and Poisson's ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in³ and 0.3 respectively.
11. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2018).

Gas Transmission and Distribution Piping Systems


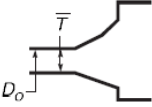
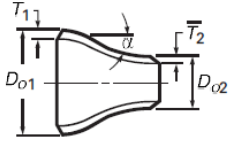
ASME B31.8 (2018)

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

Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)]		Flexibility Characteristic, h	Sketch
		Out-plane, i_o	In-plane, i_i		
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)] $s < r_2 (1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta \bar{T} s}{2 r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta \bar{T}}{2} r_2$	
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	$\frac{0.9}{h^{2/3}}$	$\frac{3}{4} i_o + \frac{1}{4}$	$\frac{(\bar{T} + \frac{1}{2} t_e)^{3/2}}{\bar{T}^{3/2} r_2}$	
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	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3 \frac{\bar{T}}{r_2}$	

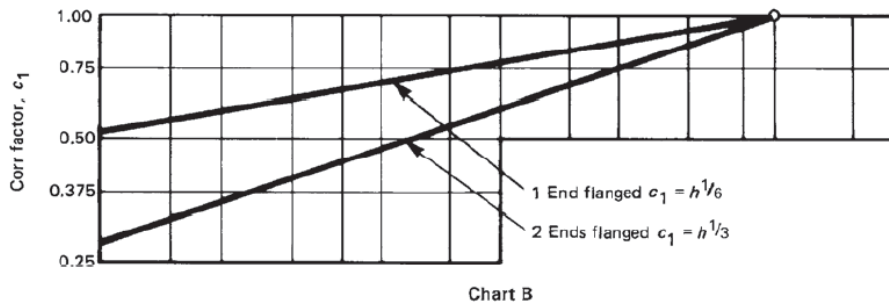
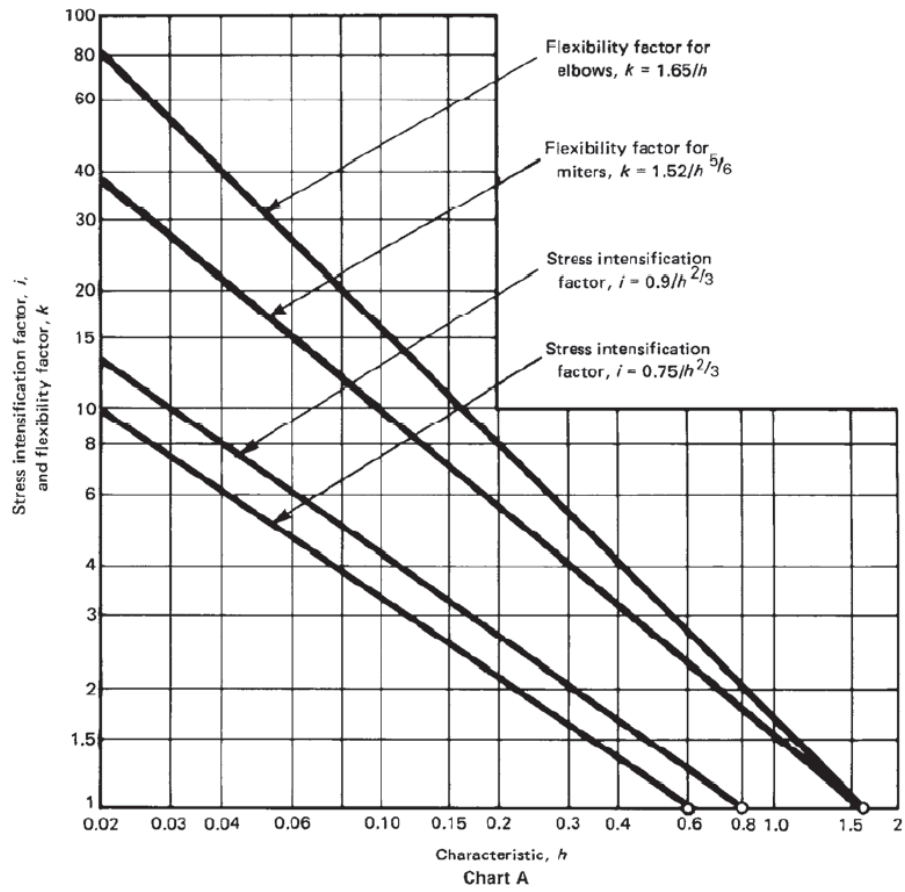
Gas Transmission and Distribution Piping Systems ASME B31.8 (2018)

Table E-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq \frac{1}{8}$ in. (3.18 mm), and $\delta_{avg}/\bar{T} = \text{any value}$	1	1.9 max. or $(0.9 + 2.7(\delta_{avg}/\bar{T}))$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \leq 0.237$ in. (6.02 mm), $\delta_{max} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{\bar{T}} + 3.6 \frac{\delta}{\bar{T}}$	
Tapered transition per ASME B16.25 [Note (1)]	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max or $2.1 \bar{T}/C_s$ 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	

Gas Transmission and Distribution Piping Systems ASME B31.8 (2018)

Table E-1 Flexibility factor, k , and Stress Intensification Factor, i (Cont'd)



Gas Transmission and Distribution Piping Systems

ASME B31.8 (2018)

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*₀ = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
*r*₂ = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
 $\frac{T}{2}$ = 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 butt-welded 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

$$\left[1 + 6 \left(\frac{P}{E_e} \right) \left(\frac{r_2}{T} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3} \right]$$

divide *i* by

$$\left[1 + 3.25 \left(\frac{P}{E_e} \right) \left(\frac{r_2}{T} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3} \right]$$

where

*E*_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

- (6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively.
- (7) When *t*_e > 1/2*T*, use *h* = 4.05*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 $(0.67/h^{2/3}) + 1/4$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.
- (10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between 0.875 \bar{T} and 1.10 \bar{T} for an axial distance of $\sqrt{D_o \bar{T}}$. *D*_o and \bar{T} are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

Gas Transmission and Distribution Piping Systems ASME B31.8 (2018)

- (13) The equation applies only if the following conditions are met.
- (a) Cone angle α does not exceed 60 deg, and the reducer is concentric.
 - (b) The larger of D_{o1}/\bar{T} and D_{o2}/\bar{T} does not exceed 100.
 - (c) The wall thickness is not less than \bar{T}_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than \bar{T}_2 .
- (14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4) (S_b A_b - PA_p)$$

A_b = total area of flange bolts, in.² (mm²)

A_p = area to outside of gasket contact, in.² (mm²)

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.

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
[Superseded by ASME B31.8 (2018)]

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

where

P = allowable pressure

S = specified minimum yield strength from para. 817.1.3 (h) and para. 841.1.4 (a)

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)

t_n = nominal pipe thickness

D = outside diameter

F = construction type design factor, obtained from Table 841.1.6-2

T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Stress due to Sustained and Occasional Loads (Unrestrained Piping)

The sum of longitudinal pressure stress due to axial loading (other than thermal expansion and pressure) and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the “include axial force in stress calculations” option is turned ON by default for ANSI B31.8 in CAEPIPE.

Sustained Stress S_L :

For Pipes and Long Radius Bends

$$S_L = \left| \frac{PD}{4t_n} + \frac{R}{A} \right|_{\text{Sustained}} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z} \right]_{\text{Sustained}} \leq 0.75ST$$

For other Fittings or Components.

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

Sustained + Occasional Stress S_{LO} :

For Pipes and Long Radius Bends

$$S_{LO} = S_L + \left| \frac{(P_{\text{peak}} - P)D}{4t_n} + \frac{R}{A} \right|_{\text{occasional}} + \left[\frac{\sqrt{(M_i)^2 + (M_o)^2 + (M_t)^2}}{Z} \right]_{\text{occasional}} \leq 0.75ST$$

For Fittings or Components

$$S_{LO} = S_{L(fc)} + \left| \frac{(P_{\text{peak}} - P)D}{4t_n} + \frac{R}{A} \right|_{\text{occasional}} + \left[\frac{\sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2 + (M_t)^2}}{Z} \right]_{\text{occasional}} \leq 0.75ST$$

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
 [Superseded by ASME B31.8 (2018)]

where

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

P_{peak} = Peak pressure factor x P

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

R = axial force component for external loads (other than thermal expansion and pressure)

A = un-corroded cross-section area

S = specified minimum yield strength from para. 841.1.1(a)

T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10} , T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations in accordance with para. 832.4(b).

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.

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

f = stress range reduction factor = $6/N^{0.2}$, where N = number of equivalent full range cycles

where $f \leq 1.0$ (from para. 833.8 (b)).

S_C = 0.33SuT at the minimum installed or operating temperature

S_h = 0.33SuT at the maximum installed or operating temperature

where

S_u = specified minimum ultimate tensile strength = 1.5 S_y (assumed), and

S_y = specified minimum yield strength as per para. 841.1.1(a)

T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
[Superseded by ASME B31.8 (2018)]

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T_1 through T_{10}, T_{ref})] is used to form the stiffness matrix for Expansion load calculations in accordance with para. 832.4(b).

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_{Lp} = S_p + S_T + S_X + S_B$$

$$S_{Ln} = S_p + S_T + S_X - S_B$$

As per 833.4 (d), both the tensile and compressive values of S_B shall be considered in analysis.

where

$$S_p = 0.3S_H = 0.3 \frac{PD}{2t_n} = \text{longitudinal stress due to internal pressure in restrained pipeline}$$

$$S_H = \text{hoop stress}$$

$$S_T = \text{longitudinal stress due to thermal expansion in restrained pipeline} = E\alpha(T_i - T_o)$$

$$S_X = \text{stress due to axial loading (other than thermal expansion and pressure)} = \frac{R}{A}$$

S_B = nominal bending stress due to weight and other external loads (other than thermal expansion)

For Pipes and Long Radius Bends

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

For other Fittings or Components.

$$S_B = \frac{\sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2 + (M_t)^2}}{Z}$$

As per para 833.3(a), note that S_B, S_L, S_T or S_X can have negative values.

where

P = maximum operating pressure = max(P1 through P10)

D = outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
 [Superseded by ASME B31.8 (2018)]

- R = axial force component for external loads (other than thermal expansion and pressure)
 A = un-corroded cross-sectional area (i.e., after deducting for corrosion)
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
 T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
 E = Young's modulus at ambient (reference) temperature
 T_i = installation temperature = T_{ref} in CAEPIPE
 T_o = warmest or coldest operating temperature
 α = coefficient of thermal expansion at T_o defined above

Combined Stress for Restrained Pipe

The combined biaxial stress state of the pipeline in the operating mode is evaluated using the calculation given below by default in CAEPIPE.

$$S_{eq1} = \max\{|S_H - S_{Lp}|, |S_H|, |S_{Lp}|\}$$

$$S_{eq2} = \max\{|S_H - S_{Ln}|, |S_H|, |S_{Ln}|\}$$

Alternatively, the stresses may be combined in accordance with the maximum distortion energy theory as follows (see Note 3 below):

$$S_{eq1} = \sqrt{(S_{Lp})^2 - S_H S_{Lp} + (S_H)^2}$$

$$S_{eq2} = \sqrt{(S_{Ln})^2 - S_H S_{Ln} + (S_H)^2}$$

$$S_{eq} = \max\{S_{eq1}, S_{eq2}\} \leq 0.9ST$$

where

S_{eq} = equivalent combined stress

Notes:

1. Young's modulus of elasticity corresponding to the lowest operating temperature [$=\min(T_1 \text{ through } T_{10}, T_{ref})$] is used to form the stiffness matrix in accordance with para. 832.4(b).
2. Refer end of this appendix for the details of "Thickness and Section Modulus used for weight, pressure and stress calculations".
3. To combine stresses in accordance with the maximum distortion energy theory as stated above, set an environmental variable with name "DET_318" with its value as "YES".

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
[Superseded by ASME B31.8 (2018)]

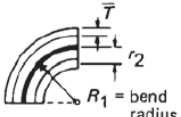
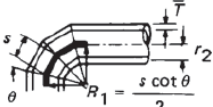
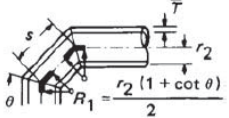
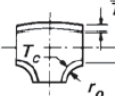
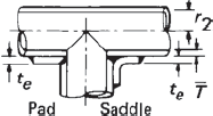
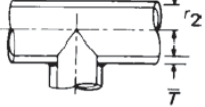
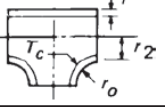
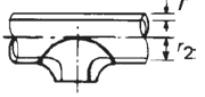
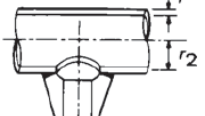
Notes on Material Library for B318-2016.mat supplied with CAEPIPE:

Material library for ASME B31.8 (2016) [B318-2016.mat] has been created and supplied with CAEPIPE as mentioned below.

1. **Coefficient of Thermal Expansion:** As stated in para. 832.2 of B31.8 (2016), Coefficient of Thermal Expansion for Carbon and low alloy steel are entered by referring to the values given in Table 832.2-1 of ASME B31.8 (2016).
2. **Modulus of Elasticity:** Modulus of Elasticity for Carbon and low alloy steel are entered by referring to the values given in Table 832.5-1 of ASME B31.8 (2016).
3. **Yield Strength:** Yield Strength for Carbon and low alloy steel are entered by referring to the values specified in Mandatory Appendix D titled “Specified Minimum Yield Strength for Steel Pipe Commonly Used in Piping Systems” of ASME B31.8 (2016).
4. **Density and Poisson’s ratio:** Density and Poisson’s ratio for Carbon and low alloy high tensile steel are entered as 0.283 lb/in³ and 0.3 respectively.
5. **Longitudinal Joint Factor:** Longitudinal Joint Factor for Carbon and low alloy steel are entered by referring to the values specified in Table 841.1.7-1 of ASME B31.8 (2016).


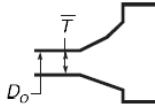
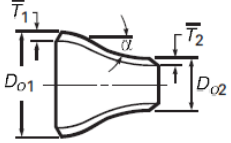
Gas Transmission and Distribution Piping Systems
 ASME B31.8 (2016)
 [Superseded by ASME B31.8 (2018)]

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

Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)]		Flexibility Characteristic, h	Sketch
		Out-plane, i_o	In-plane, i_i		
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)] $s < r_2 (1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta \bar{T} s}{r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta \bar{T}}{r_2}$	
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	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3 \frac{\bar{T}}{r_2}$	

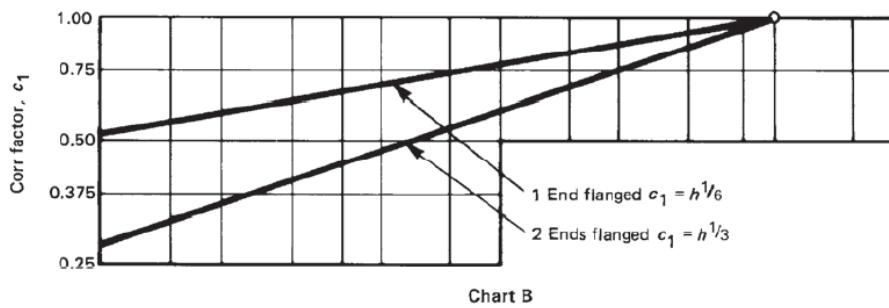
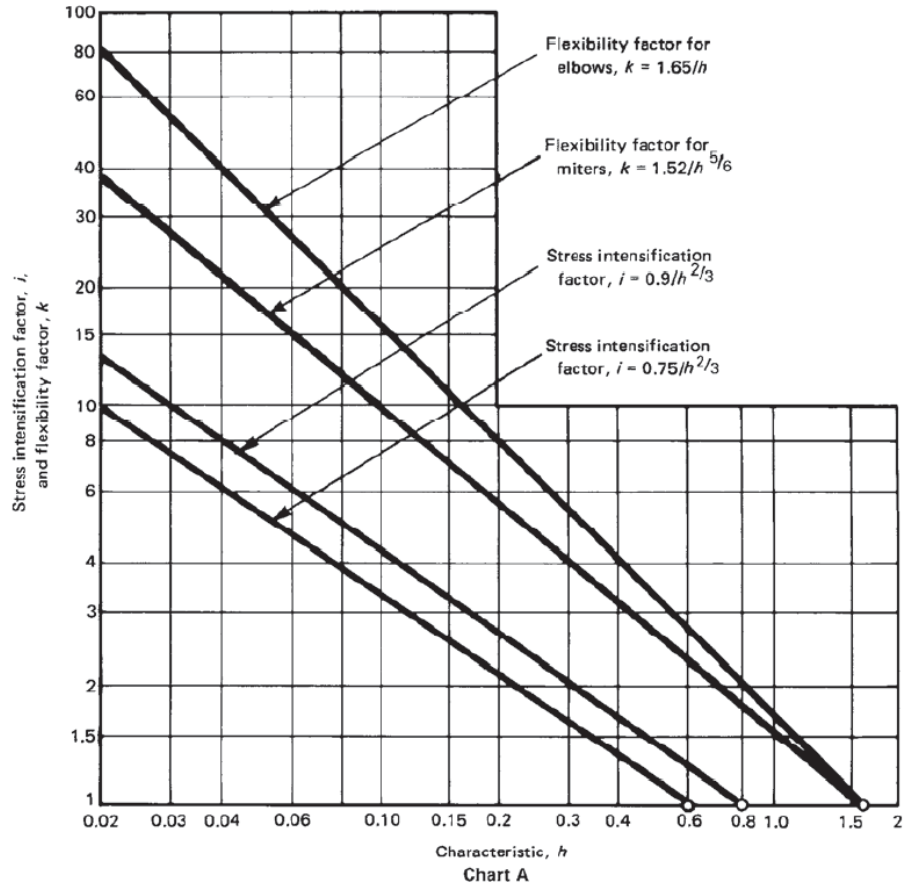
Gas Transmission and Distribution Piping Systems
 ASME B31.8 (2016)
 [Superseded by ASME B31.8 (2018)]

Table E-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{8}$ in. (3.18 mm), and $\delta_{avg}/\bar{T} =$ any value	1	1.9 max. or $(0.9 + 2.7(\delta_{avg}/\bar{T}))$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \leq 0.237$ in. (6.02 mm), $\delta_{max.} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{\bar{T}} + 3.6 \frac{\delta}{\bar{T}}$	
Tapered transition per ASME B16.25 [Note (1)]	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	1.2	
Double-welded slip-on flange [Note (14)]	1	2.1 max or $2.1 \bar{T}/C_s$ but not less than 1.3	
Socket welding flange or fitting [Notes (14) and (15)]	1	1.6	
Lap joint flange (with ASME B16.9 lap joint stub) [Note (14)]	1	2.3	
Threaded pipe joint or threaded flange [Note (14)]	5	2.5	
Corrugated straight pipe, or corrugated or creased bend [Note (16)]			

Gas Transmission and Distribution Piping Systems
 ASME B31.8 (2016)
 [Superseded by ASME B31.8 (2018)]

Table E-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)



Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
 [Superseded by ASME B31.8 (2018)]

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*₀ = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
*r*₂ = mean radius of matching pipe, in. (mm)
s = miter spacing at centerline, in. (mm)
 $\frac{s}{T}$ = 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*_{fl}, which can be read directly from Chart B, entering with the computed *h*.
- (4) The designer is cautioned that cast butt-welded 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

$$\left[1 + 6 \left(\frac{P}{E_e} \right) \left(\frac{r_2}{T} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3} \right]$$

divide *i* by

$$\left[1 + 3.25 \left(\frac{P}{E_e} \right) \left(\frac{r_2}{T} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3} \right]$$

where

*E*_e = cold modulus of elasticity, psi (MPa)
P = gage pressure, psi (MPa)

- (6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively.
- (7) When *t*_e > 1/2*T*, use *h* = 4.05*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 $(0.67/h^{2/3}) + 1/4$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.
- (10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between 0.875 \bar{T} and 1.10 \bar{T} for an axial distance of $\sqrt{D_o \bar{T}}$. *D*_o and \bar{T} are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2016)
[Superseded by ASME B31.8 (2018)]

- (13) The equation applies only if the following conditions are met.
- (a) Cone angle α does not exceed 60 deg, and the reducer is concentric.
 - (b) The larger of D_{o1}/\bar{T} and D_{o2}/\bar{T} does not exceed 100.
 - (c) The wall thickness is not less than \bar{T}_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than \bar{T}_2 .
- (14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4) (S_b A_b - PA_p)$$

- A_b = total area of flange bolts, in.² (mm²)
 A_p = area to outside of gasket contact, in.² (mm²)
 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.

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2012)
[Superseded by ASME B31.8 (2016)]

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from para. 841.1.1.

$$P = \frac{2SEt_nFT}{D}$$

where

P = allowable pressure

S = specified minimum yield strength from para. 817.1.3 (h) and para. 841.1.4 (a)

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1 and para. 817.1.3 (d)

t_n = nominal pipe thickness

D = nominal outside diameter

F = construction type design factor, obtained from Table 841.1.6-1

T = temperature derating factor, obtained from Table 841.1.8-1 and para. 841.1.8

Stress due to Sustained and Occasional Loads (Unrestrained Piping)

The sum of longitudinal pressure stress and the bending stress due to external loads, such as weight of the pipe and contents, seismic or wind, etc. is calculated according to paras. 833.6 (a) and 833.6 (b) along with paras. 805.2.3, 833.2 (b), 833.2 (d), 833.2 (e) and 833.2 (f).

Please note, the “include axial force in stress calculations” option is turned ON by default for ANSI B31.8.

Sustained Stress S_L :

For Pipes and Long Radius Bends

$$S_L = \left[\frac{PD}{4t_n} + \frac{R}{A} \right]_{\text{Sustained}} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \right]_{\text{Sustained}}$$

For other Fittings or Components.

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

Sustained + Occasional Stress S_{LO} :

For Pipes and Long Radius Bends

$$S_{LO} = S_L + \left[\frac{(P_{\text{peak}} - P)D}{4t_n} + \frac{R}{A} \right]_{\text{occasional}} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \right]_{\text{occasional}} \leq 0.75ST$$

For Fittings or Components

$$S_{LO} = S_{L(fc)} + \left[\frac{(P_{\text{peak}} - P)D}{4t_n} + \frac{R}{A} \right]_{\text{occasional}} + \left[\frac{\sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2 + (M_t)^2}}{Z} \right]_{\text{occasional}} \leq 0.75ST$$

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2012)
 [Superseded by ASME B31.8 (2016)]

where

- P = maximum operating pressure = max (P_1 through P_{10})
 P_{peak} = Peak pressure factor x P
 D = nominal outside diameter
 t_n = nominal thickness
 i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0
 i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0
 M_i = in-plane bending moment
 M_o = out-of-plane bending moment
 M_t = torsional moment
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 R = axial force component for external loads (other than thermal expansion and pressure)
 A = corroded cross-section area (i.e., after deducting for corrosion)
 S = specified minimum yield strength from para. 841.1.1(a)
 T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [=min (T_1 through T_{10} , T_{ref})] is used to form the stiffness matrix for Sustained and Occasional load calculations.

Expansion Stress (Unrestrained Piping)

The stress (S_E) due to thermal expansion is calculated from para.833.8.

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

where

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

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

M_t = torsional moment

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Please note, "Liberal allowable" option is always turned ON for ANSI B31.8.

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

f = stress range reduction factor = $6/\sqrt{N}$, where N = number of equivalent full range cycles

where $f \leq 1.0$ (from para. 833.8 (b)).

f = $0.33SuT$ at the minimum installed or operating temperature

S_h = $0.33SuT$ at the maximum installed or operating temperature

where

S_u = specified minimum ultimate tensile strength = $1.5 S_y$ (assumed), and

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2012)
 [Superseded by ASME B31.8 (2016)]

S_y = specified minimum yield strength as per para. 841.1.1(a)

T = temperature derating factor, obtained from para. 841.1.8 and Table 841.1.8-1

Note:

Young's modulus of elasticity corresponding to the lowest operating temperature [$=\min(T_1$ through T_{10}, T_{ref})] is used to form the stiffness matrix for Expansion load calculations.

Stress due to Sustained, Thermal and Occasional Loads (Restrained Piping)

The Net longitudinal stress (S_L) due to sustained, thermal expansion and occasional loads for restrained piping is calculated from paras. 833.3 (a), 833.3 (b) along with paras. 805.2.3, 833.2 (a), 833.2 (c), 833.2 (d), 833.2 (e) and 833.2 (f)

$$S_L = \max(|S_p + S_x + S_B|, |S_p + S_x - S_B|)_{sustained} + \max(|S_p + S_x + S_B|, |S_p + S_x - S_B|)_{occasional} + \max(|S_T|_{warmest}, |S_T|_{coldest}) \leq 0.9ST$$

where

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

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

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

For Pipes and Long Radius Bends

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

For other Fittings or Components.

$$S_B = \frac{\sqrt{(0.75i_i M_i)^2 + (0.75i_o M_o)^2 + (M_t)^2}}{Z}$$

Thermal expansion stress $= S_T = E\alpha(T_i - T_o)$, and may be positive or negative

Where

P = maximum operating pressure = max(P1 through P10)

D = nominal outside diameter

t_n = nominal thickness

i_i = in-plane stress intensification factor; the product $0.75i_i$ shall not be less than 1.0

i_o = out-of-plane stress intensification factor; the product $0.75i_o$ shall not be less than 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

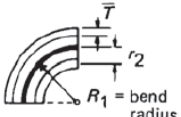
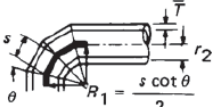
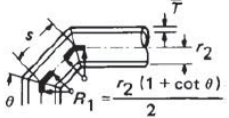
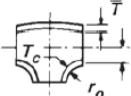
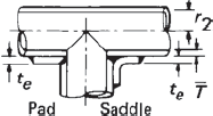
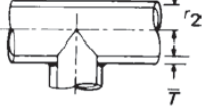
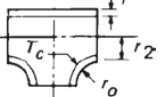
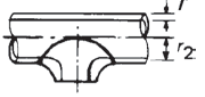
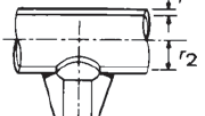
R = axial force component for external loads (other than thermal expansion and pressure)

Gas Transmission and Distribution Piping Systems
ASME B31.8 (2012)
[Superseded by ASME B31.8 (2016)]

- A = corroded cross-sectional area (i.e., after deducting for corrosion)
- Z = un-corroded section modulus; for reduced outlets, effective section modulus
- S = Specified Minimum Yield Strength (SMYS) from para. 841.1.1 (a)
- T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1
- E = Young's modulus at ambient (reference) temperature
- T_i = installation temperature = T_{ref} in CAEPIPE
- T_o = warmest or coldest operating temperature
- α = coefficient of thermal expansion at T_o defined above


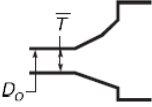
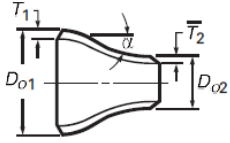
Gas Transmission and Distribution Piping Systems
 ASME B31.8 (2012)
 [Superseded by ASME B31.8 (2016)]

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

Description	Flexibility Factor, k	Stress Intensification Factor, i [Notes (1) and (2)]		Flexibility Characteristic, h	Sketch
		Out-plane, i_o	In-plane, i_i		
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)] $s < r_2 (1 + \tan \theta)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \theta \bar{T} s}{2 r_2^2}$	
Single miter bend or widely spaced miter bend $s \geq r_2 (1 + \tan \theta)$ [Notes (1), (2), and (5)]	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \theta \bar{T}}{2} \frac{\bar{T}}{r_2}$	
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	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3 \frac{\bar{T}}{r_2}$	

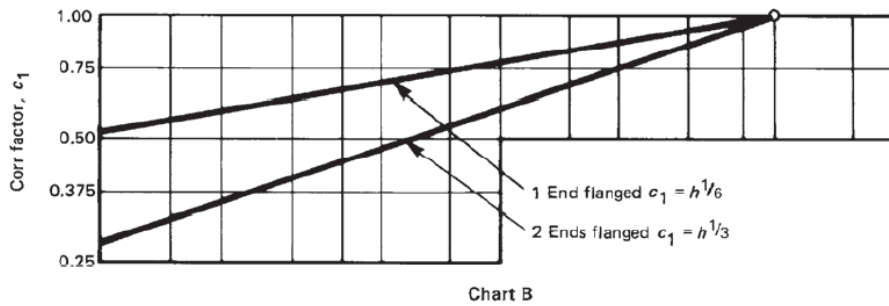
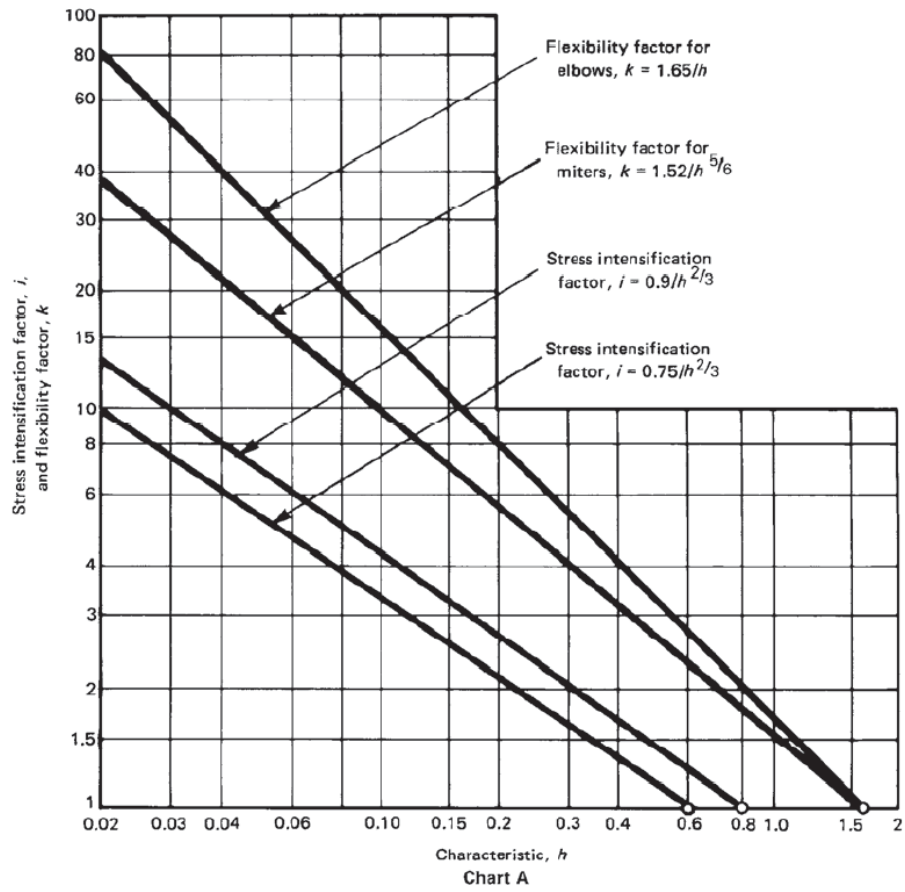
Gas Transmission and Distribution Piping Systems ASME B31.8 (2012)

Table E-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

Description	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$	1	1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max} \leq \frac{1}{8}$ in. (3.18 mm), and $\delta_{avg}/\bar{T} =$ any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\bar{T})]$, but not less than 1.0	
Buttweld [Notes (1) and (12)] $\bar{T} \leq 0.237$ in. (6.02 mm), $\delta_{max} \leq \frac{1}{16}$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{\bar{T}} + 3.6 \frac{\delta}{\bar{T}}$	
Concentric reducer per ASME B16.9 [Notes (1) and (13)]	1	2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$	
Double-welded slip-on flange [Note (14)]	1	1.2	
Socket welding flange or fitting [Notes (14) and (15)]	1	2.1 max or $2.1 \bar{T}/C_s$ 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	

Gas Transmission and Distribution Piping Systems ASME B31.8 (2012)

Table E-1 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)



Gas Transmission and Distribution Piping Systems

ASME B31.8 (2012)

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_0 = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
 r_2 = mean radius of matching pipe, in. (mm)
 s = miter spacing at centerline, in. (mm)
 \bar{T} = nominal wall thickness of piping component, in. (mm)
 = for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
 = for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
 = for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
 T_c = the crotch thickness of tees, in. (mm)
 t_c = 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 butt-welded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (5) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i . To correct values from the table, divide k by

$$\left[1 + 6 \left(\frac{P}{E_e} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3} \right]$$

divide i by

$$\left[1 + 3.25 \left(\frac{P}{E_e} \right) \left(\frac{r_2}{\bar{T}} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3} \right]$$

where

E_e = cold modulus of elasticity, psi (MPa)
 P = gage pressure, psi (MPa)

- (6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively.
- (7) When $t_c > 1/2\bar{T}$, use $h = 4.05T/r_2$.
- (8) The minimum value of the stress intensification factor shall be 1.2.
- (9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.
- (10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + 1/4$, respectively.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875\bar{T}$ and $1.10\bar{T}$ for an axial distance of $\sqrt{D_o \bar{T}}$. D_o and \bar{T} are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

Gas Transmission and Distribution Piping Systems ASME B31.8 (2012)

- (13) The equation applies only if the following conditions are met.
- (a) Cone angle α does not exceed 60 deg, and the reducer is concentric.
 - (b) The larger of D_{o1}/\bar{T} and D_{o2}/\bar{T} does not exceed 100.
 - (c) The wall thickness is not less than \bar{T}_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than \bar{T}_2 .
- (14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the following equation:

$$M_L = (C/4) (S_b A_b - PA_p)$$

A_b = total area of flange bolts, in.² (mm²)

A_p = area to outside of gasket contact, in.² (mm²)

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.

Building Services Piping ASME B31.9 (2017)

Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. 2 of para. 904.1 and 904.2.1.

$$P = \frac{2SE(t_m - A)}{D}$$

where

P = allowable pressure

SE = allowable hoop stress, given in Appendix I of B31.9 (2017) Code, where

E = longitudinal or spiral weld joint efficiency factor as per Table I-1 of Appendix I of ASME B31.9 (2017). For casting materials, factor E is replaced with Casting Qualify Factor from Table I-1 of Appendix I of ASME B31.9 (2017)

t_m = minimum required pipe thickness as per para. 904.1.1(a)

$= t_n \times (1 - \text{mill tolerance}/100)$

t_n = nominal pipe thickness

A = corrosion allowance

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

D = outside diameter

For closely and widely spaced miter bends, the allowable pressure shall be the lower positive value calculated from Eqs.(3A) and (3B) of para. 904.2.2(a)

$$P = \frac{SET}{r} \left(\frac{T}{T + 0.64 \tan \theta \sqrt{rT}} \right) \quad \text{Eq. (3A)}$$

$$P = \frac{SET}{r} \left(\frac{R-r}{R-r/2} \right) \quad \text{Eq. (3B)}$$

where

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

T = $t_m - A$, where t_m and A are defined above

R = effective bend radius of the miter

θ = miter half angle

Sustained Stress (in un-corroded condition)

The longitudinal stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated as mentioned in para. 902.3.2(d)

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

where

P = maximum of CAEPIPE input pressures P_1 through P_{10}

D_o = outside diameter

t_n = nominal wall thickness

i = stress intensification factor. The product $0.75i$ shall not be less than 1.0. See Note 1 below.

**Building Services Piping
ASME B31.9 (2017)**

M_A = resultant bending moment due to weight and other sustained loads
 Z = un-corroded section modulus; for reduced outlets, effective section modulus
 S_h = hot allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in un-corroded condition)

The longitudinal stress (S_{LO}) due to occasional loads is calculated as mentioned in para.902.3.3 (a) as the sum of stresses due to pressure, live and dead loads and stress due to occasional loads (S_O) such as earthquake or wind. Wind and earthquake are not considered to occur concurrently.

$$S_{LO} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq 1.33S_h$$

where

M_B = resultant bending moment due to occasional loads
 P_{peak} = peak pressure = (peak pressure factor) x P

Expansion Stress (in un-corroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 902.3.2(c), para. 919.2.1 and para. 919.4.1(b)

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

where

M_C = resultant moment due to thermal expansion
 $S_A = f(1.25S_C + 0.25S_h)$
 f = stress range reduction factor $6/N^{0.2}$, where N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping. Also $0.15 \leq f \leq 1.0$
 S_C = allowable stress at cold temperature, i.e. at minimum of CAEPIPE input temperatures T_1 through T_{10} and T_{ref}

When S_h is greater than S_L , the allowable stress range may be calculated as per para. 902.3.2 (d).

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

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

Notes:

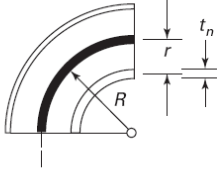
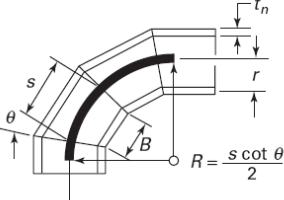
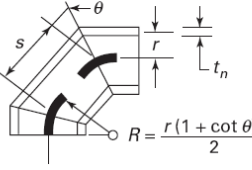
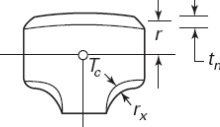
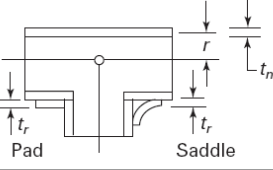
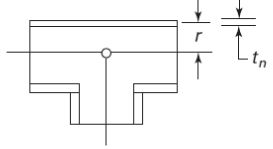
1. Stress Intensification Factors (SIFs) and Flexibility Factors (FFs) are computed using ASME B31.1 (2016) by default as given below. When the option “Use B31J for SIFs and Flexibility Factors” is Turned ON, then CAEPIPE computes SIFs and FFs as per B31J (2017).

Building Services Piping
ASME B31.9 (2017)

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

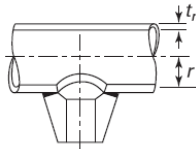
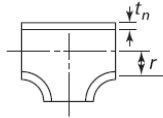
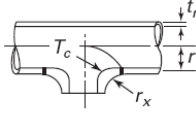
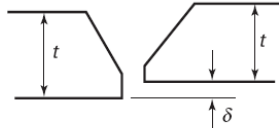
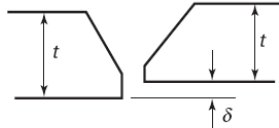
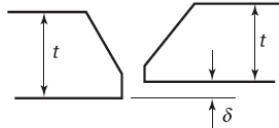
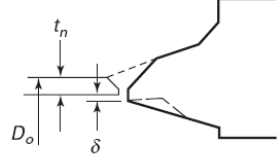
MANDATORY APPENDIX D

Table D-1 Flexibility and Stress Intensification Factors

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

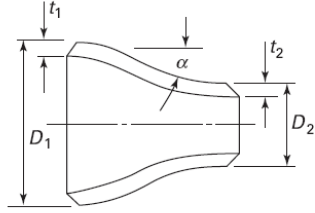
Building Services Piping ASME B31.9 (2017)

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., $\delta_{max} \leq \frac{1}{16}$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (11)]		
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq \frac{1}{8}$ 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., $\delta_{max} \leq \frac{1}{16}$ in., and $\delta_{avg}/t \leq 0.33$	1	1.0 [Note (11)]		
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 $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$		

Building Services Piping ASME B31.9 (2017)

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.

Building Services Piping
ASME B31.9 (2017)

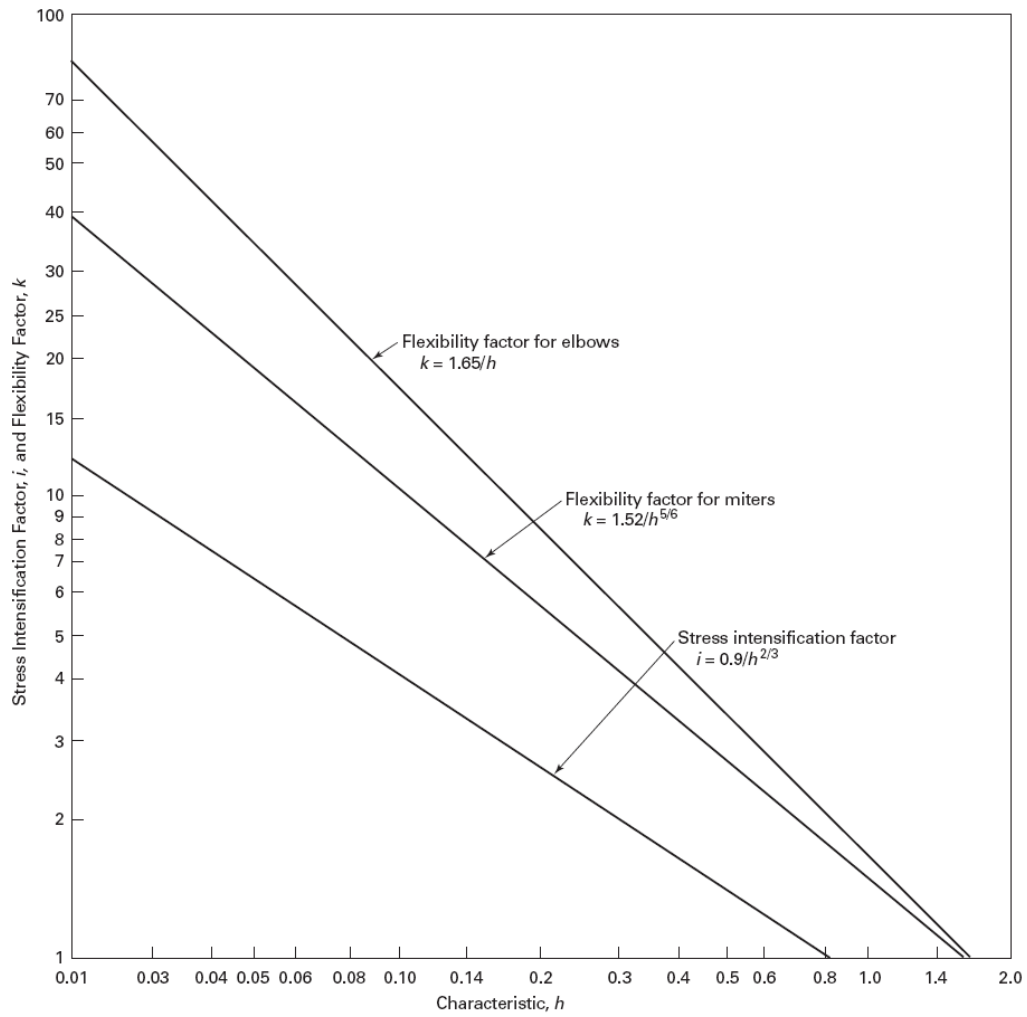
Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

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.

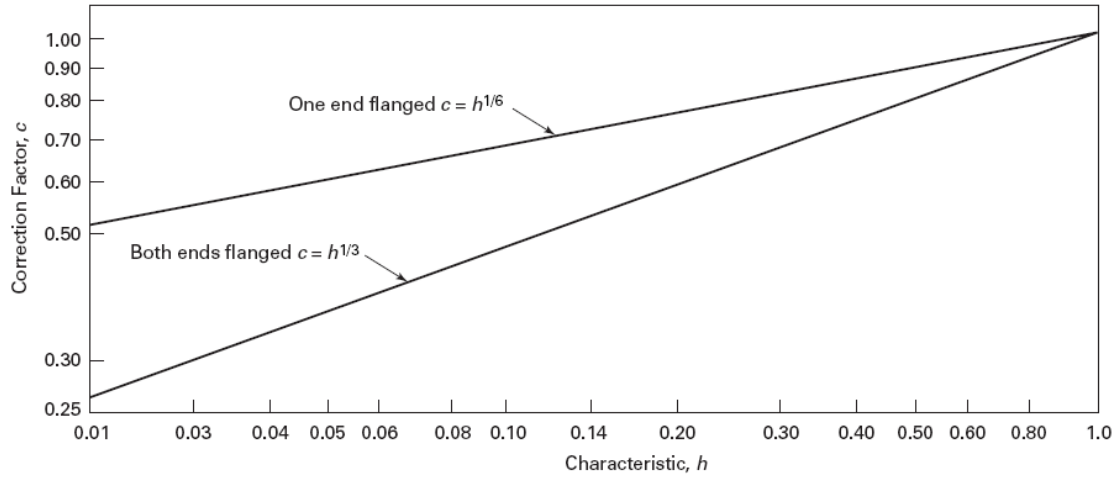
Building Services Piping
ASME B31.9 (2017)

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



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ASME B31.9 (2017)

Chart D-2 Correction Factor, c



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ASME B31.9 (2014)
[Superseded by ASME B31.9 (2017)]

Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. 2 of para. 904.1 and 904.2.1.

$$P = \frac{2SE(t_m - A)}{D}$$

where

P = allowable pressure

SE = allowable hoop stress, given in Appendix I of B31.9 (2014) Code, where

E = longitudinal or spiral weld joint efficiency factor or casting quality factor

t_m = minimum required pipe thickness as per para. 904.1.1(a)

$$= t_n \times (1 - \text{mill tolerance}/100)$$

t_n = nominal pipe thickness

A = corrosion allowance

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

D = outside diameter

For closely and widely spaced miter bends, the allowable pressure shall be the lower positive value calculated from Eqs.(3A) and (3B) of para. 904.2.2(a)

$$P = \frac{SET}{r} \left(\frac{T}{T + 0.64 \tan \theta \sqrt{rT}} \right) \quad \text{Eq. (3A)}$$

$$P = \frac{SET}{r} \left(\frac{R-r}{R-r/2} \right) \quad \text{Eq. (3B)}$$

where

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

T = $t_m - A$, where t_m and A are defined above

R = effective bend radius of the miter

θ = miter half angle

Sustained Stress (in un-corroded condition)

The longitudinal stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated as mentioned in para. 902.3.2(d)

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

where

P = maximum of CAEPIPE pressures P_1 through P_{10}

D_o = outside diameter

t_n = nominal wall thickness

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

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

Z = un-corroded section modulus; for reduced outlets, effective section modulus

Building Services Piping
ASME B31.9 (2014)
[Superseded by ASME B31.9 (2017)]

S_h = hot allowable stress at maximum of CAEPIPE input temperatures T_1 through T_{10}

Occasional Stress (in un-corroded condition)

The longitudinal stress (S_{LO}) due to occasional loads is calculated as mentioned in para.902.3.3 (a) as the sum of stresses due to pressure, live and dead loads and stress due to occasional loads (S_o) such as earthquake or wind. Wind and earthquake are not considered to occur concurrently.

$$S_{LO} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq 1.33S_h$$

where

M_B = resultant bending moment due to occasional loads

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

Expansion Stress (in un-corroded condition)

The stress (S_E) due to thermal expansion is calculated from para. 902.3.2(c), para. 919.2.1 and para. 919.4.1(b)

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

where

M_C = resultant moment due to thermal expansion

$S_A = f(1.25S_C + 0.25S_h)$

f = stress range reduction factor $6/N^{0.2}$, where N being the total number of equivalent reference displacement stress range cycles expected during the service life of the piping. Also $0.15 \leq f \leq 1.0$

S_C = allowable stress at cold temperature, i.e. at minimum of CAEPIPE input temperatures T_1 through T_{10} and T_{ref}

When S_h is greater than S_L , the allowable stress range may be calculated as per para. 902.3.2 (d).

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

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

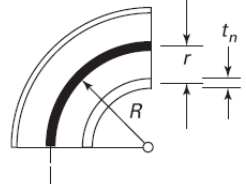
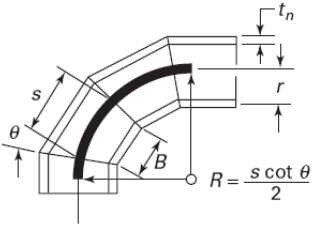
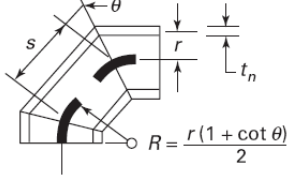
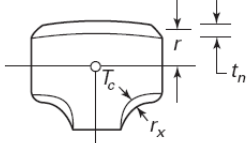
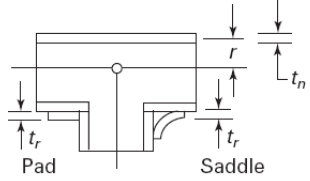
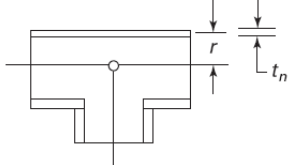
Note:

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

Stress Intensification Factor (SIF) values for B31.9 (2014) are referred from Appendix D of B31.1 (2012). The same is provided below for details.

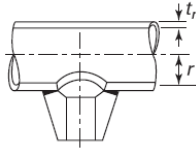
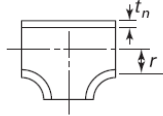
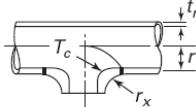
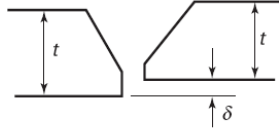
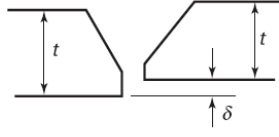
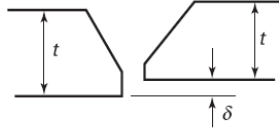
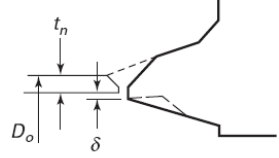
MANDATORY APPENDIX D

Table D-1 Flexibility and Stress Intensification Factors

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

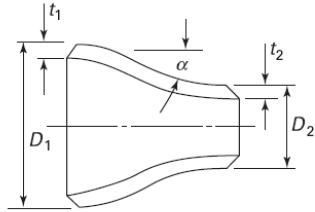
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[Superseded by ASME B31.9 (2017)]

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)]	1	1.0 [Note (11)]		
Butt weld [Note (1)]	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/\theta)]$, but not less than 1.0 [Note (11)]		
Butt weld [Note (1)]	1	1.0 [Note (11)]		
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 $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$		

Building Services Piping
ASME B31.9 (2014)
[Superseded by ASME B31.9 (2017)]

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.

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ASME B31.9 (2014)
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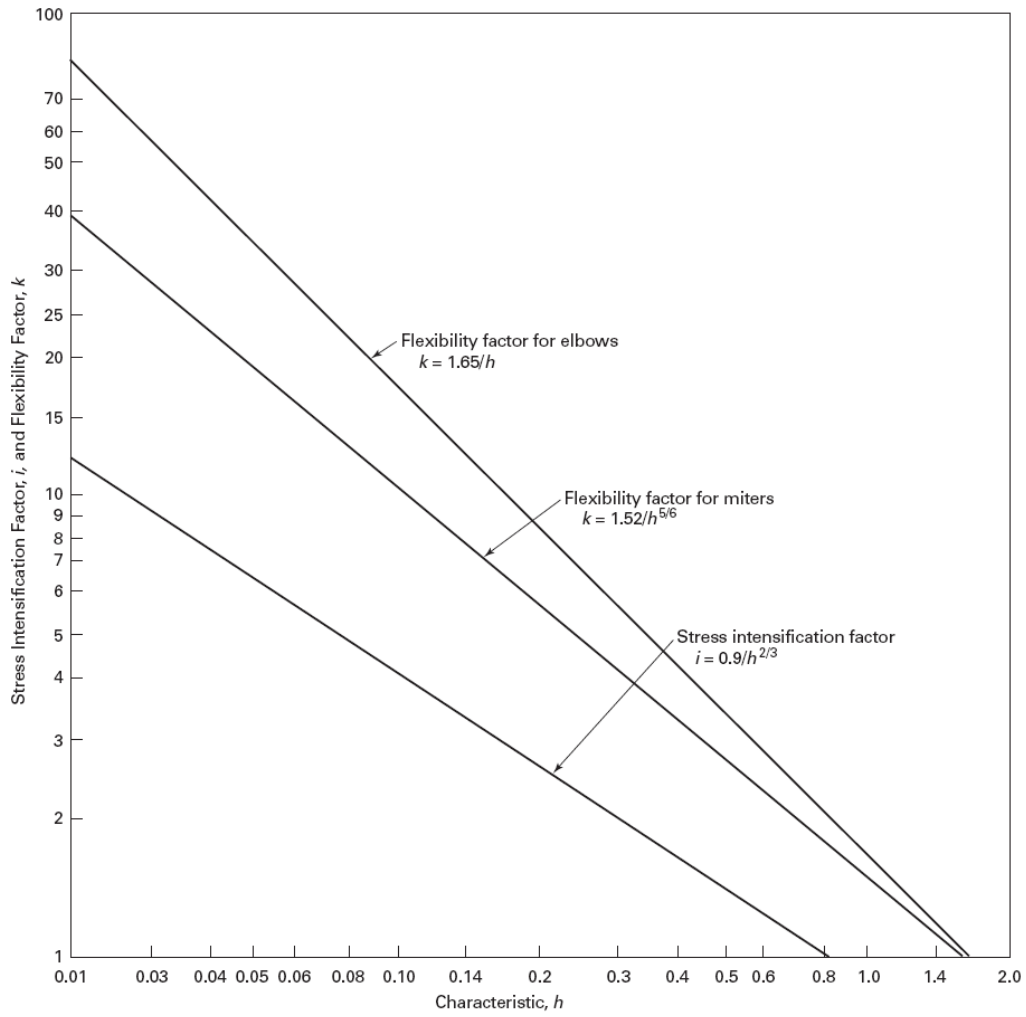
Table D-1 Flexibility and Stress Intensification Factors (Cont'd)

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.

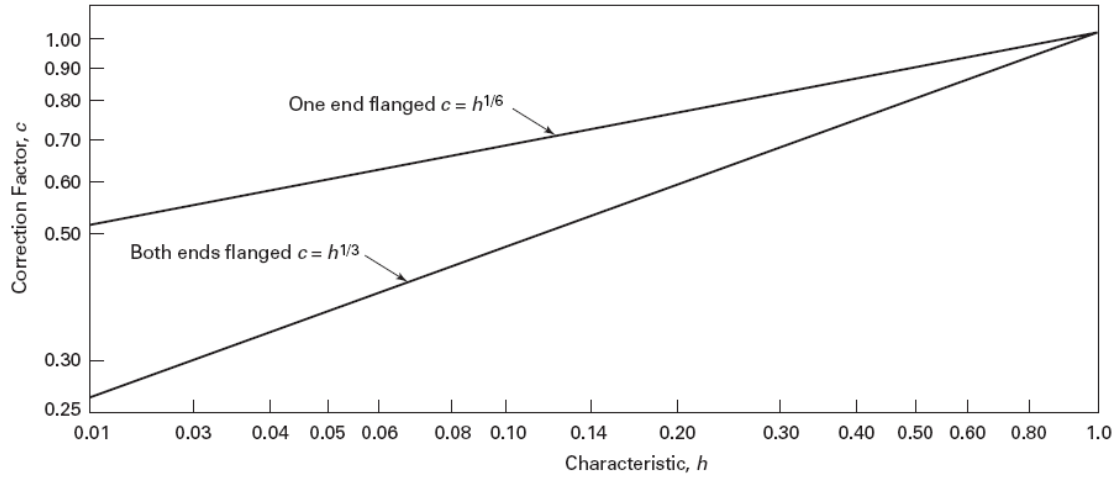
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Chart D-1 Flexibility Factor, k , and Stress Intensification Factor, i



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ASME B31.9 (2014)
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Chart D-2 Correction Factor, c



Hydrogen Piping and Pipelines ASME B31.12 (2019)

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with $I = 1.0$ for bends from paras. IP-3.2.1 and IP-3.3.1 respectively.

$$P_a = \frac{2SEM_f t_a}{D - 2Y t_a}$$

where

P_a = allowable pressure

S = stress value for material from Table IX-1A

E = quality factor from Table IX-2 or Table IX-3A

M_f = material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

t_n = available thickness for pressure design

$$= t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance "c"}$$

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

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = coefficient from Table IP-3.2.1, valid for $t_a < D/6$ for Ferritic and Austenitic steels. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE for all available materials.

$Y = \frac{d+2c}{D+d+2c}$, valid for $t_a \geq D/6$ for all material types.

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4b) from para. IP-3.3.3.

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

For widely spaced miter bends with $\theta \leq 22.5$ deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. IP-3.3.3 as

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

For widely spaced miter bends with $\theta > 22.5$ deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. IP-3.3.3 as

Hydrogen Piping and Pipelines
ASME B31.12 (2019)

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

where

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

R = effective bend radius of the miter (see para. IP-3.3.3 (d) of code for definition) [an input in CAEPIPE for miters]

θ = angle of miter cut (see para. IP-3.3.3 of code for definition)

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) from para. 320.2 of ASME B31.3 (2018) and compared against the allowable provided in para. IP-2.2.10.

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

where

$$S_a = \left[\frac{I_a F_a}{A_p} \right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p} \right]_{Sustained}$$

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

For branch (Leg 3 in Fig. 319.4.4B) of ASME B31.3 (2018),

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

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

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_s = wall thickness used for sustained stress calculation obtained by deducting corrosion allowance from the nominal thickness

t_n = nominal thickness - corrosion allowance in CAEPIPE, as per para. 320.1 of ASME B31.3 (2018)

A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 320.1 of ASME B31.3 (2018)

I_a = longitudinal force index = 1.0

F_a = longitudinal force due to sustained loads such as pressure and weight

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

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

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

Hydrogen Piping and Pipelines
ASME B31.12 (2019)

where, i_i and i_o are taken from Appendix D of ASME B31.3 (2018) [reprinted at the end of this Section] or from B31J (2017) when the option “Use B31J for SIFs and Flexibility Factors” is Turned ON.

I_t = torsional moment index = 1.0

M_i = in-plane bending moment due to sustained loads such as pressure and weight

M_o = out-of-plane bending moment due to sustained loads such as pressure and weight

M_t = torsional moment due to sustained loads such as pressure and weight

Z_m = corroded section modulus as per para. 320.1 of ASME B31.3 (2018)

Z_e = effective corroded section modulus for branch as per para.320.2 of ASME B31.3 (2018) when Appendix D of ASME B31.3 is used to compute Stress Intensification Factors (SIFs) (or) corroded section modulus when B31J is used to compute to compute SIFs.

M_f = material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

S_h = basic allowable stress at maximum temperature, i.e., max (T_{ref} , T_1 through T_{10})

Sustained plus Occasional Stress

The stress (S_{LO}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. IP-2.2.11).

For temp $\leq 427^\circ\text{C}$ or 800°F (see Note 1 below)

$$S_{LO} \leq 1.33S_hM_f$$

For temp $> 427^\circ\text{C}$ or 800°F

$$S_{LO} \leq 0.9WS_yM_f$$

where

$S_{LO} = S_L + S_o$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b1), (23b2), (23c) and (23d) of ASME B31.3 (2018) with applicable loads.

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

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

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

For branch (Leg 3 in Fig. 319.4.4B) of ASME B31.3 (2018)

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

Hydrogen Piping and Pipelines
ASME B31.12 (2019)

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

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

P = maximum of CAEPIPE input pressures P1 through P10

R = axial force due to occasional loads such as earthquake or wind

M_i = in-plane bending moment due to occasional loads such as earthquake or wind

M_o = out-of-plane bending moment due to occasional loads such as earthquake or wind

M_t = torsional moment due to occasional loads such as earthquake or wind

S_y = yield strength at maximum temperature, i.e., max (T_{ref} , T_1 through T_{10})

W = 1.0 for Austenitic stainless steel and 0.8 for other materials as per para. IP-2.2.11(a)

Z_m = corroded section modulus as per para. 320.1 of ASME B31.3 (2018)

Z_e = effective corroded section modulus for branch as per para.320.2 of ASME B31.3 (2018) when Appendix D of ASME B31.3 is used to compute Stress Intensification Factors (SIFs) (or) corroded section modulus when B31J is used to compute to compute SIFs.

Note 1:

The allowable stress equations for (S_{LO}) are taken from para. 302.3.6 of ASME B31.3 (2018), as the sentence “At temperatures warmer than 427 deg. C (800 deg.F), use 1.33.Sh.M_f” in para. IP-2.2.11 of ASME B31.12 (2019) code seems to be incorrectly worded.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. IP-6.1.5. The Axial Stress term (S_a) is included in Expansion Stress calculation as per Eq. 17 of para. 319.4.4 of ASME B31.3 (2018) code.

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

where

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

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

For branch (Leg 3 in Fig. IP-6.1.5-2)

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

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

Hydrogen Piping and Pipelines ASME B31.12 (2019)

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D as per IP-6.1.4 (e).

i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ or i for other components as listed in Appendix D of B31.3 (2018)

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

i_i = in-plane stress intensification factor from Appendix D of ASME B31.3 (2018) or from B31J (2017) when the option “Use B31J for SIFs and Flexibility Factors” is Turned ON. i_i shall not be less than 1.0.

i_o = out-of-plane stress intensification factor Appendix D of ASME B31.3 (2018) or from B31J (2017) when the option “Use B31J for SIFs and Flexibility Factors” is Turned ON. i_o shall not be less than 1.0.

i_t = torsional stress intensification factor = 1.0

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torsional moment

Z = un-corroded section modulus as per IP-6.1.4 (e)

Z_e = un-corroded effective section modulus as per IP-6.1.4 (e)

$S_A = f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. IP-2.2.10 (d)

f = stress range reduction factor from Eq. (1c) of para. IP-2.2.10 (d) = $6N^{-0.2}$
where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)

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

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

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

$S_A = f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. IP-2.2.10 (d).

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

Notes:

1. As per para. IP-2.2.10 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at metal temperatures $\leq 371^\circ\text{C}$ (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence $f \leq 1.0$ for all materials including Ferrous materials.
2. Young’s modulus of elasticity corresponding to reference temperature (E_{ref}) is used to form the stiffness matrix in accordance with para. IP-6.1.5 (d)(1).
3. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

Hydrogen Piping and Pipelines
ASME B31.12 (2019)

Notes on Material Library for B3112-2019.mat supplied with CAEPIPE:

1. Material library for ASME B31.12 (2019) [B3112-2019.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix IX of ASME B31.12 (2019).
2. **Coefficient of Thermal Expansion:** Coefficient of Thermal Expansion data are entered by referring to the values provided in Table C-1 of Appendix C of ASME B31.3 (2018).
3. **Modulus of Elasticity:** Modulus of Elasticity data are entered by referring to the values provided in Table C-6 of Appendix C of ASME B31.3 (2018).
4. **Longitudinal Joint Factor:** Longitudinal Joint Factor are entered by referring to the values specified in Table IX-3A of ASME B31.12 (2019).

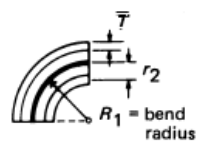
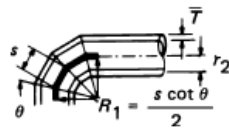
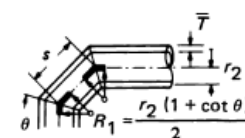
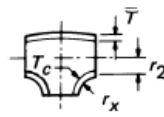
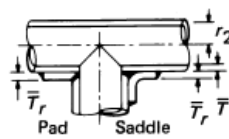
Hydrogen Piping and Pipelines
ASME B31.12 (2019)

Stress Intensification Factor (SIF) values for B31.12 (2019) are referred from Appendix D of B31.3 (2018). The same is provided below for details.

APPENDIX D
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

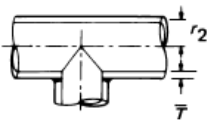
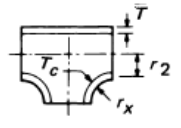
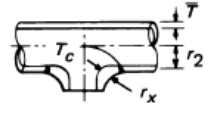
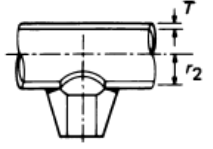
See Table D300.

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

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

Hydrogen Piping and Pipelines ASME B31.12 (2019)

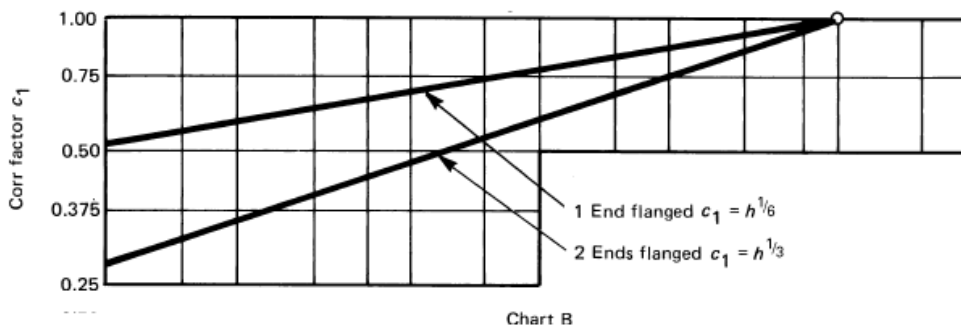
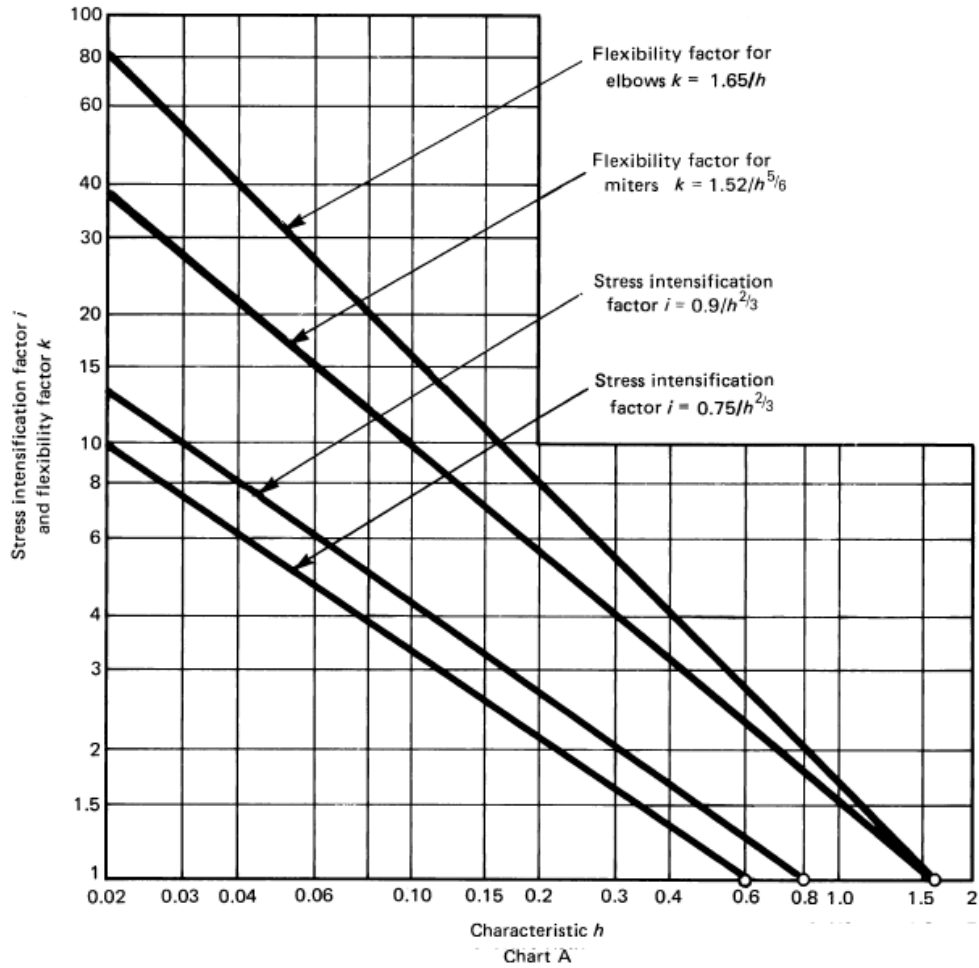
Table D300 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

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

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

Hydrogen Piping and Pipelines ASME B31.12 (2019)

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



Hydrogen Piping and Pipelines ASME B31.12 (2019)

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

(14)

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

NOTES:

- (1) The flexibility factor, k , in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k , and stress intensification factors, i , shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.
- (2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.
- (3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:
 - D_b = outside diameter of branch
 - R_1 = bend radius of welding elbow or pipe bend
 - r_x = see definition in para. 304.3.4(c)
 - r_2 = mean radius of matching pipe
 - s = miter spacing at centerline
 - \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting
 - = for tees, the nominal wall thickness of the matching pipe
 - \bar{T}_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
 - \bar{T}_r = pad or saddle thickness
 - θ = one-half angle between adjacent miter axes
- (4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 , which can be read directly from Chart B, entering with the computed h .
- (5) The designer is cautioned that cast butt-welded 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

$$1 + 6 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3}$$

divide i by

$$1 + 3.25 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3}$$

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

- (7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5 \bar{T}$, a flexibility characteristic of $4.4 \bar{T}/r_2$ may be used.
- (8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.
- (9) When \bar{T}_r is $> 1\frac{1}{2} \bar{T}$, use $h = 4 \bar{T}/r_2$.
- (10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.
- (13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Hydrogen Piping and Pipelines
ASME B31.12 (2019)

Coefficient ‘Y’ used in CAEPIPE to compute Allowable Design Pressure

[Sl. Nos. 1 & 2 below are from Table IP-3.2.1 and Sl. Nos. 3, 4 & 5 are from Table 304.1.1 of ASME B31.3 (2018)]

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

Carbon Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as “CS” (from Table IX-5B)

Sl. No.	Specified Min. Yield Strength (ksi)	System Design Pressure, psig					
		<=1000	2000	3000	4000	5000	6000
1.	<= 52	1.000	0.948	0.912	0.884	0.860	0.839
2.	<= 56	0.930	0.881	0.848	0.824	0.800	0.778
3.	<= 65	0.839	0.796	0.766	0.745	0.724	0.706
4.	<= 80	0.715	0.678	0.645	0.633	0.618	0.600

Low and Intermediate Alloy Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as “AS” (from Table IX-5C)

Sl. No.	Specified Min. Tensile Strength (ksi)	System Design Pressure, psig						
		0.000	1000	2000	3000	4000	5000	6000
1.	<= 35	1.000	0.918	0.881	0.875	0.836	0.815	0.800
2.	<= 45	0.791	0.724	0.696	0.675	0.660	0.642	0.630
3.	<= 60	0.655	0.601	0.577	0.561	0.547	0.533	0.524
4.	<= 65	0.580	0.532	0.511	0.497	0.485	0.472	0.464

Note:

For materials not covered by Tables given above, Material Performance Factor (M_f) is taken as 1.00.

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (3a) for straight pipes and Eq. (3c) with $I = 1.0$ for bends from paras. IP-3.2.1 and IP-3.3.1 respectively.

$$P_a = \frac{2SEM_f t_a}{D - 2Y t_a}$$

where

P_a = allowable pressure

S = stress value for material from Table IX-1A

E = quality factor from Table IX-2 or Table IX-3A

M_f = material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

t_a = available thickness for pressure design

$$= t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance "c"}$$

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

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = coefficient from Table IP-3.2.1, valid for $t_a < D/6$ for Ferritic and Austenitic steels. Refer to the Table listed at the end of this Section for details on 'Y' used in CAEPIPE for all available material.

$$Y = \frac{d+2c}{D+d+2c}, \text{ valid for } t_a \geq D/6 \text{ for all material types.}$$

For closely spaced miter bends, the allowable pressure is calculated in CAEPIPE using Eq. (4b) from para. IP-3.3.3.

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

For widely spaced miter bends with $\theta \leq 22.5$ deg, the allowable pressure is calculated in CAEPIPE using Eq. (4a) from para. IP-3.3.3 as

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

For widely spaced miter bends with $\theta > 22.5$ deg, the allowable pressure is calculated in CAEPIPE using Eq. (4c) from para. IP-3.3.3 as

Hydrogen Piping and Pipelines
ASME B31.12 (2014)
[Superseded by ASME B31.12 (2019)]

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

where

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

R = effective bend radius of the miter (see para. IP-3.3.3 (d) of code for definition) [an input in CAEPIPE for miters]

θ = angle of miter cut

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eqs. (23a), (23b), (23c) and (23d) from para. 320.2 of ASME B31.3 (2014) and compared against the allowable provided in para. IP-2.2.10.

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

where

$$S_a = \left[\frac{I_a F_a}{A_p} \right]_{Sustained} = \left[\frac{PD}{4t_s} + \frac{R}{A_p} \right]_{Sustained}$$

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

For branch (Leg 3 in Fig. 319.4.4B) of ASME B31.3 (2014),

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

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

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t_s = wall thickness used for sustained stress calculation obtained by deducting corrosion allowance from the nominal thickness

t_n = nominal thickness - corrosion allowance in CAEPIPE, as per para. 320.1 of ASME B31.3 (2014)

A_p = corroded cross-sectional area of the pipe computed using t_s as per para. 320.1 of ASME B31.3 (2014)

I_a = longitudinal force index = 1.0

F_a = longitudinal force due to sustained loads such as pressure and weight

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

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

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

Hydrogen Piping and Pipelines
ASME B31.12 (2014)
[Superseded by ASME B31.12 (2019)]

where, i_i and i_o are taken from Appendix D of ASME B31.3 (2014) [reprinted at the end of this Section].

I_t = torsional moment index = 1.0

M_i = in-plane bending moment due to sustained loads such as pressure and weight

M_o = out-of-plane bending moment due to sustained loads such as pressure and weight

M_t = torsional moment due to sustained loads such as pressure and weight

Z_m = corroded section modulus as per para. 320.1 of ASME B31.3 (2014)

Z_e = effective corroded section modulus for branch as per para. 320.2 of ASME B31.3 (2014)

M_f = material performance factor that addresses loss of material properties associated with hydrogen gas service from Tables IX-5B and IX-5C from Appendix IX.

Sustained plus Occasional Stress

The stress (S_{Lo}) due to sustained and occasional loads is calculated as the sum of stress (S_L) due to sustained loads such as pressure and weight and stress (S_o) due to occasional loads such as earthquake or wind. Wind and earthquake are not considered as acting concurrently (see para. IP-2.2.11).

For temp $\leq 427^\circ\text{C}$ or 800°F

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

For temp $> 427^\circ\text{C}$ or 800°F

$$S_{Lo} \leq 0.9WS_yM_f$$

where

$S_{Lo} = S_L + S_o$, where S_L is computed as above, and S_o is calculated using Eqs. (23a), (23b), (23c) and (23d) of ASME B31.3 (2014) with applicable loads.

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

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

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

For branch (Leg 3 in Fig. 319.4.4B) of ASME B31.3 (2014)

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

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

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

Hydrogen Piping and Pipelines
ASME B31.12 (2014)
[Superseded by ASME B31.12 (2019)]

- 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 Austenitic stainless steel and 0.8 for other materials as per para. IP-2.2.11(a)
 Z_m = corroded section modulus as per para. 320.1 of ASME B31.3 (2014)
 Z_e = effective corroded section modulus for branch as per para. 320.2 of ASME B31.3 (2014)

Note 1:

The allowable stress equations for (S_{LO}) are taken from para. 302.3.6 of ASME B31.3 (2014), as the sentence “At temperatures warmer than 427 deg. C (800 deg.F), use 1.33.Sh.M_f” in para. IP-2.2.11 of ASME B31.12 (2014) code seems to be incorrectly worded.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated using Eq. 17 from para. IP-6.1.5

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

where

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

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

For branch (Leg 3 in Fig. IP-6.1.5-2)

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

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

A = un-corroded cross-sectional area of the pipe/fitting computed using nominal thickness t_n and outer diameter D as per IP-6.1.4 (e).

i_a = axial stress intensification factor = 1.0 for elbows, pipe bends and miter bends and $i_a = i_o$ or i for other components as listed in Appendix D of B31.3 (2014)

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

i_i = in-plane stress intensification factor from Appendix D of ASME B31.3 (2014) shall not be less than 1.0

i_o = out-of-plane stress intensification factor Appendix D of ASME B31.3 (2014) shall not be less than 1.0

Hydrogen Piping and Pipelines
ASME B31.12 (2014)
[Superseded by ASME B31.12 (2019)]

i_t = torsional stress intensification factor = 1.0
 M_i = in-plane bending moment
 M_o = out-of-plane bending moment
 M_t = torsional moment
 Z = un-corroded section modulus as per IP-6.1.4 (e)
 Z_e = un-corroded effective section modulus as per IP-6.1.4 (e)

S_A = $f(1.25S_C + 0.25S_h)$, Eq. (1a) of para. IP-2.2.10 (d)
 f = stress range reduction factor from Eq. (1c) of para. IP-2.2.10 (d) = $6N^{-0.2}$
where $f \geq 0.15$ and $f \leq 1.0$ (see Note 1 below)
 S_C = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis
 S_h = basic allowable stress at maximum metal temperature expected during the displacement cycle under analysis

When S_h is greater than Sustained Stress S_L , the allowable stress range may be calculated as
 $S_A = f[1.25(S_C + S_h) - S_L]$, Eq. (1b) of para. IP-2.2.10 (d).

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

Notes:

4. As per para. IP-2.2.10 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at metal temperatures $\leq 371^\circ\text{C}$ (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence $f \leq 1.0$ for all materials including Ferrous materials.
5. Young’s modulus of elasticity corresponding to reference temperature (E_{ref}) is used to form the stiffness matrix in accordance with para. IP-6.1.5 (d)(1).
6. Refer end of this appendix for the details of “Thickness and Section Modulus used for weight, pressure and stress calculations”.

Notes on Material Library for B3112-2014.mat supplied with CAEPIPE:

Material library for ASME B31.12 (2014) [B3112-2014.mat] supplied with CAEPIPE has been created by referring to the values provided in Appendix IX of ASME B31.12 (2014).

APPENDIX D FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

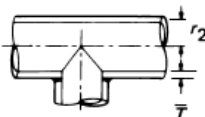
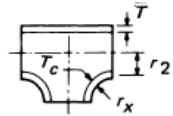
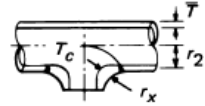
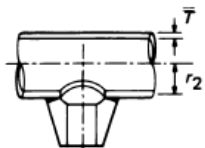
See Table D300.

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

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

Hydrogen Piping and Pipelines
ASME B31.12 (2014)
[Superseded by ASME B31.12 (2019)]

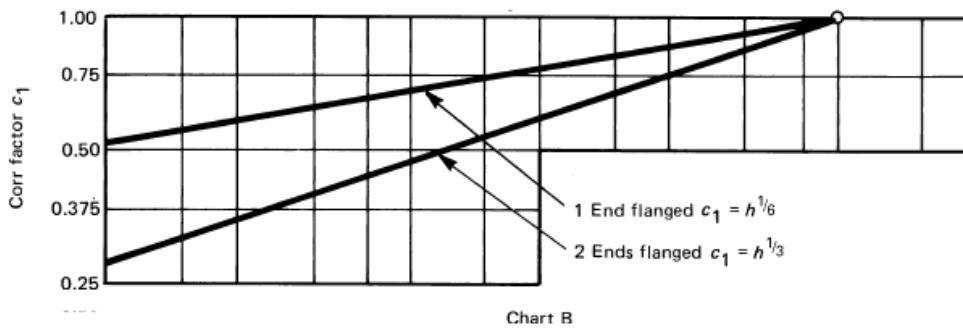
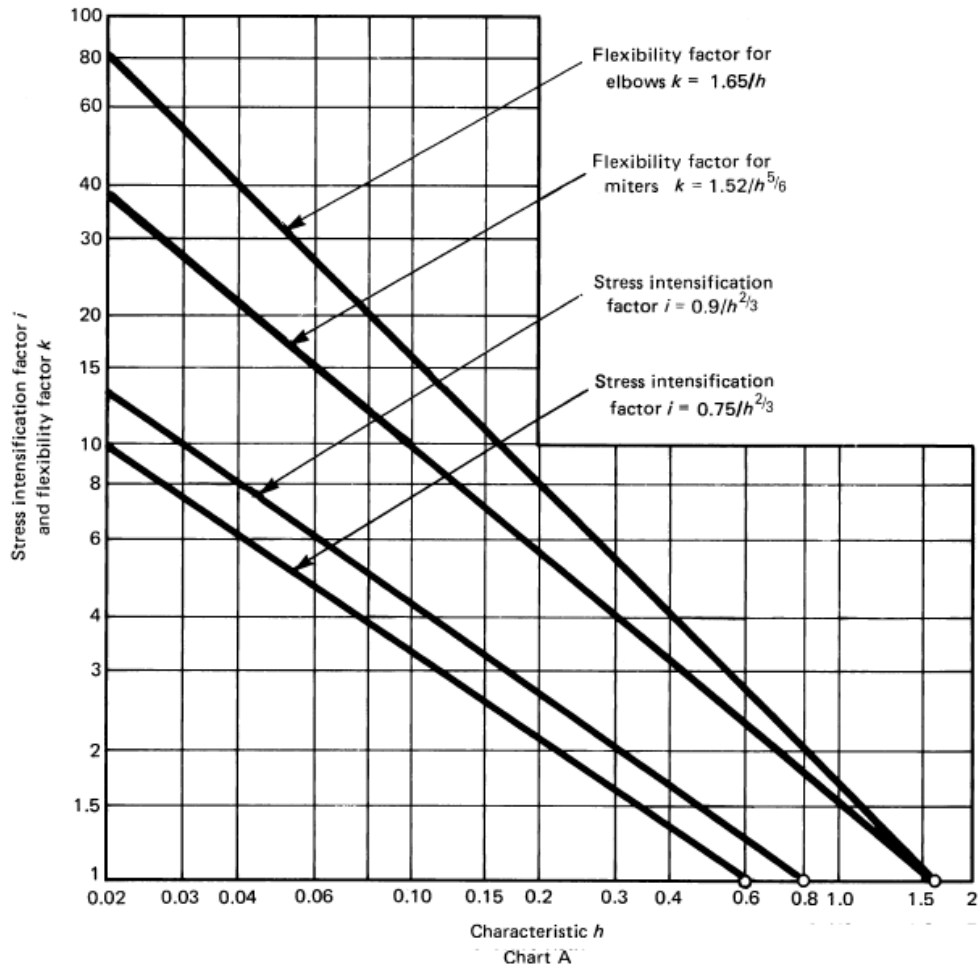
Table D300 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

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

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

Hydrogen Piping and Pipelines
 ASME B31.12 (2014)
 [Superseded by ASME B31.12 (2019)]

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



Hydrogen Piping and Pipelines ASME B31.12 (2014)

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

(14)

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

NOTES:

- (1) The flexibility factor, k , in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k , and stress intensification factors, i , shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.
- (2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_i and i_o if desired.
- (3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:
 - D_b = outside diameter of branch
 - R_1 = bend radius of welding elbow or pipe bend
 - r_x = see definition in para. 304.3.4(c)
 - r_2 = mean radius of matching pipe
 - s = miter spacing at centerline
 - \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting
 - = for tees, the nominal wall thickness of the matching pipe
 - \bar{T}_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
 - \bar{T}_r = pad or saddle thickness
 - θ = one-half angle between adjacent miter axes
- (4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 , which can be read directly from Chart B, entering with the computed h .
- (5) The designer is cautioned that cast butt-welded 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

$$1 + 6 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3}$$

divide i by

$$1 + 3.25 \left(\frac{P_1}{E_1} \right) \left(\frac{r_2}{\bar{T}} \right)^{5/2} \left(\frac{R_1}{r_2} \right)^{2/3}$$

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

- (7) If $r_x \geq \frac{1}{8} D_b$ and $T_c \geq 1.5 \bar{T}$, a flexibility characteristic of $4.4 \bar{T}/r_2$ may be used.
- (8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.
- (9) When \bar{T}_r is $> 1\frac{1}{2} \bar{T}$, use $h = 4 \bar{T}/r_2$.
- (10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.
- (13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Hydrogen Piping and Pipelines
ASME B31.12 (2014)

Coefficient ‘Y’ used in CAEPIPE to compute Allowable Design Pressure

[Sl. Nos. 1 & 2 below are from Table IP-3.2.1 and Sl. Nos. 3, 4 & 5 are from Table 304.1.1 of ASME B31.3 (2014)]

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

Carbon Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as ‘CS’ (from Table IX-5B)

Sl. No.	Specified Min. Yield Strength (ksi)	System Design Pressure, psig					
		<=1000	2000	3000	4000	5000	6000
1.	<= 52	1.000	0.948	0.912	0.884	0.860	0.839
2.	<= 56	0.930	0.881	0.848	0.824	0.800	0.778
3.	<= 65	0.839	0.796	0.766	0.745	0.724	0.706
4.	<= 80	0.715	0.678	0.645	0.633	0.618	0.600

Low and Intermediate Alloy Steel Piping Materials Performance Factor (M_f) used in CAEPIPE for Material Type as ‘AS’ (from Table IX-5C)

Sl. No.	Specified Min. Tensile Strength (ksi)	System Design Pressure, psig						
		0.000	1000	2000	3000	4000	5000	6000
1.	<= 35	1.000	0.918	0.881	0.875	0.836	0.815	0.800
2.	<= 45	0.791	0.724	0.696	0.675	0.660	0.642	0.630
3.	<= 60	0.655	0.601	0.577	0.561	0.547	0.533	0.524
4.	<= 65	0.580	0.532	0.511	0.497	0.485	0.472	0.464

Note:

For materials not covered by Tables given above, Material Performance Factor (M_f) is taken as 1.00.

ASME B31J – 2017
Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and Their
Determination for Metallic Piping Components

- Implemented as an optional feature for ASME B31.1, B31.3, B31.4, B31.5, B31.8 and B31.9 codes. This feature can be turned ON or OFF through Layout Frame > Options > Analysis.
- Turning on the Option B31J will allow users to select and specify among those Branch SIF types defined in B31J for all the above codes.
- When B31J is turned ON, CAEPIPE will calculate SIFs as per B31J and report Torsional, In-plane and Out-of-plane SIFs in Element Forces and Moments results irrespective of whether they are being used or not in Code Compliance as per the Piping Code selected for Analysis. For Example, CAEPIPE will not include Torsional Moment and Torsional SIF while calculating Sustained Stress as per ASME B31.5 (2016).
- For Equal TEEs, the Run and Branch should be differentiated in CAEPIPE model by defining the Branch OD slightly less than the Run OD through CAEPIPE Sections input. Otherwise, CAEPIPE will use the equations corresponding to Run pipe even for Branch pipe.
- ASME B31.3 (2016) includes the term Axial SIF in Stress Calculations. On the other hand, B31J is silent about the Axial SIF for various components. Hence, CAEPIPE will use the Axial SIF values as stated in the respective text portions of B31.3 (2016) while computing stresses irrespective of whether the option B31J is turned ON or OFF.
- As per para 402.6.1 of ASME B31.4 (2016), Torsion moment is not included in the equation for Sustained Stress for Restrained piping. In line with the code, CAEPIPE will not use Torsion Moment and Torsion SIF while calculating Sustained Stress for Restrained pipe even with the option B31J turned ON.
- For ASME B31.5 (2016), paras. 502.3.2(d), 502.3.3 (a), 519.4.5 and 519.3.5 do not include Torsional moment in computing Stresses. Accordingly, CAEPIPE will not include Torsional Moment and Torsional SIF while calculating Stresses as per ASME B31.5 (2016) even when the option B31J is turned ON.
- For ASME B31.8 (2016), para. 833.2 (e) states that the nominal Bending Stress for Fittings and Components as M_R/Z , where M_R is the resultant intensified moment across the fittings or components with Stress Intensification Factor (SIF) as 0.75i.

On the other hand, for Pipe and Long Radius Bends, para.833.2 (d) of the Code states that the nominal Bending Stress as M/Z , where M is the bending moment across the pipe cross section without SIF being considered. In other words, the moments are NOT intensified for Pipe and Long Radius Bends.
- As ASME B31.8 (2016) does not include SIF for Pipe and Long Radius Bends in Sustained Stress equation, SIF calculated as per B31J will NOT be included in Sustained Stress calculation for Pipes and Long Radius bends at this time when the

ASME B31J – 2017
Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and Their
Determination for Metallic Piping Components

option B31J is selected. On the other hand, the SIF calculated as per B31J will be displayed in the Element Forces and Moments results.

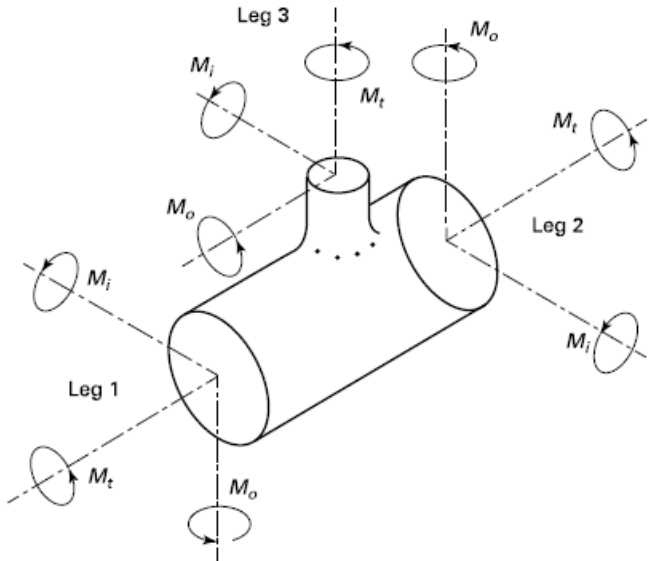
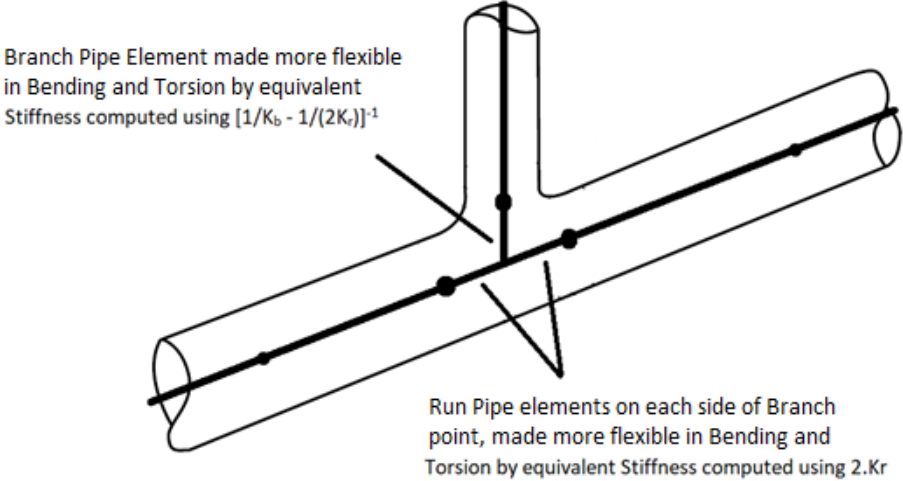
- When B31J is turned ON, In-plane and Out-of-plane Flexibility Factors for Bends, Miter bends and TEEs will be calculated as per B31J and included by CAEPIPE in the corresponding element stiffness matrices. Similarly, CAEPIPE will calculate the Torsion Flexibility Factors as per B31J and include them in the element stiffness matrices irrespective of whether the code includes or excludes Torsional Moment and Torsional SIF in Stress equations.
- As it is not possible to identify the number of Flanges or Rigids at Run Pipe ends located within $0.1D^{1.4}/T^{0.4}$ from Branch intersection node using CAEPIPE (required for applying the correction factor while computing Flexibility Factors as per B31J), a provision is made in the Branch SIF definition to input the no. of Flanges or Rigids that fall within the distance given by B31J.
- When the bend angle is 90 degree and the thickness of the bend is equal to the thickness of the matching pipe, the K_i and K_o should be calculated from $1.3/h$. This is not implemented in CAEPIPE software at this time.
- Flexibility Factors computed for TEEs as per B31J are always applied to both ends of the first elements belonging to Leg 1, Leg 2 and Leg 3 that are connected at the Branch node as shown in Figure 1-1 of B31J.

CAEPIPE includes a feature “Layout Frame > Edit > Refine Branches for B31J” to refine the elements connected to the Branch node to compute and apply Flexibility Factors for Run (Leg 1 and Leg 2) and BranchPipe (Leg 3) as stated above.

When the above command is used, CAEPIPE will add the following.

- a. Two (2) nodes on Run Pipe (one on either side of the Branch SIF node) at a distance equal to Run Split Factor x Run Pipe OD, where the Run Split Factor can be input by the user.
- b. One (1) node on Branch Pipe at a distance equal to Branch Split Factor x Branch Pipe OD from the Branch SIF node, where the Branch Split Factor can be input by the user.

ASME B31J – 2017
 Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and Their
 Determination for Metallic Piping Components



Moment	Flexibility Factor, k	Stiffness, in.-lb/rad (N-mm/rad)	Stiffness, in.-lb/rad (N-mm/rad)
M_{i3} (Leg 3)	k_{ib}	M_{ib} / θ_{ib}	$(E)(I_b) / (k_{ib} d)$
M_{o3} (Leg 3)	k_{ob}	M_{ob} / θ_{ob}	$(E)(I_b) / (k_{ob} d)$
M_{t3} (Leg 3)	k_{tb}	M_{tb} / θ_{tb}	$(E)(I_b) / (k_{tb} d)$
$M_{i1,2}$ (Legs 1, 2)	k_{ir}	M_{ir} / θ_{ir}	$(E)(I_r) / (k_{ir} D)$
$M_{o1,2}$ (Legs 1, 2)	k_{or}	M_{or} / θ_{or}	$(E)(I_r) / (k_{or} D)$
$M_{t1,2}$ (Legs 1, 2)	k_{tr}	M_{tr} / θ_{tr}	$(E)(I_r) / (k_{tr} D)$

Table 1-1 Flexibility and Stress Intensification Factors

Term	Equation	Sketch
1.1 Pipe Bend or Welding Elbow Meeting ASME B16.9 [Notes (1), (2), (3), (4)]		
Flexibility characteristic, k	TR_1 / R^2	
Flexibility factor in plane, k_f	$1.65/k$	
Flexibility factor out of plane, k_o	$1.65/k$	
SIF in plane, i_f	$0.9k^{2/3}$	
SIF out of plane, i_o	$0.75k^{2/3}$	
SIF torsional, i_t	1	
1.2 Closely Spaced Miter Bend, $s < R(1 + \tan \theta)$ [Notes (1), (2), (4)]		
Flexibility characteristic, k	$sT \cot \theta / (2R^2)$	
Flexibility factor in plane, k_f	$1.52/k^{5/6}$	
Flexibility factor out of plane, k_o	$1.52/k^{5/6}$	
SIF in plane, i_f	$0.9/k^{2/3}$	
SIF out of plane, i_o	$0.9/k^{2/3}$	
SIF torsional, i_t	1	
1.3 Widely Spaced Miter Bend $s \geq R(1 + \tan \theta)$ [Notes (1), (4), (5)]		
Flexibility characteristic, k	$T(1 + \cot \theta) / (2R)$	
Flexibility factor in plane, k_f	$1.52/k^{5/6}$	
Flexibility factor out of plane, k_o	$1.52/k^{5/6}$	
SIF in plane, i_f	$0.9/k^{2/3}$	
SIF out of plane, i_o	$0.9/k^{2/3}$	
SIF torsional, i_t	1	

ASME B31J-2017

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

Term	Equation	Sketch
2.1 Welding Tee Meeting ASME B16.9 [Notes (1), (6), (7)]		
Run in-plane flexibility factor, k_{Tf}	$0.18(R/T)^{0.85} (d/D)^5$	
Run out-of-plane flexibility factor, k_{Tf}	1	
Run torsional flexibility factor, k_{Tf}	$0.08(R/T)^{0.81} (d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{Tb}	$[1.91(d/D) - 4.32(d/D)^2 + 2.7(d/D)^3][R/T]^{0.77} (d/D)^{0.67} (t/T)$	
Branch out-of-plane flexibility factor, k_{Tb}	$[0.34(d/D) - 0.49(d/D)^2 + 0.18(d/D)^3][R/T]^{1.46} (t/T)$	
Branch torsional flexibility factor, k_{Tb}	$[1.08(d/D) - 2.44(d/D)^2 + 1.52(d/D)^3][R/T]^{0.77} (d/D)^{1.61} (t/T)$	
Run SIF in plane, i_{Tf}	$0.98(R/T)^{0.35} (d/D)^{0.72} (t/T)^{-0.52}$	
Run SIF out of plane, i_{Tf}	$0.61(R/T)^{0.29} (d/D)^{1.85} (t/T)^{-0.53}$	
Run SIF torsional, i_{Tf}	$0.34(R/T)^{2/3} (d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{Tb}	$0.33(R/T)^{2/3} (d/D)^{0.18} (t/T)^{0.7}$	
Branch SIF out of plane, i_{Tb}	$0.42(R/T)^{2/3} (d/D)^{0.87} (t/T)^{0.87}$	
Branch SIF torsional, i_{Tb}	$0.42(R/T)^{2/3} (d/D)^{1.1} (t/T)^{1.1}$	
2.2 Reinforced Fabricated Tee (When $t_p > 1.5T$, Use $t_p = 1.5T$) [Notes (1), (7)]		
Run in-plane flexibility factor, k_{Tf}	$0.21[R/(T + 0.5t_p)]^{0.87} (t/T)^{-0.65} (d/D)^{5.4}$	
Run out-of-plane flexibility factor, k_{Tf}	1	
Run torsional flexibility factor, k_{Tf}	$0.12[R/(T + 0.5t_p)]^{1.88} (t/T)^{-0.74} (d/D)^{8.5}$	
Branch in-plane flexibility factor, k_{Tb}	$[1.29(d/D) - 2.73(d/D)^2 + 1.62(d/D)^3][R/(T + 0.5t_p)]^{1.4} (t/T)^{0.56} (d/D)$	
Branch out-of-plane flexibility factor, k_{Tb}	$[0.84(d/D) - 1.27(d/D)^2 + 0.5(d/D)^3][R/(T + 0.5t_p)]^{1.88} (t/T)^{0.68} (d/D)$	
Branch torsional flexibility factor, k_{Tb}	$1.1[R/(T + 0.5t_p)]^{0.8} (d/D)^{5.43}$	
Run SIF in plane, i_{Tf}	$[R/(T + 0.5t_p)]^{0.45} (d/D)^{0.52} (t/T)^{0.34} \geq 1.5$	
Run SIF out of plane, i_{Tf}	$[1.29(d/D) - 2.87(d/D)^2 + 2.39(d/D)^3][t/T]^{-0.45}[R/(T + 0.5t_p)]^{0.95}$	
Run SIF torsional, i_{Tf}	$0.36[R/(T + 0.5t_p)]^{2/3} (t/T)^{-0.6} (d/D)^{1.4}$	
Branch SIF in plane, i_{Tb}	$[3.33(d/D) - 5.49(d/D)^2 + 2.94(d/D)^3][TR^{2/3}(T + 0.5t_p)]^{-5/3} (t/T)^{0.8}$	
Branch SIF out of plane, i_{Tb}	$[2.86(d/D) + 2.4(d/D)^2 - 4.34(d/D)^3][TR^{2/3}(T + 0.5t_p)]^{-5/3} (t/T)^{0.8}$ (when $t/T < 0.85$, use $t/T = 0.85$)	
Branch SIF torsional, i_{Tb}	$0.642(d/D)^2 [TR^{2/3}(T + 0.5t_p)]^{-5/3} (t/T)^{0.3}$	

ASME B31J-2017

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

Term	Equation	Sketch
2.3 Fabricated Tee [Notes (1), (7), (8)]		
Run in-plane flexibility factor, k_{r1}	$1.23 (R/T)^{0.47} (t/T)^{-0.47} (d/D)^{5.3}$	
Run out-of-plane flexibility factor, k_{o1}	1	
Run torsional flexibility factor, k_{t1}	$(R/T)^{0.78} (t/T)^{-0.8} (d/D)^{7.2}$	
Branch in-plane flexibility factor, k_{i2}	$[3.15 (d/D) - 6.4 (d/D)^2 + 4 (d/D)^3] (R/T)^{0.83} (t/T)^{0.48} (d/D)^{-0.2}$	
Branch out-of-plane flexibility factor, k_{o2}	$[2.05 (d/D) - 2.94 (d/D)^2 + 1.1 (d/D)^3] (R/T)^{1.4} (t/T)^{0.6} (d/D)^{0.14}$	
Branch torsional flexibility factor, k_{t2}	$0.95 (R/T)^{0.83} (d/D)^{5.42}$	
Run SIF in plane, i_{r1}	$1.2 (d/D)^{0.5} (R/T)^{0.4} (t/T)^{-0.35} \geq 1.5$	
Run SIF out of plane, i_{o1}	$[(d/D) - 2.7 (d/D)^2 + 2.62 (d/D)^3] (R/T)^{0.43} (t/T)^{-0.7}$ [when $d/D < 0.5$, use $d/D = 0.5$; when $t/T < 0.5$, use $t/T = 0.5$]	
Run SIF torsional, i_{t1}	$1.2 (R/T)^{0.46} (t/T)^{-0.45} (d/D)^{1.37}$ [when $t/T < 0.15$, use $t/T = 0.15$]	
Branch SIF in plane, i_{i2}	$[0.038 + 1.45 (d/D) - 2.39 (d/D)^2 + 1.34 (d/D)^3] (R/T)^{0.76} (t/T)^{0.74}$ [when $t/T < 1$, use $t/T = 1$]	
Branch SIF out of plane, i_{o2}	$[0.038 + 2 (d/D) + 2 (d/D)^2 - 3.1 (d/D)^3] (R/T)^{2/3} (t/T)$ [when $t/T < 0.85$, use $t/T = 0.85$]	
Branch SIF torsional, i_{t2}	$0.45 (R/T)^{0.8} (t/T)^{0.29} (d/D)^2$	

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

Term	Equation	Sketch
2.4 Extruded Outlet With $r_x \geq 0.05d_o$ and $T < T_o < 1.5T$ [Notes (1), (7), (9)]		
Run in-plane flexibility factor, k_{ri}	$0.18(R/T)^{0.85} (d/D)^5$	
Run out-of-plane flexibility factor, k_{ro}	1	
Run torsional flexibility factor, k_{rt}	$0.08(R/T)^{0.81} (d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{bi}	$[1.91(d/D) - 4.32(d/D)^2 + 2.7(d/D)^3](R/T)^{0.77} (d/D)^{0.47} (t/T)$	
Branch out-of-plane flexibility factor, k_{bo}	$[0.34(d/D) - 0.49(d/D)^2 + 0.18(d/D)^3](R/T)^{1.46} (t/T)$	
Branch torsional flexibility factor, k_{bt}	$[1.08(d/D) - 2.44(d/D)^2 + 1.52(d/D)^3](R/T)^{0.77} (d/D)^{1.78} (t/T)$	
Run SIF in plane, i_{ri}	$1.45(1 + r_x/R)^{-2/3} (R/T)^{0.95} (d/D)^{0.74} (t/T)^{0.52}$	
Run SIF out of plane, i_{ro}	$0.58(1 + r_x/R)^{-2/3} (R/T)^{2/3} (d/D)^{2.69}$	
Run SIF torsional, i_{rt}	$0.55(1 + r_x/R)^{-2/3} (R/T)^{2/3} (d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{bi}	$0.56(1 + r_x/R)^{-2/3} (R/T)^{2/3} (d/D)^{0.62}$	
Branch SIF out of plane, i_{bo}	$0.85(1 + r_x/R)^{-2/3} (R/T)^{2/3} (d/D)^{0.5}$	
Branch SIF torsional, i_{bt}	$0.71(1 + r_x/R)^{-2/3} (R/T)^{2/3} (d/D)^2$	
2.5 Welded-in Contour Insert (When r_x Is Not Provided, Use $r_x = 0$) [Notes (1), (6), (7)]		
Run in-plane flexibility factor, k_{ri}	$0.18(R/T)^{0.85} (d/D)^5$	
Run out-of-plane flexibility factor, k_{ro}	1	
Run torsional flexibility factor, k_{rt}	$0.1(R/T)^{0.81} (d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{bi}	$[2.36(d/D) - 5.33(d/D)^2 + 3.33(d/D)^3](R/T)^{0.77} (d/D)^{0.47} (t/T)$	
Branch out-of-plane flexibility factor, k_{bo}	$[1 + r_x/R][0.67(d/D) - 0.97(d/D)^2 + 0.36(d/D)^3](R/T)^{1.46} (t/T)$	
Branch torsional flexibility factor, k_{bt}	$[1.05(d/D) - 2.36(d/D)^2 + 1.49(d/D)^3](R/T)^{0.77} (d/D)^{1.61} (t/T)$	
Run SIF in plane, i_{ri}	$(R/T)^{0.95} (d/D)^{0.74} (t/T)^{-0.52}$	
Run SIF out of plane, i_{ro}	$0.72(R/T)^{0.95} (d/D)^{1.65} (t/T)^{-0.53}$	
Run SIF torsional, i_{rt}	$0.36(R/T)^{2/3} (d/D)(t/T)^{-0.5}$	
Branch SIF in plane, i_{bi}	$0.35(R/T)^{2/3} (d/D)^{0.15} (t/T)^{0.7}$	
Branch SIF out of plane, i_{bo}	$0.48(R/T)^{2/3} (d/D)^{0.97} (t/T)^{0.97}$	
Branch SIF torsional, i_{bt}	$0.44(R/T)^{2/3} (d/D)^{1.1} (t/T)^{1.1}$	

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

Term	Equation	Sketch
2.6 Integrally Reinforced Branch Welded on Fittings [Notes (1), (7), (10)]		
Run in-plane flexibility factor, k_{ri}	$0.5(R/T)^{0.55} (d/D)^5$	
Run out-of-plane flexibility factor, k_{ro}	1	
Run torsional flexibility factor, k_{rt}	$0.1(R/T)(d/D)^{5.7}$	
Branch in-plane flexibility factor, k_{bi}	$[0.55(d/D) - 1.13(d/D)^2 + 0.69(d/D)^3](R/T)(t/T)$	
Branch out-of-plane flexibility factor, k_{bo}	$[1.03(d/D) - 1.55(d/D)^2 + 0.59(d/D)^3](R/T)^{1.4} (t/T)(d/D)^{0.33}$	
Branch torsional flexibility factor, k_{bt}	$[0.37(d/D) - 0.75(d/D)^2 + 0.46(d/D)^3](R/T)(t/T)(d/D)^{1.2}$	
Run SIF in plane, i_{ri}	$(R/T)^{0.43} (d/D)^{0.2} \geq 1.5$	
Run SIF out of plane, i_{ro}	$[0.02 + 0.88(d/D) - 2.56(d/D)^2 + 2.58(d/D)^3](R/T)^{0.43}$	
Run SIF torsional, i_{rt}	$1.3(R/T)^{0.45} (d/D)^{1.37}$	
Branch SIF in plane, i_{bi}	$[0.08 + 1.28(d/D) - 2.35(d/D)^2 + 1.45(d/D)^3](R/T)^{0.43} (t/T)(r/r_p)$	
Branch SIF out of plane, i_{bo}	$[1.83(d/D) - 1.07(d/D)^2] (R/T)^{0.43} (t/T)(r/r_p)^{1.18}$	
Branch SIF torsional, i_{bt}	$0.77(R/T)^{0.43} (t/T)(d/D)^2 (r/r_p)$	
3.1 Concentric or Eccentric Reducer Meeting ASME B16.9 [Note (11)]		
SIF in plane, i_t	$0.6 + 0.003(\alpha T_2/T_1)^{0.85} (D_2/T_2)^{0.25} (D_2/r_2)$	
SIF out of plane, i_o	$0.6 + 0.003(\alpha T_2/T_1)^{0.85} (D_2/T_2)^{0.25} (D_2/r_2)$	
SIF torsional, i_t	$0.3 + 0.0015(\alpha T_2/T_1)^{0.85} (D_2/T_2)^{0.25} (D_2/r_2)$	

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

Term	Equation	Sketch
4.1 Butt Weld, $T \geq 6 \text{ mm (0.237 in.)}$, $\delta_{\text{max}} \leq 1.5 \text{ mm (1/16 in.)}$, and $\delta_{\text{avg}}/T \leq 0.13$ [Note (12)]		
SIF in plane, i_t	1.0	
SIF out of plane, i_o	1.0	
SIF torsional, i_t	1.0	
4.2 Butt Weld, $T \geq 6 \text{ mm (0.237 in.)}$, $\delta_{\text{max}} \leq 3 \text{ mm (1/8 in.)}$, and $\delta_{\text{avg}}/T = \text{Any Value}$ OR $T < 6 \text{ mm (0.237 in.)}$, $\delta_{\text{max}} \leq 1.5 \text{ mm (1/16 in.)}$, and $\delta_{\text{avg}}/T \leq 0.33$ [Note (12)]		
SIF in plane, i_t	1.9 max. or $0.9 + 2.7(\delta_{\text{avg}}/T)$ but not less than 1.0	
SIF out of plane, i_o	1.9 max. or $0.9 + 2.7(\delta_{\text{avg}}/T)$ but not less than 1.0	
SIF torsional, i_t	$0.45 + 1.35(\delta_{\text{avg}}/T)$ but not less than 1.0	
4.3 Fillet-Welded Joint or Socket-Welded Flange Meeting ASME B16.5 or Socket-Welded Fitting Meeting ASME B16.11 [Note (13)]		
SIF in plane, i_t	1.3	
SIF out of plane, i_o	1.3	
SIF torsional, i_t	1.3	
4.4 Tapered Transition in Accordance With Applicable Code Sections and ASME B16.25		
SIF in plane, i_t	$1.9 \text{ max. or } 1.3 + 0.0036(D_o/T) + 3.6(S/T)$	
SIF out of plane, i_o	$1.9 \text{ max. or } 1.3 + 0.0036(D_o/T) + 3.6(S/T)$	
SIF torsional, i_t	1.3	
4.5 Weld Neck Flange		
SIF in plane, i_t	1.0	...
SIF out of plane, i_o	1.0	
SIF torsional, i_t	1.0	

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

Term	Equation	Sketch
4.6 Single Welded Slip-on Flange		
SIF in plane, i_f	1.3	...
SIF out of plane, i_o	1.3	...
SIF torsional, i_t	1.3	...
4.7 Double Welded Slip-on Flange		
SIF in plane, i_f	1.2	...
SIF out of plane, i_o	1.2	...
SIF torsional, i_t	1.2	...
4.8 Lap Joint Flange (With ASME B16.9 Lap Joint Stub)		
SIF in plane, i_f	1.6	...
SIF out of plane, i_o	1.6	...
SIF torsional, i_t	1.6	...
5.1 Threaded Pipe Joint or Threaded Flange in Accordance With Acceptable Code Detail		
SIF in plane, i_f	2.3	...
SIF out of plane, i_o	2.3	...
SIF torsional, i_t	2.3	...

GENERAL NOTES:

(a) The following symbols are used in this table:

- A_p = metal area of pipe cross section, in.² (mm²)
- B = length of miter segment at crotch, in. (mm)
- b = branch subscript corresponding to Leg 3 in Figure 1-1
- c = factor for rigid ends adjacent to bends, miters, and branch connections in Sketches 1.1, 1.2, and 2.1 through 2.6
- C_k = minimum socket weld leg length, in. (mm)
- D = mean diameter of matching pipe found from $(D_o - T)$, in. (mm); for Sketches 2.1 through 2.6, the mean diameter of the matching run pipe
- d = mean diameter of matching branch pipe found from $(d_o - t)$, in. (mm)
- d' = effective branch diameter used with Figure 1-3, illustrations (a), (b), and (c), in. (mm)
- D_1, D_2 = outside diameter of matching pipe at large and small ends of reducer, respectively, in. (mm)
- D_r = inside diameter of matching run pipe found from $(D_o - 2T)$, in. (mm)
- d_r = inside diameter of matching branch pipe found from $(d_o - 2t)$, in. (mm)
- D_o = outside diameter of matching pipe, in. (mm)
- d_o = outside diameter of the matching branch pipe, in. (mm); for Sketches 2.1 through 2.6, the outside diameter of the matching run pipe
- E = modulus of elasticity, psi (kPa)
- I = stress intensification factor (SIF)
- I_b, I_r = matching branch and run pipe moment of inertia used in Table 1-2, in.⁴ (mm⁴)
- k = flexibility factor with respect to the plane and component indicated (see Nonmandatory Appendix B, Ref. [1] for a more detailed definition of flexibility factor as it applies to straight and curved pipe and branch connections)
- L_1 = length of taper or thicker branch section in Figure 1-2, in. (mm)
- L_2 = length of the cylindrical portion at the small end of the reducer in Sketch 3.1, in. (mm)
- M = moment on branch or run legs shown in Figure 1-1, in.-lb (N-mm)

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

GENERAL NOTES (Cont'd):

N_c = number of flanges or other rigid components adjacent to the run pipe end of a branch connection (1 or 2)
 P = gage pressure, psi (MPa)
 R = mean radius of matching pipe found from $(D_o - T)/2$, in. (mm)
 r = mean radius of matching branch pipe found from $(d_o - t)/2$ for Sketches 2.1 through 2.6, in. (mm)
 R_T = bend radius of welding elbow or pipe bend, in. (mm)
 r_D = radii used with Figure 1-3 and in Sketch 3.1, in. (mm)
 r_i = inside radius used with Figure 1-3, in. (mm)
 r_o = radius to outside edge of fitting for Sketches 2.3 and 2.6 measured in longitudinal plane, in. (mm)
 r_N = external crotch radius of welding tee in accordance with ASME B16.9, extruded outlet and welded-in contour insert (Sketches 2.1, 2.4, and 2.5), measured in the plane containing the centerline axes of the run and branch, in. (mm)
 s = miter spacing at centerline, in. (mm)
SIF = stress intensification factor
 T = nominal wall thickness of matching pipe or the average wall thickness of the fitting, if available, for welding elbows in Sketch 1.1; nominal wall thickness of pipe or the average wall thickness of the fitting, if available, for pipe bends in Sketch 1.1; nominal wall thickness of pipe for miter bends in Sketches 1.2 and 1.3; nominal wall thickness of matching run pipe for tees in Sketches 2.1 and 2.4; nominal wall thickness of run pipe for tees in Sketches 2.2, 2.3, 2.5, and 2.6; nominal wall thickness of pipe for weld joints in Sketches 4.1 through 4.4
 t = nominal wall thickness of matching branch pipe, in. (mm)
 t' = effective branch thickness used with Figure 1-3, illustrations (a), (b), and (c), in. (mm)
 T_L , T_S = nominal wall thickness of matching pipe at the large and small ends of the reducer, respectively, in. (mm)
 T_c = crotch thickness in Sketches 2.1, 2.4, and 2.5 measured at the center of the crotch and in the plane shown, in. (mm)
 t_n = local branch pipe thickness used with Figure 1-3, illustrations (a) and (b), in. (mm)
 t_p = reinforcement pad or saddle thickness, in. (mm)
 y = large end of taper used with Figure 1-3, illustration (c), and found from $(L_1 \tan \theta_n)$, in. (mm)
 Z = section modulus of pipe, in.³ (mm³) [see Note (7)]
 Z_b = section modulus of matching branch pipe, in.³ (mm³) [see Note (7)]
 α = reducer cone angle, deg
 δ = mismatch, in. (mm)
 θ = one-half angle between adjacent miter axes, deg
 θ_n = angle used with Figure 1-3, illustration (c), deg
 θ_{br} , θ_{ob} , θ_{bs} , θ_{br} , θ_{or} , θ_{or} = rotations at branch or run legs shown in Figure 1-1, rad

(b) Stress intensification and flexibility factor data in this table shall be used in the absence of more directly applicable data. Their validity has been demonstrated for $D/T \leq 100$. Other limits are provided as needed below.

- (1) Flexibility and stress intensification factors shall not be less than 1.0.
 - (2) Stress intensification factors may be used without flexibility factors.
 - (3) Stress intensification and flexibility factors in this table have been developed from fatigue tests of representative commercially available matching product forms with assemblies manufactured from ductile ferrous materials and from numerical analysis using finite elements. Caution should be exercised when applying these rules for certain nonferrous materials (e.g., copper and aluminum alloys) for other than low-cycle applications.
 - (4) Corrugated straight pipe or corrugated or creased bends should be designed using the principles found in ASME B31.3 Nonmandatory Appendix X, standards from the Expansion Joint Manufacturers Association, or similar standards.
- (c) The highest in-plane or out-of-plane stress intensification factor shall be used when only a single stress intensification factor is needed. Flexibility factors should always be used with the orientation specified. For Sketches 3.1 through 5.1, the in-plane and out-of-plane orientations must be orthogonal to each other and to the pipe axis.

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

GENERAL NOTES (Cont'd):

- (d) Where sustained stress or moment factors are required by the applicable Code (e.g., ASME B31.1, ASME B31.3), and in lieu of more applicable data, for components of Sketches 1.1, 1.3, 2.1, and 2.2, the directional sustained stress or moment multiplier can be taken as the component stress intensification factor. For all components of Sketch 1.2, the directional sustained stress or moment multiplier can be conservatively taken as the smaller of (1) and either (2) or (3) below
 - (1) 0.75 times the applicable stress intensification factor
 - (2) (t/T) times the square root of the applicable stress intensification factor when $t/T > 1$
 - (3) the square root of the applicable stress intensification factor when $t/T \leq 1$
 The sustained stress or moment factors should always be used with the section modulus of the matching pipe and should not be less than 1.0.

NOTES:

- (1) Stress intensification and flexibility factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bend and may be read from Figure 1-4. Stress intensification factors for Sketches 2.1 through 2.6 apply to the intersection point for Legs 1 and 2 as shown in Figures 1-1 and 1-6. Stress intensification factors apply to the intersection point for branch Leg 3 in Figures 1-1 and 1-6 when $d_o/D_o > 0.5$, and to the branch centerline at the surface of the run pipe when $d_o/D_o \leq 0.5$. Flexibility factors for Sketches 2.1 through 2.6 shall be applied as shown in Figures 1.1 and 1.6 for all d_o/D_o .
- (2) Where flanges or other rigid components are attached to one or both ends, the in-plane and out-of-plane values of k and i shall be multiplied by the factor c from Figure 1-5, entering with the computed k .
- (3) When the bend angle is 90 deg and the thickness of the bend is equal to the thickness of the matching pipe, the flexibility factors k_r and k_o may be found from $1.3/k$ and adjusted by the factor c from Figure 1-5 where applicable.
- (4) In large-diameter thin-wall elbows and bends, pressure can affect the magnitudes of k and i . To correct values from this table, divide k by

$$\left[1 + 6 \left(\frac{P}{E} \right) \left(\frac{R}{T} \right)^{7/3} \left(\frac{R_1}{R} \right)^{1/3} \right]$$

and divide i by

$$\left[1 + 3.25 \left(\frac{P}{E} \right) \left(\frac{R}{T} \right)^{5/2} \left(\frac{R_1}{R} \right)^{2/3} \right]$$

For consistency, use kPa and mm for SI and psi and in. for U.S. customary notation. Stress intensification factors shall be used with the section modulus of the matching pipe or the section modulus of the bend, whichever is smaller.

- (5) Sketch 1.3 includes single miter joints.
- (6) If $r_x \geq (1/8)(d_o)$ and $T_c \geq 1.5T$, the factors k and i may be divided by 1.26.
- (7) The flexibility and stress intensification factors apply only if the following conditions are satisfied:
 - (a) The branch pipe axis is normal to within 5 deg of the surface of the run pipe unless otherwise noted.
 - (b) $R/T \leq 50$
 - (c) $d/D \leq 1$
 - (d) $r/t \leq 50$
 - (e) The matching run pipe thickness, T , and diameter, D , are maintained for at least two run pipe diameters on each side of the branch centerline.
 - (f) For Sketches 2.1, 2.4, and 2.5, $t/T \leq 1.2$ and $T_c/T > 1.1$.

When a Table 1-2 flexibility factor is less than or equal to 1.0, the stiffness associated with that flexibility factor shall be rigid. Flexibility factors k_{rb} , k_{ob} , and k_{cb} in Sketches 2.1 through 2.6 shall be multiplied by the factor c from Table 1-3 when flanges or other rigid components are adjacent to one or more of the run pipe ends. A flange or other rigid component is adjacent to the run pipe end when the length of any straight run pipe between the branch and the flange or rigid component is less than $0.1D^{1.4}/T^{0.4}$. Stress intensification factors i_{rb} , i_{ob} , i_{cb} , i_{rm} , i_{om} , and i_{cm} and flexibility factors k_{rb} , k_{ob} , k_{rb} , k_{rm} , k_{om} , and k_{cm} in Sketches 2.1, 2.2, 2.4, 2.5, and 2.6 shall not be greater than the corresponding stress intensification and flexibility factors for Sketch 2.3 and Figure 1-3, illustration (d), calculated using matching branch and run pipe dimensions and $r_d = 0$. Stress intensification factors i_{rb} , i_{ob} , i_{cb} , i_{rm} , i_{om} , and i_{cm} and flexibility factors k_{rb} , k_{ob} , k_{rb} , k_{rm} , k_{om} , and k_{cm} in Sketches 2.2, 2.3, 2.4, 2.5, and 2.6 shall not be less than the corresponding stress intensification and flexibility factors for Sketch 2.1 calculated using $T_c = 1.1T$.

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

NOTES (Cont'd):

If $i_{ob} < i_{os}$ for any of Sketches 2.1 through 2.6, then use $i_{ob} = i_{os}$. If $i_r < i_{or}$ for any of Sketches 2.1 through 2.6, then use $i_r = i_{or}$. Stress intensification factors i_{ob} , i_{os} , i_r , i_{or} , and d_p from this table can be used for Sketches 2.2, 2.3, 2.5, and 2.6 when the branch pipe axis is in the same plane as the run pipe axis and is normal to within 45 deg of the surface of the run pipe, provided $D/T < 5.0$ and $d/D \leq 0.6$; in the absence of more applicable data, i_{ob} can be taken equal to i_{os} . The stress intensification factor i_{ob} in Sketch 2.3 shall be multiplied by the larger of $[0.75(t/T) - 0.89(t/T)^2 + 0.18](D/T)^{0.34}$ or 1.0 when $t/T \leq 0.85$, $d/D < 1$, and $D/T \geq 25$.

The stress intensification factor i_{ob} in Sketch 2.2 shall be multiplied by the larger of $[1.07(t/T) - 1.08(t/T)^2 + 0.026](D/T)^{0.34}$ or 1.0 when $t/T \leq 0.85$, $d/D < 1$, and $D/T \geq 25$.

The designer must be satisfied that the branch connection pressure rating is greater than or equal to that of the matching run pipe. Branch connection stress intensification factors shall be used with the section modulus of the matching pipe. The section modulus shall be calculated using the following equation for the run:

$$Z = \left(\frac{\pi}{32} \right) \left(\frac{D_o^4 - D_i^4}{D_o} \right)$$

and by the following equation for the branch:

$$Z_b = \left(\frac{\pi}{32} \right) \left(\frac{d_o^4 - d_i^4}{d_o} \right)$$

(8) The in-plane, out-of-plane, and torsional stress intensification factors for both the branch and the run may be multiplied by the factor 0.7 for the geometries shown in Figure 1-3 when the outer radius r_o is provided and is not less than the smallest of $T/2$, $t/2$, $(r_p - r)/2$, or $(t + y)/2$. For Figure 1-3, illustrations (a), (b), and (c), the following hold:

- (a) Flexibility and stress intensification factors shall be calculated by replacing the parameters t/T with t'/T and d/D with d'/D .
- (b) Stress intensification factors i_{ob} , i_{os} , and i_r and flexibility factors k_{ob} , k_{os} , and k_{or} shall also be multiplied by $(t'/t)(d/d')^2$.
- (c) Calculate t' as follows

(-1) For Figure 1-3, illustrations (a) and (b)

$$t' = t_n \text{ if } L_1 \geq 0.5(2r t_n)^{1/2}$$

$$= t \text{ if } L_1 < 0.5(2r t_n)^{1/2}$$

(-2) For Figure 1-3, illustration (c)

$$t' = t + (2/3)y \text{ if } \theta_n \leq 30 \text{ deg}$$

$$= t + 0.38SL_1 \text{ if } \theta_n > 30 \text{ deg}$$

(d) Calculate d' as follows

$$d' = d - t + t'$$

(e) Stress intensification factors i_{ob} , i_{os} , i_r , and i_{or} shall not be less than 1.5.

(9) When r_k is not provided, use $r_k = 0.05d_o$. If $r_k/r > 1$ use $r_k/r = 1$.

(10) When r_p is not available, a value of 0.85 may be used. If $r_p < 0.6$, then use $r_p = 0.6$. For size-on-size branch connections when $D/T < 40$, i_{ob} may be multiplied by 0.75. When the weld sizes and actual dimensions of the fitting are available, r_p can be taken as the distance along the surface of the run pipe from the branch centerline to the toe of the attachment fillet weld in the longitudinal plane. When $d/D > 0.8$, the geometry of commercially available fittings varies considerably from manufacturer to manufacturer. More applicable data from the manufacturer should be used when available. Results from tests where $D/T < 40$ should not be extrapolated to branch connections where $D/T > 40$.

(11) The flexibility and stress intensification factors apply only if the following conditions are satisfied:

- (a) $5 \text{ deg} < \alpha < 60 \text{ deg}$
- (b) $5 < D_2/T_2 < 80$
- (c) The wall thickness is not less than T_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than T_2 .
- (d) $0.08 < r_2/D_2 < 0.7$
- (e) $1 < T_1/T_2 < 2.12$
- (f) If $L_2 < (D_2 T_2)^{0.5}$, the stress intensification factors should be multiplied by $[2 - L_2/(D_2 T_2)^{0.5}]$.

Table 1-1 Flexibility and Stress Intensification Factors (Cont'd)**NOTES (Cont'd):**

The maximum stress intensification factor need not be greater than 2.0 but shall in no case be less than 1.0. Reducers with $D_2/T_2 \leq 55$ can be modeled as a step change in diameter and thickness from D_2, T_2 to D_1, T_1 at the middle of the reducer, or with any more applicable geometry. When $D_2/T_2 > 55$, consideration should be given to adding flexibility to the beam model to more accurately represent the stiffness of the reducer. For eccentric reducers, the dimensions shown in Sketch 3.1 are to be taken at the location on the circumference where α is the maximum. When r_2 is not given, use $r_2 = 0.1D_1$. When L_2 is not given, use $L_2 = 0.1D_2$. When α is not given, use α equal to the smaller of $60(D_1/D_2 - 1)$ or 60.

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875T$ and $1.10T$ for an axial distance of $(D_o T)^{1/2}$. D_o and T are the nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) For welds to socket-welded flanges and fittings, the stress intensification factor is based on the following:

(a) the assumption that the pipe and fitting are matched in accordance with ASME B16.11 or that socket-welded pipe, flanges, and other fittings greater than NPS 2 meet the fabrication requirements of the applicable Code

(b) the weld is made as shown in Sketch 4.3

(c) the pipe wall thickness is greater than the lesser of schedule 40 or standard weight

(d) the weld size C_w is in accordance with the applicable Code. For pipe whose wall thickness is thinner than the lesser of schedule 40 or standard weight, the stress intensification factor for all directions shall be equal to 2.1 unless otherwise justified. Blending the toe of the fillet weld with no undercut smoothly into the pipe wall, as shown in Figure 1-7, illustrations (b) and (d), has been shown to improve the fatigue performance of the weld. Large-diameter socket-welded and slip-on flanges with welds smaller than those required by the applicable Code may induce stresses not considered by the stress intensification factors.

Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and Their Determination for Metallic Piping Components

Table 1-2 Moment-Rotation Relationships for Sketches 2.1 Through 2.6 of Table 1-1

Moment (Figs 1-1)	Flexibility Factor, k	Stiffness, in.-lb/rad (N-mm/rad)	Stiffness, in.-lb/rad (N-mm/rad)
M_{i3} (Leg 3)	k_{w3}	M_{i3} / θ_{w3}	$(E)(I_w) / (k_{w3} d)$
M_{a2} (Leg 3)	k_{w2}	M_{a2} / θ_{w2}	$(E)(I_w) / (k_{w2} d)$
M_{a3} (Leg 3)	k_{w3}	M_{a3} / θ_{w3}	$(E)(I_w) / (k_{w3} d)$
$M_{i1,2}$ (Legs 1, 2)	k_r	$M_{i1,2} / \theta_r$	$(E)(I_r) / (k_r D)$
$M_{a1,2}$ (Legs 1, 2)	k_r	$M_{a1,2} / \theta_r$	$(E)(I_r) / (k_r D)$
M_{i2} (Legs 1, 2)	k_{r2}	M_{i2} / θ_{r2}	$(E)(I_r) / (k_{r2} D)$

GENERAL NOTE: The moment-rotation relationships in this table are developed by independently applying moments to the respective run or branch leg. Simultaneous run and branch moment-rotation interaction must be accommodated by the model.

Table 1-3 Flanged End Correction Coefficients for Sketches 2.1 through 2.6 of Table 1-1

Flexibility Factor	Flexibility Factor Multiplier, c
k_{w3}	$1 - 0.032 N_c^{1.246} (D/I)^{0.421} (d/I)^{0.983}$
k_{w2}	$1 - 0.017 N_c^{0.661} (D/I)^{0.444} (d/I)^{0.229}$
k_{w3}	$1 - 0.003 N_c^{2.962} (D/I)^{0.348} (d/I)^{0.643}$

Figure 1-1 Orientations for Sketches 2.1 Through 2.6 of Table 1-1

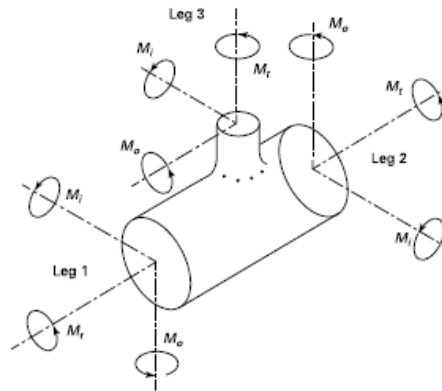


Figure 1-3 Branch Dimensions

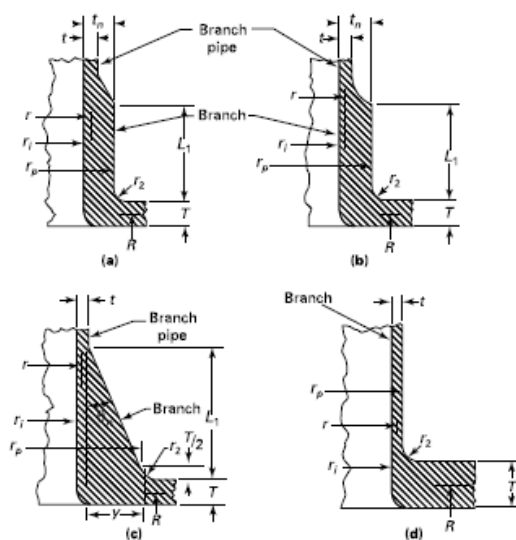
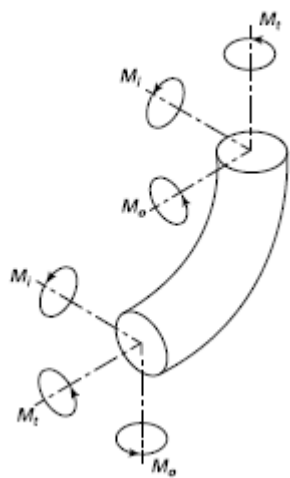


Figure 1-2 Orientations for Bends



ASME B31J – 2017
 Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and Their
 Determination for Metallic Piping Components

Figure 1-4 Flexibility and Stress Intensification Factors for Bends and Miters

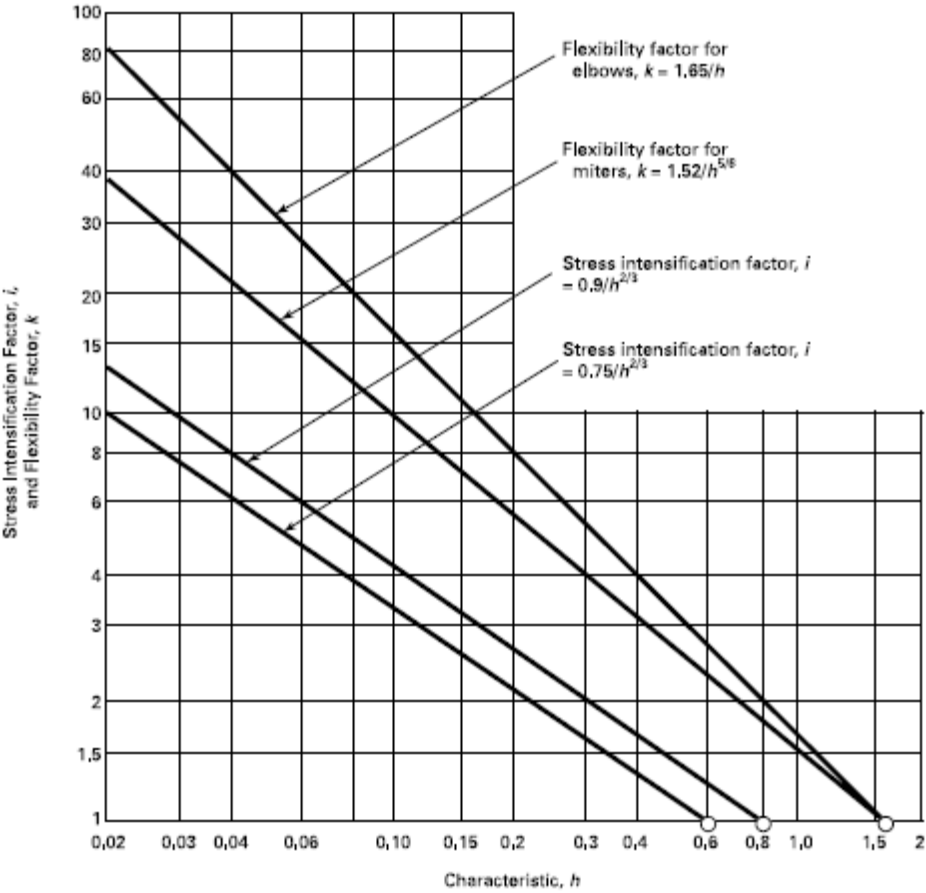
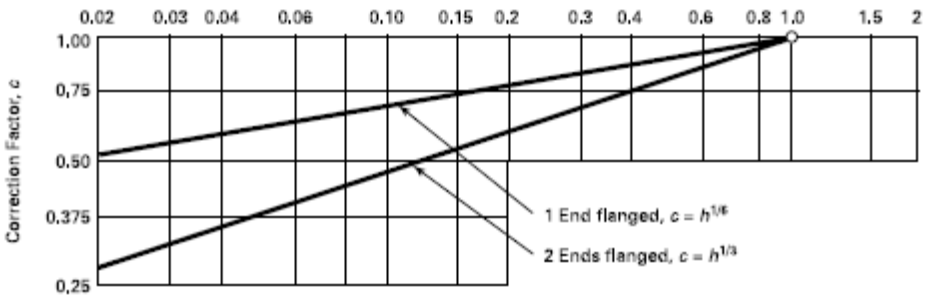
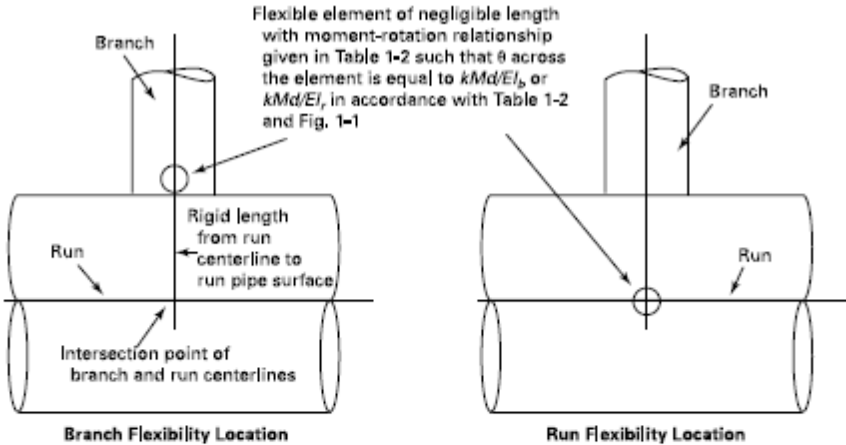


Figure 1-5 Flanged End Corrections for Bends and Miters



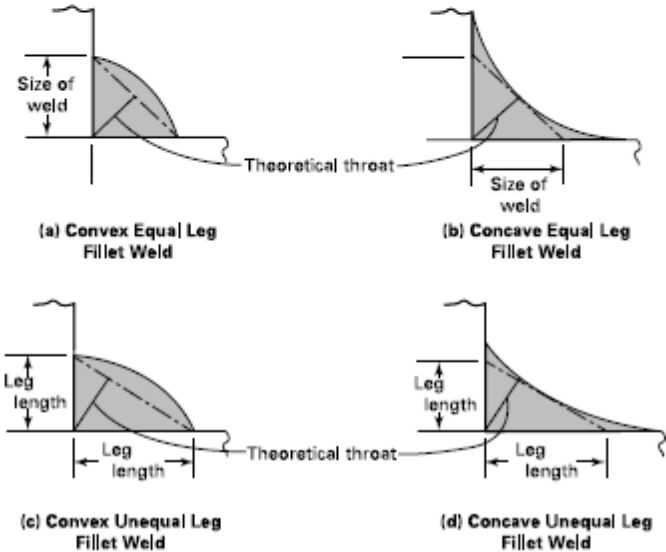
ASME B31J – 2017
 Stress Intensification Factors (i-Factors), Flexibility Factors (k-Factors), and Their
 Determination for Metallic Piping Components

Figure 1-6 Flexibility Element Locations



GENERAL NOTE: See Figure 1-1 for flexibility orientations.

Figure 1-7 Fillet Weld Contours



ASME Section III, Subsection NC - Class 2 (1980)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

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

where

P = allowable pressure

S = allowable stress

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical and corrosion allowances

= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

= 0.4 for $D/t_m \geq 6$

= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 9 of NC-3652.

$$S_L = \frac{PD}{4t} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum pressure

D = outside diameter

t = nominal wall thickness

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

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

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

S_h = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) such as earthquake or wind from Equation 10 of NC-3652.2. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 11 of NC-3652.3.

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

where

M_C = resultant moment due to thermal expansion

S_A = $f(1.25S_c + 0.25S_h)$

S_c = allowable stress at cold temperature

f = stress range reduction factor from Table NC-3611.2(e)-1

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 13 of NC-3652.2.

$$S_{TE} = S_L + S_E \leq S_h + S_A$$

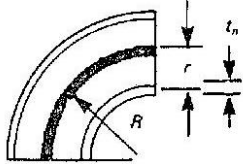
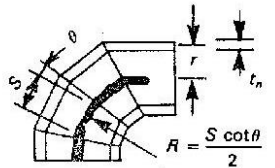
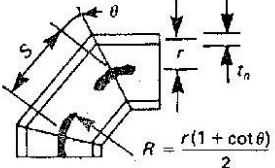
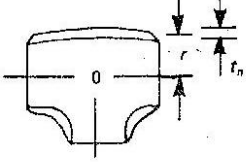
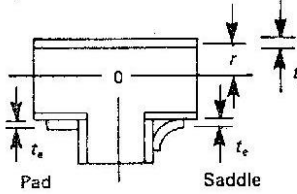
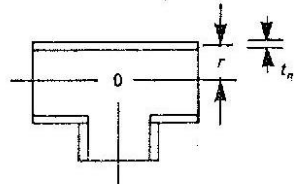
Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r(1 + \tan \theta)$	$\frac{st_n \cot \theta}{2r^2}$	$\frac{1.52}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r(1 + \tan \theta)$	$\frac{t_n(1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ANSI B16.9 [Notes (1), (2)]	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (5)]	$\frac{(t_n + \frac{t_c}{2})^{3/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

ASME Section III, Subsection NC - Class 2 (1980)

Fig. NC-3673.2(b)-1

SECTION III, DIVISION 1 — SUBSECTION NC

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Note (5)]	1	For checking branch end $Z = \pi (r'_m)^2 T_b$ $i = 1.5 \left(\frac{R_m}{T}\right)^{1/2} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T_b}{T}\right) \left(\frac{r_m}{r'_m}\right)$	Fig. NC-3673.2(b)-2
		For checking run ends $Z = \pi (R_m) r^2 T_r$ $i = 0.4 \left(\frac{R_m}{T_r}\right)^{1/2} \left(\frac{r'_m}{R_m}\right)$ but not less than 1.5	
Butt weld [Note (1)] $t_n > 3/16$ and $\frac{\delta}{t_n} \leq 0.1$	1	1.0	
Butt weld [Note (1)] $t_n \leq 3/16$ or $\frac{\delta}{t_n} > 0.1$	1	1.0 for flush weld 1.8 for as-welded	
Fillet welded joint, socket welded flange, or single welded slip-on flange	1	2.1	Fig. NC-3673.2(b)-3 sketches (a), (b), (c), (e), and (f)
Brazed joint	1	2.1	Fig. NC-4511-1
Full fillet weld	1	1.3	Fig. NC-3673.2(b)-3 sketch (d)
30 deg. tapered transition (ANSI B16.25) [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{l_n} + 3.6 \frac{\delta}{t_n}$	
Concentric reducer [Note (7)] (ANSI B16.9 or MSS SP48)	1	2.0 max. or $0.5 + 0.01 \alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2.5	

(See notes on next page)

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) (CONT'D)

NOTES TO FIG. NC-3673.2(b)-1:

- (1) The following nomenclature applies.
- r = mean radius of pipe, in. (matching pipe for tees and elbows)
 - t_n = nominal wall thickness of pipe, in. [matching pipe for tees and elbows, see Note (9)]
 - R = bend radius of elbow or pipe bend, in.
 - θ = one-half angle between adjacent miter axes
 - s = miter spacing at center line, in.
 - t_s = reinforced thickness, in.
 - δ = mismatch, in.
 - D_o = outside diameter, in.
- (2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly by entering with the characteristic h computed from the equations given.
- (3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below, which can be read directly from Fig. NC-3673.2(b)-5, entering with the computed h .
- (a) One end flanged, $c = h^{1/4}$
 - (b) Both ends flanged, $c = h^{1/2}$
- (4) Also includes single miter joints.
- (5) When $t_s > 1.5t_n$, $h = 4.05t_n/r$
- (6) The equation applies only if the following conditions are met:
- (a) The reinforcement area requirements of NC-3643 are met.
 - (b) The axis of the branch pipe is normal to the surface of run pipe wall.
 - (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.
 - (d) The inside corner radius r_1 [Fig. NC-3673.2(b)-2] is between 10% and 50% of T_r .
 - (e) The outer radius r_2 is not less than the larger of $T_o/2$, $(T_o + Y)/2$ [Fig. NC-3673-2(b)-2 sketch (c)] or $T_r/2$.
 - (f) The outer radius r_3 is not less than the larger of
 - (1) $0.002\theta d_o$
 - (2) $2(\sin \theta)^2$ times the offset for the configurations shown in Figs. NC-3673.2(b)-2 sketches (a) and (b).
 - (g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$.
- (7) The equation applies only if the following conditions are met:
- (a) Cone angle α does not exceed 60 deg., and the reducer is concentric.
 - (b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
 - (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
- (8) Factors shown apply to bending; flexibility factor for torsion equals 0.9.
- (9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

ASME Section III, Subsection NC - Class 2(1986)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

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

where

P = allowable pressure

S = allowable stress

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

= 0.4 for $D/t_m \geq 6$

= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652.

$$S_L = B1 \frac{PD}{2t} + B2 \frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from NB-3680

P = maximum pressure

D = outside diameter

t = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

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

S_h = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) such as earthquake or wind from Equation 9 of NC-3653.1. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + B2 \frac{M_B}{Z} \leq 1.8S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 10 of NC-3653.2.

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

where

i = stress intensification factor

M_C = resultant moment due to thermal expansion

$S_A = f(1.25S_c + 0.25S_h)$

S_c = allowable stress at cold temperature

f = stress range reduction factor from Table NC-3611.2(e)-1

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c).

$$S_{TE} = \frac{PD}{4t} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_h + S_A$$

$0.75i$ shall not be less than 1.0.

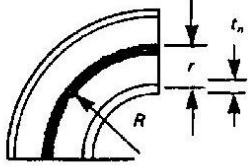
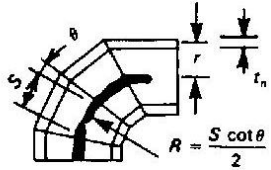
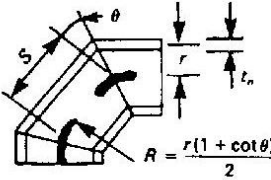
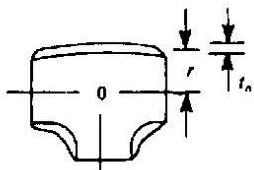
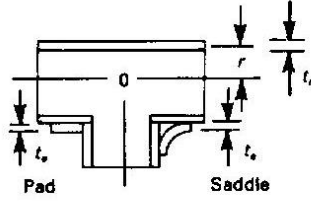
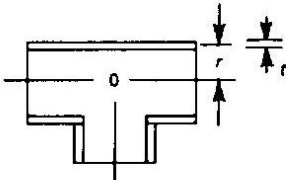
Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{1/2}}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r(1 + \tan \theta)$	$\frac{st_n \cot \theta}{2r^2}$	$\frac{1.52}{h^{1/2}}$	$\frac{0.9}{h^{1/2}}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r(1 + \tan \theta)$	$\frac{t_n(1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{1/2}}$	$\frac{0.9}{h^{1/2}}$	
Welding tee per ANSI B16.9 [Notes (1), (2)]	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{1/2}}$	
Reinforced fabricated tee [Notes (1), (5), (10)]	$\frac{(t_n + \frac{t_s}{2})^{1/2}}{r(t_n)^{1/2}}$	1	$\frac{0.9}{h^{1/2}}$	
Unreinforced fabricated tee [Notes (1), (10)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{1/2}}$	

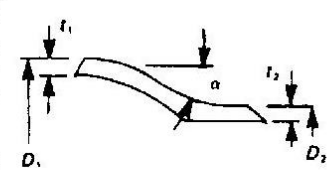
FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

ASME Section III, Subsection NC - Class 2 (1986)

Fig. NC-3673.2(b)-1

SECTION III, DIVISION 1 — SUBSECTION NC

1986 Edition

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Note (6)]	1	For checking branch end $Z = \pi (r'_m)^2 T'_b$ $i = 1.5 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/3} \left(\frac{T'_b}{T_r}\right) \left(\frac{r'_m}{r_p}\right)$	Fig. NC-3673.2(b)-2
		For checking run ends $Z = \pi (R_m)^2 T_r$ $i = 0.4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)$ but not less than 1.5	
Girth butt weld [Note (1)] $t_n \geq 0.237$ in.	1	1.0	
Girth butt weld [Note (1)] $t_n < 0.237$ in.	1	1.9 max. or $0.9(1 + 3\delta/t_n)$ but not less than 1.0	
Circumferential fillet welded or socket welded joints [Note (11)]	1	$2.1/(C_x/t_n)$ but not less than 1.3	Fig. NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	1	2.1	Fig. NC-4511-1
30 deg. tapered transition (ANSI B16.25) [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$	
Concentric and eccentric reducers [Note (7)] (ANSI B16.9)	1	2.0 max. or $0.5 + 0.01 \alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2.5	

(See notes on next page)

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) (CONT'D)

FIG. NC-3673.2(b)-1 (CONT'D):

NOTES:

- (1) The following nomenclature applies:
- r = mean radius of pipe, in. [matching pipe for tees and elbows]
 - t_n = nominal wall thickness of pipe, in. [matching pipe for tees and elbows, see Note (9)]
 - R = bend radius of elbow or pipe bend, in.
 - θ = one-half angle between adjacent miter axes, deg.
 - s = miter spacing at center line, in.
 - t_r = reinforced thickness, in.
 - δ = average permissible mismatch at girth butt welds as shown in Fig. NC-4233-1. A value of δ less than $\frac{1}{32}$ in. may be used provided the smaller mismatch is specified for fabrication. For "flush" welds, as defined in Fig. NB-3683.1(c)-1, δ may be taken as zero, $i = 1.0$, and flush welds need not be ground.
 - D_o = outside diameter, in.
- (2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly by entering with the characteristic h computed from the equations given.
- (3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below, which can be read directly from Fig. NC-3673.2(b)-5, entering with the computed h .
- (a) One end flanged, $c = h^{1/8}$
 - (b) Both ends flanged, $c = h^{1/4}$
- (4) Also includes single miter joints.
- (5) When $t_r > 1.5t_n$, $h = 4.05t_n/r$
- (6) The equation applies only if the following conditions are met.
- (a) The reinforcement area requirements of NC-3643 are met.
 - (b) The axis of the branch pipe is normal to the surface of run pipe wall.
 - (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
 - (d) The inside corner radius r_i [Fig. NC-3673.2(b)-2] for nominal branch pipe size greater than 4 in. shall be between 10% and 50% T_r . The radius r_i is not required for nominal branch pipe size smaller than 4 in.
 - (e) The outer radius r_2 is not less than the larger of $T_b/2$, $(T_b + Y)/2$ [Fig. NC-3673-2(b)-2 sketch (c)] or $T_r/2$.
 - (f) The outer radius r_3 is not less than the larger of
 - (1) $0.002\theta d_o$
 - (2) $2(\sin \theta)^2$ times the offset for the configurations shown in Fig. NC-3673.2(b)-2 sketches (a) and (b).
 - (g) $R_m/T_r \leq 50$ and $r'_m/R_m \leq 0.5$.
 - (h) The outer radius r_2 is not required provided an additional multiplier of 2.0 is included in the equations for branch end and run end stress intensification factors. In this case, the calculated value of i for the branch or run shall not be less than 2.1.
- (7) The equation applies only if the following conditions are met.
- (a) Cone angle α does not exceed 60 deg.
 - (b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
 - (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
 - (d) For eccentric reducers, α is the maximum cone angle.
- (8) Factors shown apply to bending; flexibility factor for torsion equals 0.9.
- (9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (10) The stress intensification factor i shall in no case be taken as less than 2.1.
- (11) C_s is the fillet weld length. For unequal leg lengths, use the smaller leg length for C_s .

ASME Section III, Subsection NC - Class 2 (1992)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

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

where

P = allowable pressure

S = allowable stress

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

= 0.4 for $D/t_m \geq 6$

= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652 (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_L = 2.B1.ABS \left(\frac{PD}{4t_n} \right) + B2 \frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from NB-3680

P = internal Design Pressure = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_h = material allowable stress at Design Temperature = maximum of CAEPIPE Input Temperatures T1 through T10

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 8 of NC-3652 as follows.

$$S_L = 2.B1.ABS \left[\left(\frac{PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} \right] + B2 \frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as earthquake or wind) from Equation 9 of NC-3653.1 (**in case the option “Include Axial force in stress calculations” is turned OFF**). Wind and earthquake are not considered concurrently.

$$S_{LO} = 2. B1. ABS \left(\frac{f_p PD}{4t_n} \right) + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 9a as follows.

$$S_{LO} = 2. B1. ABS \left[\left(\frac{f_p PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} + \left(\frac{F}{A} \right)_{occa} \right] + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

where

- M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements
= $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- f_p = peak pressure factor input into CAEPIPE
- P = internal Design Pressure defined above
- D = outside diameter
- t_n = nominal wall thickness
- Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
- $S_{LO(All)}$ = minimum (1.80 S_h , 1.5 S_y) for Level B Service Limits as per NC-3653.1
= minimum (2.25 S_h , 1.8 S_y) for Level C Service Limits as per NC-3654.2 (a)
= minimum (3.0 S_h , 2.0 S_y) for Level D Service Limits as per NC-3655 (a)(2)
- S_h = material allowable stress at Design Temperature defined above
- S_y = material yield strength at Design Temperature

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NC-3653.2.

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

where

i = stress intensification factor from NB-3680

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

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

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

f = stress range reduction factor from Table NC-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c) (in case the option “Include Axial force in stress calculations” is turned OFF)..

$$S_{TE} = ABS \left(\frac{PD}{4t_n} \right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 11 as follows.

$$S_{TE} = ABS \left[\left(\frac{PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} \right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75*i* shall not be less than 1.0.

where

P = internal Design Pressure = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

ASME Section III, Subsection NC - Class 2 (1992)

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

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

S_H = material allowable stress at Design Temperature defined above

f = stress range reduction factor from Table NC-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NC-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_c$$

where

i = stress intensification factor from Table NC-3673.2(b)-1

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

Fig. NC-3673.2(b)-1

1992 SECTION III, DIVISION I — NC

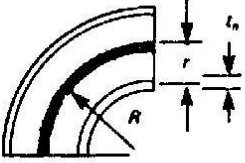
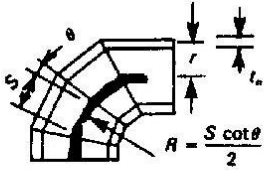
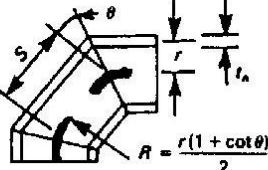
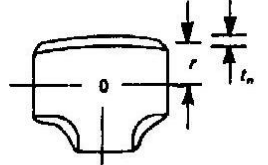
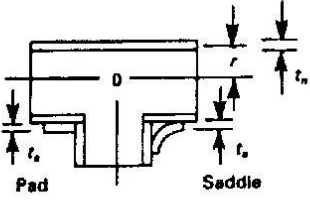
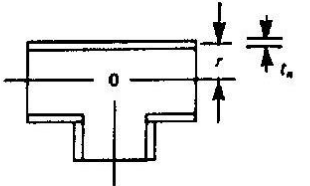
Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3)]	$\frac{t_w R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{1/2}}$	
Closely spaced miter bend [Notes (1), (2), (3)] $s < r(1 + \tan \theta)$	$\frac{st_m \cot \theta}{2r^2}$	$\frac{1.52}{h^{1/2}}$	$\frac{0.9}{h^{1/2}}$	
Widely spaced miter bend [Notes (1), (2), (4)] $s \geq r(1 + \tan \theta)$	$\frac{t_m(1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{1/2}}$	$\frac{0.9}{h^{1/2}}$	
Welding tee per ANSI B16.9 [Notes (1), (2)]	$\frac{4.4 t_w}{r}$	1	$\frac{0.9}{h^{1/2}}$	
Reinforced fabricated tee [Notes (1), (5), (10)]	$\frac{(t_w + \frac{t_s}{2})^{3/2}}{r(t_w)^{1/2}}$	1	$\frac{0.9}{h^{1/2}}$	
Unreinforced fabricated tee [Notes (1), (10)]	$\frac{t_w}{r}$	1	$\frac{0.9}{h^{1/2}}$	

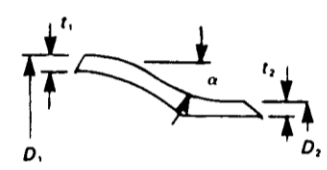
FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_w \leq 100$)

ASME Section III, Subsection NC - Class 2 (1992)

Fig. NC-3673.2(b)-1

SECTION III, DIVISION 1 — SUBSECTION NC

1986 Edition

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Note (6)]	1	For checking branch end $Z = \pi (r'_m)^2 T'_b$ $i = 1.5 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{T'_b}{T_r}\right) \left(\frac{r'_m}{r_o}\right)$	Fig. NC-3673.2(b)-2
		For checking run ends $Z = \pi (R_m)^2 T_r$ $i = 0.4 \left(\frac{R_m}{T_r}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)$ but not less than 1.5	
Girth butt weld [Note (1)] $t_n \geq 0.237$ in.	1	1.0	
Girth butt weld [Note (1)] $t_n < 0.237$ in.	1	1.9 max. or $0.9(1 + 3\delta/t_n)$ but not less than 1.0	
Circumferential fillet welded or socket welded joints [Note (11)]	1	$2.1/(C_x/t_n)$ but not less than 1.3	Fig. NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	1	2.1	Fig. NC-4511-1
30 deg. tapered transition (ANSI B16.25) [Note (1)]	1	1.9 max. or $1.3 + 0.0036 \frac{D_o}{t_n} + 3.6 \frac{\delta}{t_n}$	
Concentric and eccentric reducers [Note (7)] (ANSI B16.9)	1	2.0 max. or $0.5 + 0.01 \alpha \left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2.3	
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2.5	

(See notes on next page)

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$) (CONT'D)

NOTES:

- (1) The following nomenclature applies:
- r = mean radius of pipe, in. (matching pipe for tees and elbows)
 - t_n = nominal wall thickness of pipe, in. [matching pipe for tees and elbows, see Note (9)]
 - R = bend radius of elbow or pipe bend, in.
 - θ = one-half angle between adjacent miter axes, deg.
 - s = miter spacing at center line, in.
 - t_r = reinforced thickness, in.
 - D_o = outside diameter, in.
- (2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
- (3) Where flanges are attached to one or both ends, the values of k and i shall be corrected by the factor c given below.
- (a) One end flanged, $c = h^{1/4}$
 - (b) Both ends flanged, $c = h^{1/2}$
- (4) Also includes single miter joints.
- (5) When $t_r > 1.6t_n$, $h = 4.05t_n/r$
- (6) The equation applies only if the following conditions are met.
- (a) The reinforcement area requirements of NC-3643 are met.
 - (b) The axis of the branch pipe is normal to the surface of run pipe wall.
 - (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
 - (d) The inside corner radius r_1 [Fig. NC-3673.2(b)-2] for nominal branch pipe size greater than 4 in. shall be between 10% and 50% T_r . The radius r_1 is not required for nominal branch pipe size smaller than 4 in.
 - (e) The outer radius r_2 is not less than the larger of $T_n/2$, $(T_n + Y)/2$ [Fig. NC-3673.2(b)-2 sketch (c)] or $T_r/2$.
 - (f) The outer radius r_3 is not less than the larger of
 - (1) $0.002\theta D_o$,
 - (2) $2(\sin \theta)^2$ times the offset for the configurations shown in Fig. NC-3673.2(b)-2 sketches (a) and (b).
 - (g) $R_n/T_r \leq 50$ and $r_n/R_n \leq 0.5$.
 - (h) The outer radius r_3 is not required provided an additional multiplier of 2.0 is included in the equations for branch end and run end stress intensification factors. In this case, the calculated value of i for the branch or run shall not be less than 2.1.
- (7) The equation applies only if the following conditions are met.
- (a) Cone angle α does not exceed 60 deg.
 - (b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
 - (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
 - (d) For eccentric reducers, α is the maximum cone angle.
- (8) Factors shown apply to bending; flexibility factor for torsion equals 0.8.
- (9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (10) The stress intensification factor i shall in no case be taken as less than 2.1.
- (11) In Fig. NC-4427-1(c-1) and (c-2), C_r shall be taken as X_{min} and $C_r \geq 1.25 t_n$. In Fig. NC-4427-1 (c-3), $C_r \geq 0.75 t_n$. For unequal leg lengths use the smaller leg length for C_r .

FIG. NC-3673.2(b)-1 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n = 100$) (CONT'D)

ASME Section III, Subsection NC - Class 2 (2015)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

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

where

P_a = allowable pressure

S = allowable stress for the material at the Design Temperature

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

= 0.4 for $D/t_m \geq 6$

= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652 (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_L = 2.B1.ABS \left(\frac{PD}{4t_n} \right) + B2 \frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from Table NC-3673.2(b)-1

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 8 of NC-3652 as follows.

$$S_L = 2.B1.ABS \left[\left(\frac{PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} \right] + B2 \frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and non-reversing dynamic loads) from Equation 9a of NC-3653.1 (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_{LO} = 2. B1. ABS \left(\frac{f_p PD}{4t_n} \right) + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 9a of NC-3653.1 as follows.

$$S_{LO} = 2. B1. ABS \left[\left(\frac{f_p PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} + \left(\frac{F}{A} \right)_{occa} \right] + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

where

- M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and nonreversing dynamic loads
= $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- f_p = peak pressure factor input into CAEPIPE
- P = maximum of CAEPIPE Input pressures P1 through P10
- D = outside diameter
- t_n = nominal wall thickness
- Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
- $S_{LO(All)}$ = minimum (1.80 S_h , 1.5 S_y) for Level B Service Limits as per NC-3653.1
= minimum (2.25 S_h , 1.8 S_y) for Level C Service Limits as per NC-3654.2 (a)
= minimum (3.0 S_h , 2.0 S_y) for Level D Service Limits as per NC-3655 (a)(2)
- S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10
- S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and nonreversing dynamic loads are to be input as “specified displacements” for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NC-3653.2.

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

where

i = stress intensification factor from Table NC-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

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

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

f = stress range reduction factor from Table NC-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c) (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_{TE} = ABS \left(\frac{PD}{4t_n} \right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 11 of NC-3653.2(c) as follows.

$$S_{TE} = ABS \left[\left(\frac{PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} \right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75*i* shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

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

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

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table NC-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NC-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_c$$

where

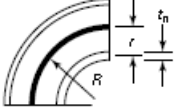
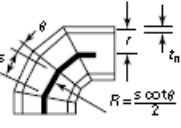
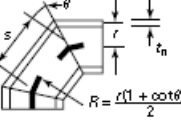
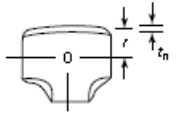
i = stress intensification factor from Table NC-3673.2(b)-1

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

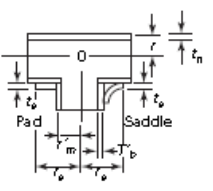
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

ASME Section III, Subsection NC - Class 2 (2015)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors						
Description	Primary Stress Index		Flexibility Characteristic, f_r	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4h - 0.1 \leq 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_w R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r(1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s_h \cot \theta}{2r^2}$	$\frac{1.52}{h^{3/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r(1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_w(1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{3/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4 \left(\frac{r}{t_w} \right)^{2/3}$	$\frac{4.4 t_w}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet use $\frac{0.9 \left(\frac{r_h}{r} \right)}{h^{2/3}}$	
		Run end: $B_{2r} = 0.5 \left(\frac{r}{t_w} \right)^{2/3}$				

Additional Note for Welding elbow or Pipe bend:

If the value of $B_1 = (0.4h - 0.1) < 0.0$, then B_1 is set to 0.0.

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)						
Description	Primary Stress Index		Flexibility Characteristic, f_r	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75 \left(\frac{r}{t_w} \right)^{2/3} \left(\frac{r_{in}}{r} \right)^{1/2} \left(\frac{r_o}{t_w} \right) \left(\frac{r_{in}}{q_w} \right) \geq 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_w)^{2/3}}{[1 + (r'_m/2t_w)]^{5/3}} \geq 1.0$ [Note (8)]	$\frac{t_w + t'_m}{r(t_w)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$ For branch leg of a reduced outlet use $\frac{0.9 \left(\frac{r_h}{r} \right)}{h^{2/3}} \geq 2.1$	

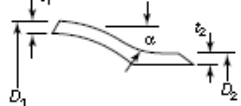
Additional Note for Reinforced fabricated tee:

For calculating the value of r_{ps} and t'_e , the value of r_c is assumed to be equal to $2 \times r'_m$, where r'_m is the mean radius of the branch leg.

ASME Section III, Subsection NC - Class 2 (2015)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)					
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $[r'_m/R_m] \leq 0.9$ $B_{2b} = 0.75 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{t_p} \right)$ for $[r'_m/R_m] = 1.0$ $B_{2b} = 0.45 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{t_p} \right)$ for $0.9 < [r'_m/R_m] < 1.0$ use linear interpolation	1	Branch leg: for $[r'_m/R_m] \leq 0.9$ $\dot{i}_b = 1.5 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{t_p} \right) \geq 1.5$ for $[r'_m/R_m] = 1.0$ $\dot{i}_b = 0.9 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{t_p} \right) \geq 1.5$ for $0.9 < [r'_m/R_m] < 1.0$ use linear interpolation	Figure NC-3673.2(b)-2
		Run legs: for $[r'_m/R_m] \leq 0.5$ $B_{2r} = 0.75 \left(\frac{r'_m}{t_b} \right)^{0.3}$ but not < 1.0 for $[r'_m/R_m] > 0.5$ $B_{2r} = 0.9 \left(\frac{r'_m}{t_b} \right)^{1/4}$		Run legs: for $[r'_m/R_m] \leq 0.5$ $\dot{i}_r = 0.8 \left(\frac{r'_m}{t_b} \right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5 \left(t_b/T_r \right) \left(t_b/d \right)^{0.5}$ but not > 0.5 for $[r'_m/R_m] > 0.5$ $\dot{i}_r = 0.8 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	

ASME Section III, Subsection NC - Class 2 (2015)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)					
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (5)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25 \left(\frac{R_m}{r_f}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{r'_a}{r_f}\right) \left(\frac{r'_m}{r_p}\right) \geq 1.5$ Run legs: $B_{2r} = 1.3 \left(\frac{r'_m}{r_b}\right)^{1/4} \geq 1.5$	1	Branch leg: $i_b = 4.5 \left(\frac{R_m}{r_f}\right)^{2/3} \left(\frac{r'_m}{R_m}\right)^{1/2} \left(\frac{r'_a}{r_f}\right) \left(\frac{r'_m}{r_p}\right) \geq 3.0$ Run legs: $i_r = 0.8 \left(\frac{R_m}{r_f}\right)^{2/3} \left(\frac{r'_m}{R_m}\right) \geq 2.1$	Figure NC-3643.2(b)-2
Single butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75 \left(\frac{5t}{r_s}\right) \geq 0.5$	$1.5 \left(\frac{5t}{r_s}\right)$	1	For $C_x \geq 1.09 t_n$, $i = 1.3$ For $C_x < 1.09 t_n$, $i = 2.1 (t_n/C_x) \geq 1.3$	Figure NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NC-4511-1
30 deg tapered transition [ASME B16.25] $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	(U.S. Customary Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 0.113/t_n \leq 1.9$ (SI Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 2.87/t_n \leq 1.9$	...
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
30 deg tapered transition [ASME B16.25] $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036 D_o / t_n \leq 1.9$	...
Concentric and eccentric reducers [ASME B16.9] [Note (12)]	0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg < $\alpha \leq 60$ deg	1.0	1	$0.5 + 0.01 \left(\frac{D_2}{t}\right)^{1/2} \leq 2.0$	

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

1. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.
2. The definition of Cx as per Note 11 of Table NC-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure NC-4427-1.

ASME Section III, Subsection NC - Class 2 (2015)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)					
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Threaded pipe joint or threaded flange	0.75	1.7	1	2.9	...

GENERAL NOTES:

(a) The following nomenclature applies:
*d*_i = nominal inside diameter of branch, in. (mm)
*D*_o = nominal outside diameter, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
*R*_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
s = miter spacing at center line, in. (mm)
*t*₂ = thickness in reinforcement zone of branch, in. (mm)
*t*₂ = pad or saddle thickness, in. (mm)
*t*_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees and elbows, see Note (2))
*t*_r = nominal wall thickness of run pipe, in. (mm)
T'₂ = nominal wall thickness of branch pipe, in. (mm)
 θ = one-half angle between adjacent miter axes, deg

For Figure NC-3673.2(b)-2, sketches (a) and (b):
 $t_2 = T_2$ if $L_2 \geq 0.5(2r'_m T_2)^{1/2}$
 $t_2 = T_2$ if $L_2 < 0.5(2r'_m T_2)^{1/2}$

For Figure NC-3673.2(b)-2, sketch (c):
 $t_2 = T_2 + (\frac{3}{2})y$ if $\theta \leq 30$ deg
 $t_2 = T_2 + 0.385L_2$ if $\theta > 30$ deg

For Figure NC-3673.2(b)-2, sketch (d):
 $t_2 = T_2 = T_2$

For branch connection nomenclature, refer to Figs. NC-3643.2(b)-2 and NC-3673.2(b)-2.

(b) The flexibility factors *k*, stress intensification factors *i*, and stress indices *B*₂ apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to *D*_o/*t*_n ≤ 50 and stress intensification factors are applicable to *D*_o/*t*_n ≤ 100. For products and joints with 50 < *D*_o/*t*_n ≤ 100, the *B*₂ index in Table NC-3673.2(b)-1 is valid. The *B*₂ index shall be multiplied by the factor 1/(*X**T*), where:
 $X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
 $Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; *T* = Design temperature (°F)
 $Y = 1.024 - 0.000594T$ for Ferritic Material, not to exceed 1.0; *T* = Design temperature (°C)
 = 1.0 for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of *k* and *i* shall be corrected by the factor *c* given below:
 (a) One end flanged, $c = h^{1/4}$
 (b) Both ends flanged, $c = h^{1/2}$
 But after such multiplication, values of *k* and *i* shall not be taken as less than 1.0.

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

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)	
<p>NOTES (CONT'D):</p> <p>(3) Also includes single miter joints.</p> <p>(4) For checking branch leg stress:</p> $Z = \pi (r'_m)^2 T_2$ <p>For checking run leg stress:</p> $Z = \pi (R_m)^2 T_r$ <p>(5) When $t_2 \geq 1.5 t_n$, $h = 4.05 t_n / r$.</p> <p>(6) The equation applies only if the following conditions are met: (a) The reinforcement area requirements of NC-3643 are met. (b) The axis of the branch pipe is normal to the surface of the run pipe wall. (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe. (d) The run pipe is a straight pipe.</p> <p>(7) r'_m / r shall be taken as 0.5 for $r'_m / r > 0.5$. r'_m / r_{ps} shall not be taken as less than 0.5.</p> <p>The definition of r_{ps} is: $r_{ps} = (r'_m + r_2) / 2$ for $t_2 \geq 0.8t_n$ $r_{ps} = r'_m + (T'_2 / 2)$ for $t_2 < 0.8t_n$</p> <p>(8) The definition of t'_2 is: $t'_2 = t_2 [(r_2 / r'_m) - 1]$ but not greater than 1.0<i>t</i>_n.</p> <p>(9) If an r_2 radius is provided [Figure NC-3673.2(b)-2] that is not less than the larger of $T_2 / 2$, $(T'_2 + y) / 2$ [sketch (c)], or $T_r / 2$, then the calculated values of Z and <i>i</i> may be divided by 2, but with $t_2 \geq 1.5$ and $i_r \geq 1.5$. For $r'_m / R_m \leq 0.5$, the <i>i</i> factors for checking run ends are independent of whether r_2 is provided or not.</p> <p>(10) The equations apply only if $r'_m / R_m \leq 0.5$.</p> <p>(11) In Figure NC-4427-1 sketches (c-1) and (c-2), <i>C</i>₁ shall be taken as <i>X</i>_{min} and <i>C</i>₂ ≥ 1.25 <i>t</i>_n. In Figure NC-4427-1 sketch (c-3), <i>C</i>₂ ≥ 0.75 <i>t</i>_n. For unequal leg lengths, use the smaller leg length for <i>C</i>₂.</p> <p>(12) The equation applies only if the following conditions are met: (a) Cone angle α does not exceed 60 deg. (b) The larger of D_1 / t_1 and D_2 / t_2 does not exceed 100. (c) The wall thickness is not less than <i>t</i>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 <i>t</i>₂. (d) For eccentric reducers, α is the maximum cone angle.</p>	

ASME Section III, Subsection NC - Class 2 (2017)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of NC-3641.1.

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

where

P_a = allowable pressure

S = allowable stress for the material at the Design Temperature

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

= 0.4 for $D/t_m \geq 6$

= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of NC-3652 (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

$B1, B2$ = primary stress indices from Table NC-3673.2(b)-1

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 8 of NC-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and nonreversing dynamic loads) from Equation 9a of NC-3653.1 **(in case the option “Include Axial force in stress calculations” is turned OFF).**

$$S_{LO} = 2. B1. ABS \left(\frac{f_p PD}{4t_n} \right) + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 9a of NC-3653.1 as follows.

$$S_{LO} = 2. B1. ABS \left[\left(\frac{f_p PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} + \left(\frac{F}{A} \right)_{occa} \right] + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

where

- M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and non-reversing dynamic loads
= $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- f_p = peak pressure factor input into CAEPIPE
- P = maximum of CAEPIPE Input pressures P1 through P10
- D = outside diameter
- t_n = nominal wall thickness
- Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)
- $S_{LO(All)}$ = minimum (1.80 S_h , 1.5 S_y) for Level B Service Limits as per NC-3653.1
= minimum (2.25 S_h , 1.8 S_y) for Level C Service Limits as per NC-3654.2 (a)
= minimum (3.0 S_h , 2.0 S_y) for Level D Service Limits as per NC-3655 (a)(2)
- S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10
- S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and nonreversing dynamic loads are to be input as “specified displacements” for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of NC-3653.2.

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

where

i = stress intensification factor from Table NC-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

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

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

f = stress range reduction factor from Table NC-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of NC-3653.2(c) (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_{TE} = ABS \left(\frac{PD}{4t_n} \right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 11 of NC-3653.2(c) as follows.

$$S_{TE} = ABS \left[\left(\frac{PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} \right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75*i* shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per NC-3611.2(e)

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

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

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table NC-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single nonrepeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of NC-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_c$$

where

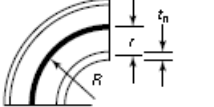
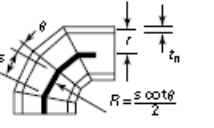
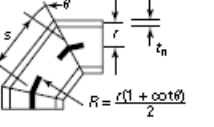
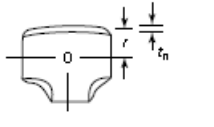
i = stress intensification factor from Table NC-3673.2(b)-1

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

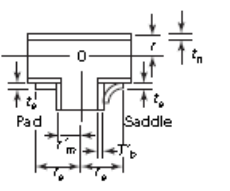
Z = section modulus; for reduced outlets, effective section modulus as per NC-3653.3(d)

ASME Section III, Subsection NC - Class 2 (2017)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors						
Description	Primary Stress Index		Flexibility Characteristic, f_r	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4h - 0.1 \leq 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_w R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r(1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s_h \cot \theta}{2r^2}$	$\frac{1.52}{h^{2/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r(1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_w(1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{2/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4 \left(\frac{r}{t_w} \right)^{2/3}$	$\frac{4.4 t_w}{r}$	1	$\frac{0.9}{h^{2/3}}$ For branch leg of a reduced outlet use $\frac{0.9 \left(\frac{r_h}{r} \right)}{h^{2/3}}$	
		Run end: $B_{2r} = 0.5 \left(\frac{r}{t_w} \right)^{2/3}$				

Additional Note for Welding elbow or Pipe bend:

If the value of $B_1 = (0.4h - 0.1) < 0.0$, then B_1 is set to 0.0.

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)						
Description	Primary Stress Index		Flexibility Characteristic, f_r	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75 \left(\frac{r}{t_w} \right)^{2/3} \left(\frac{r_{in}}{r} \right)^{1/2} \left(\frac{r_h}{t_w} \right) \left(\frac{r_{in}}{q_w} \right) \geq 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_w)^{2/3}}{[1 + (r'_m/2t_w)]^{5/3}} \geq 1.0$ [Note (8)]	$\frac{t_w + t'_m}{r(t_w)^{3/2}}$	1	$\frac{0.9}{h^{2/3}} \geq 2.1$ For branch leg of a reduced outlet use $\frac{0.9 \left(\frac{r_h}{r} \right)}{h^{2/3}} \geq 2.1$	

Additional Note for Reinforced fabricated tee:

For calculating the value of r_{ps} and t'_e , the value of r_c is assumed to be equal to $2 \times r'_m$, where r'_m is the mean radius of the branch leg.

ASME Section III, Subsection NC - Class 2 (2017)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)					
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $[r'_m/R_m] \leq 0.9$ $B_{2b} = 0.75 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{t_p} \right)$ for $[r'_m/R_m] = 1.0$ $B_{2b} = 0.45 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{t_p} \right)$ for $0.9 < [r'_m/R_m] < 1.0$ use linear interpolation	1	Branch leg: for $[r'_m/R_m] \leq 0.9$ $\dot{i}_b = 1.5 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{t_p} \right) \geq 1.5$ for $[r'_m/R_m] = 1.0$ $\dot{i}_b = 0.9 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{t_p} \right) \geq 1.5$ for $0.9 < [r'_m/R_m] < 1.0$ use linear interpolation	Figure NC-3673.2(b)-2
		Run legs: for $[r'_m/R_m] \leq 0.5$ $B_{2r} = 0.75 \left(\frac{r'_m}{t_b} \right)^{0.3}$ but not < 1.0 for $[r'_m/R_m] > 0.5$ $B_{2r} = 0.9 \left(\frac{r'_m}{t_b} \right)^{1/4}$		Run legs: for $[r'_m/R_m] \leq 0.5$ $\dot{i}_r = 0.8 \left(\frac{r'_m}{t_b} \right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5 \left(t_b/T_r \right) \left(t_b/d \right)^{0.5}$ but not > 0.5 for $[r'_m/R_m] > 0.5$ $\dot{i}_r = 0.8 \left(\frac{R_m}{T_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	

ASME Section III, Subsection NC - Class 2 (2017)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)					
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (5)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25 \left(\frac{R_m}{r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{r_A}{r} \right) \left(\frac{r'_m}{r_p} \right) \geq 1.5$ Run legs: $B_{2r} = 1.3 \left(\frac{r'_m}{r_b} \right)^{1/4} \geq 1.5$	1	Branch leg: $i_b = 4.5 \left(\frac{R_m}{r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{r_A}{r} \right) \left(\frac{r'_m}{r_p} \right) \geq 3.0$ Run legs: $i_r = 0.8 \left(\frac{R_m}{r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	Figure NC-3643.2(b)-2
Single butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75 \left(\frac{t_n}{t_s} \right) \geq 0.5$	$1.5 \left(\frac{t_n}{t_s} \right)$	1	For $C_x \geq 1.09 t_n$, $i = 1.3$ For $C_x < 1.09 t_n$, $i = 2.1 (t_n / C_x) \geq 1.3$	Figure NC-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure NC-4511-1
30 deg tapered transition [ASME B16.25] $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	(U.S. Customary Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 0.113 / t_n \leq 1.9$ (SI Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 2.87 / t_n \leq 1.9$	...
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
30 deg tapered transition [ASME B16.25] $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036 D_o / t_n \leq 1.9$	...
Concentric and eccentric reducers [ASME B16.9] [Note (12)]	0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg < $\alpha \leq 60$ deg	1.0	1	$0.5 + 0.01 \left(\frac{D_2}{t} \right)^{1/2} \leq 2.0$	

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

- There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.
- The definition of Cx as per Note 11 of Table NC-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure NC-4427-1.

ASME Section III, Subsection NC - Class 2 (2017)

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)					
Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Threaded pipe joint or threaded flange	0.75	1.7	1	2.9	...

GENERAL NOTES:

(a) The following nomenclature applies:
*d*_i = nominal inside diameter of branch, in. (mm)
*D*_o = nominal outside diameter, in. (mm)
R = nominal bend radius of elbow or pipe bend, in. (mm)
r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
*R*_m = mean radius of run pipe, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
s = miter spacing at center line, in. (mm)
*t*₂ = thickness in reinforcement zone of branch, in. (mm)
*t*₂ = pad or saddle thickness, in. (mm)
*t*_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees and elbows, see Note (2))
*t*_r = nominal wall thickness of run pipe, in. (mm)
T'₂ = nominal wall thickness of branch pipe, in. (mm)
 θ = one-half angle between adjacent miter axes, deg

For Figure NC-3673.2(b)-2, sketches (a) and (b):
 $t_2 = T_2$ if $L_2 \geq 0.5(2r'_m T_2)^{1/2}$
 $t_2 = T_2$ if $L_2 < 0.5(2r'_m T_2)^{1/2}$

For Figure NC-3673.2(b)-2, sketch (c):
 $t_2 = T_2 + (T_2/3)$ if $\theta \leq 30$ deg
 $t_2 = T_2 + 0.385L_2$ if $\theta > 30$ deg

For Figure NC-3673.2(b)-2, sketch (d):
 $t_2 = T_2 = T_2$

For branch connection nomenclature, refer to Figs. NC-3643.2(b)-2 and NC-3673.2(b)-2.

(b) The flexibility factors *k*, stress intensification factors *i*, and stress indices *B*₂ apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.

(c) Primary stress indices are applicable to *D*_o/*t*_n ≤ 50 and stress intensification factors are applicable to *D*_o/*t*_n ≤ 100. For products and joints with 50 < *D*_o/*t*_n ≤ 100, the *B*₂ index in Table NC-3673.2(b)-1 is valid. The *B*₂ index shall be multiplied by the factor 1/(*X**Y*), where:
 $X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
 $Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; *T* = Design temperature (°F)
 $Y = 1.024 - 0.000594T$ for Ferritic Material, not to exceed 1.0; *T* = Design temperature (°C)
 = 1.0 for other materials

NOTES:

(1) Where flanges are attached to one or both ends, the values of *k* and *i* shall be corrected by the factor *c* given below:
 (a) One end flanged, $c = h^{1/4}$
 (b) Both ends flanged, $c = h^{1/2}$
 But after such multiplication, values of *k* and *i* shall not be taken as less than 1.0.

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

Table NC-3673.2(b)-1 Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)	
<p>NOTES (CONT'D):</p> <p>(3) Also includes single miter joints.</p> <p>(4) For checking branch leg stress:</p> $Z = \pi (r'_m)^2 T_2$ <p>For checking run leg stress:</p> $Z = \pi (R_m)^2 T_r$ <p>(5) When $t_2 \geq 1.5 t_n$, $h = 4.05 t_n/r$.</p> <p>(6) The equation applies only if the following conditions are met: (a) The reinforcement area requirements of NC-3643 are met. (b) The axis of the branch pipe is normal to the surface of the run pipe wall. (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe. (d) The run pipe is a straight pipe.</p> <p>(7) r'_m/r shall be taken as 0.5 for $r'_m/r > 0.5$. r'_m/r_{ps} shall not be taken as less than 0.5.</p> <p>The definition of r_{ps} is: $r_{ps} = (r'_m + r_2) / 2$ for $t_2 \geq 0.8t_n$ $r_{ps} = r'_m + (T'_2/2)$ for $t_2 < 0.8t_n$</p> <p>(8) The definition of t'_2 is: $t'_2 = t_2 [(r_2 / r'_m) - 1]$ but not greater than 1.0<i>t</i>_n.</p> <p>(9) If an <i>r</i>₂ radius is provided [Figure NC-3673.2(b)-2] that is not less than the larger of $T_2/2$, $(T'_2 + y)/2$ [sketch (c)], or $T_r/2$, then the calculated values of <i>i</i>₂ and <i>i</i>_r may be divided by 2, but with <i>i</i>₂ ≥ 1.5 and <i>i</i>_r ≥ 1.5. For $r'_m/R_m \leq 0.5$, the <i>i</i> factors for checking run ends are independent of whether <i>r</i>₂ is provided or not.</p> <p>(10) The equations apply only if $r'_m/R_m \leq 0.5$.</p> <p>(11) In Figure NC-4427-1 sketches (c-1) and (c-2), <i>C</i>₂ shall be taken as <i>X</i>_{min} and <i>C</i>₂ ≥ 1.25 <i>t</i>_n. In Figure NC-4427-1 sketch (c-3), <i>C</i>₂ ≥ 0.75 <i>t</i>_n. For unequal leg lengths, use the smaller leg length for <i>C</i>₂.</p> <p>(12) The equation applies only if the following conditions are met: (a) Cone angle α does not exceed 60 deg. (b) The larger of <i>D</i>₁/<i>t</i>₁ and <i>D</i>₂/<i>t</i>₂ does not exceed 100. (c) The wall thickness is not less than <i>t</i>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 <i>t</i>₂. (d) For eccentric reducers, α is the maximum cone angle.</p>	

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 5 of ND-3641.1.

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

where

- P_a = allowable pressure
- S = allowable stress for the material at the Design Temperature
- E = joint factor (input as material property)
- t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$
- t = nominal pipe thickness
- D = outside diameter
- d = inside diameter
- Y = pressure coefficient
= 0.4 for $D/t_m \geq 6$
= $d/(D + d)$ for $D/t_m < 6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 8 of ND-3652 (**in case the option “Include Axial force in stress calculations” is turned OFF**).

$$S_L = 2.B1.ABS\left(\frac{PD}{4t_n}\right) + B2\frac{M_A}{Z} \leq 1.5S_h$$

where

- $B1, B2$ = primary stress indices from Table ND-3673.2(b)-1
- P = maximum of CAEPIPE Input pressures P1 through P10
- D = outside diameter
- t_n = nominal wall thickness
- M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)
- S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 8 of ND-3652 as follows.

$$S_L = 2.B1.ABS\left[\left(\frac{PD}{4t_n}\right) + \left(\frac{F}{A}\right)_{sust}\right] + B2\frac{M_A}{Z} \leq 1.5S_h$$

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_L may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O) (such as thrusts from relief and safety valve loads from pressure and flow transients, and reversing and nonreversing dynamic loads, if the Design Specification requires calculation of moments due to reversing and non-reversing dynamic loads) from Equation 9a of ND-3653.1 (in case the option “Include Axial force in stress calculations” is turned OFF).

$$S_{LO} = 2. B1. ABS \left(\frac{f_p PD}{4t_n} \right) + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 9a of ND-3653.1 as follows.

$$S_{LO} = 2. B1. ABS \left[\left(\frac{f_p PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} + \left(\frac{F}{A} \right)_{occa} \right] + B2 \left(\frac{M_A + M_B}{Z} \right) \leq S_{LO(All)}$$

where

- M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- M_B = resultant moment due to occasional loads, inclusive of seismic anchor movements and movements due to reversing and non-reversing dynamic loads
 $= \sqrt{M_X^2 + M_Y^2 + M_Z^2}$
- f_p = peak pressure factor input into CAEPIPE
- P = maximum of CAEPIPE Input pressures P1 through P10
- D = outside diameter
- t_n = nominal wall thickness
- Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)
- $S_{LO(All)}$ = minimum (1.80 S_h , 1.5 S_y) for Level B Service Limits as per ND-3653.1
 $=$ minimum (2.25 S_h , 1.8 S_y) for Level C Service Limits as per ND-3654.2 (a)
 $=$ minimum (3.0 S_h , 2.0 S_y) for Level D Service Limits as per ND-3655 (a)(2)
- S_h = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10
- S_y = material yield strength at maximum of CAEPIPE Input temperatures T1 through T10

As an option, the pressure stress term $\left(\frac{PD}{4t_n}\right)$ in the above equations for S_{LO} may be replaced with the expression $\left(\frac{Pd^2}{D^2-d^2}\right)$ using the CAEPIPE Options > Analysis > Pressure.

Note:

Movements at anchors and nozzles due to seismic event and due to reversing and non-reversing dynamic loads are to be input as “specified displacements” for seismic and they will be included as a part of the Occasional Stress evaluation given above.

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation (10a) of ND-3653.2.

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

where

i = stress intensification factor from Table ND-3673.2(b)-1

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per ND-3611.2(e)

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

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

f = stress range reduction factor from Table ND-3611.2(e)-1

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 11 of ND-3653.2(c) (in case the option “Include Axial force in stress calculations” is turned OFF)..

$$S_{TE} = ABS \left(\frac{PD}{4t_n} \right) + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

In case the option “Include Axial force in stress calculations” is turned ON, then CAEPIPE evaluates Equation 11 of ND-3653.2(c) as follows.

$$S_{TE} = ABS \left[\left(\frac{PD}{4t_n} \right) + \left(\frac{F}{A} \right)_{sust} \right] + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq S_H + S_A$$

0.75*i* shall not be less than 1.0.

where

P = maximum of CAEPIPE Input pressures P1 through P10

D = outside diameter

t_n = nominal wall thickness

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of moment ONLY due to thermal anchor movements = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

S_A = allowable stress range for expansion stress = $f(1.25S_c + 0.25S_h)$ as per ND-3611.2(e)

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

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

S_H = material allowable stress at maximum of CAEPIPE Input temperatures T1 through T10

f = stress range reduction factor from Table ND-3611.2(e)-1

Settlement Stress

The stress (S_S) due to single non-repeated anchor movement (e.g., predicted building settlement) is calculated from Equation (10b) of ND-3653.2.

$$S_S = \frac{iM_D}{Z} \leq 3S_c$$

where

i = stress intensification factor from Table ND-3673.2(b)-1

M_D = resultant moment due to any single nonrepeated anchor movement (e.g., predicted building settlement)

S_c = allowable stress at the Reference Temperature in CAEPIPE

Z = section modulus; for reduced outlets, effective section modulus as per ND-3653.3(d)

ASME Section III, Subsection ND - Class 3 (2017)

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors

Description	Primary Stress Index		Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Welding elbow or pipe bend [Note (1)], [Note (2)]	$0.4h - 0.1 \leq 0.5$ and > 0	$\frac{1.30}{h^{2/3}}$	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Note (1)] $s < r(1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{s_n \cot \theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Note (1)], [Note (3)] $s \geq r(1 + \tan \theta)$	0.5	$\frac{1.30}{h^{2/3}}$	$\frac{t_n[1 + \cot \theta]}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Note (4)]	0.5	Branch end: $B_{2b} = 0.4 \left(\frac{r}{t_n} \right)^{2/3}$ Run end: $B_{2r} = 0.5 \left(\frac{r}{t_n} \right)^{2/3}$	$\frac{4.4 t_n}{r}$	1	For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}} \left(\frac{T_b}{T_r} \right)$	

Additional Note for Welding elbow or Pipe bend:

If the value of $B_1 = (0.4h - 0.1) < 0.0$, then B_1 is set to 0.0.

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Characteristic, h	Flexibility Factor, k	Stress Intensification Factor, i	Sketch
	B_1	B_2				
Reinforced fabricated tee [Note (4)], [Note (5)], [Note (6)]	0.5	Branch end: $B_{2b} = 0.75 \left(\frac{r}{t_n} \right)^{2/3} \left(\frac{r'_m}{r} \right)^{1/2} \left(\frac{T_b}{T_r} \right) \left(\frac{r'_m}{r_{ps}} \right) \geq 1.0$ [Note (7)] Run end: $B_{2r} = \frac{0.675(r/t_n)^{2/3}}{[1 + (r'_e/2t_n)^{5/3}]} \geq 1.0$ [Note (8)]	$\left(\frac{t_n + \frac{t_n}{2}}{r(t_n)} \right)^{5/2}$	1	For branch leg of a reduced outlet, use $\frac{0.9}{h^{2/3}} \left(\frac{T_b}{T_r} \right) \geq 2.1$	

Additional Note for Reinforced fabricated tee:

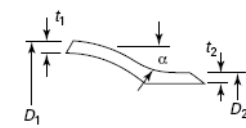
For calculating the value of r_{ps} and t'_e , the value of r_e is assumed to be equal to $2 \times r'_m$, where r'_m is the mean radius of the branch leg.

ASME Section III, Subsection ND - Class 3 (2017)

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Branch connection or unreinforced fabricated tee [Note (4)], [Note (6)], [Note (9)]	0.5	Branch leg: for $(r'_m/R_m) \leq 0.9$ $B_{2b} = 0.75 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{r'_h}{r_r} \right) \left(\frac{r'_m}{r_p} \right)$ for $(r'_m/R_m) = 1.0$ $B_{2b} = 0.45 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{r_p} \right)$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation	1	Branch leg: for $(r'_m/R_m) \leq 0.9$ $i_b = 1.5 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{r'_h}{r_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 1.5$ for $(r'_m/R_m) = 1.0$ $i_b = 0.9 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{r_p} \right) \geq 1.5$ for $0.9 < (r'_m/R_m) < 1.0$, use linear interpolation Run legs: for $(r'_m/R_m) \leq 0.5$ $i_r = 0.8 \left(\frac{r'_m}{t_b} \right)^{0.3}$ but not less than the larger of 1.0 and $1.5(1 - Q)$ where $Q = 0.5(t_b/r_r)(t_b/d)^{0.5}$ but not > 0.5 for $(r'_m/R_m) > 0.5$ $i_r = 0.8 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	Figure ND-3673.2(b)-2
		Run legs: for $(r'_m/R_m) \leq 0.5$ $B_{2r} = 0.75 \left(\frac{r'_m}{t_b} \right)^{0.3}$ but not < 1.0 for $(r'_m/R_m) > 0.5$ $B_{2r} = 0.9 \left(\frac{r'_m}{t_b} \right)^{1/4}$			

Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)

Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Fillet welded and partial penetration welded branch connections [Note (4)], [Note (6)], [Note (10)]	0.5	Branch leg: $B_{2b} = 2.25 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{r'_h}{r_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 1.5$ Run legs: $B_{2r} = 1.3 \left(\frac{r'_m}{t_b} \right)^{1/4} \geq 1.5$	1	Branch leg: $i_b = 4.5 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{r'_h}{r_r} \right) \left(\frac{r'_m}{r_p} \right) \geq 3.0$ Run legs: $i_r = 0.8 \left(\frac{R_m}{r_r} \right)^{2/3} \left(\frac{r'_m}{R_m} \right) \geq 2.1$	Figure ND-3643.2(b)-2
Girth butt weld	0.5	1.0	1	1.0	...
Circumferential fillet welded or socket welded joints [Note (11)]	$0.75 \left(\frac{t_n}{c_x} \right) \geq 0.5$	$1.5 \left(\frac{t_n}{c_x} \right)$	1	For $C_x \geq 1.09t_n$, $i = 1.3$ For $C_x < 1.09t_n$, $i = 2.1 (t_n/C_x) \geq 1.3$	Figure ND-4427-1 sketches (c-1), (c-2), and (c-3)
Brazed joint	0.5	1.6	1	2.1	Figure ND-4511-1
30 deg tapered transition (ASME B16.25) $t_n < 0.237$ in. (6 mm)	0.5	1.0	1	(U.S. Customary Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 0.113 / t_n \leq 1.9$ (SI Units) $1.3 + 0.0036 \frac{D_o}{t_n} + 2.87 / t_n \leq 1.9$	...
30 deg tapered transition (ASME B16.25) $t_n \geq 0.237$ in. (6 mm)	0.5	1.0	1	$1.3 + 0.0036 D_o / t_n \leq 1.9$	...
Concentric and eccentric reducers (ASME B16.9) [Note (12)]	0.5 for $\alpha \leq 30$ deg 1.0 for 30 deg $< \alpha \leq 60$ deg	1.0	1	$0.5 + 0.01 \alpha \left(\frac{D_2}{t_2} \right)^{1/2} \leq 2.0$	

Additional Note for Circumferential fillet welded or socket welded joints:

Values of B1, B2 and Stress Intensification Factor (SIF) are taken as 0.75, 1.50 and 1.3 respectively in CAEPIPE for the following reasons.

5. There is no provision to input the value of Cx in CAEPIPE for fillet and socket welded flanges.
6. The definition of Cx as per Note 11 of Table ND-3673.2(b)-1 contradicts with the definition of Cx as defined in Notes (3) and (4) of Figure ND-4427-1.

**Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)**

Description	Primary Stress Index		Flexibility Factor, <i>k</i>	Stress Intensification Factor, <i>i</i>	Sketch
	<i>B</i> ₁	<i>B</i> ₂			
Threaded pipe joint or threaded flange	0.75	1.7	1	2.3	...

GENERAL NOTES:

- a) The following nomenclature applies:
 - D_o = nominal outside diameter, in. (mm)
 - d_i = nominal inside diameter of branch, in. (mm)
 - r = mean radius of pipe, in. (mm) (matching pipe for tees and elbows)
 - r'_m = mean radius of branch pipe, in. (mm)
 - R = nominal bend radius of elbow or pipe bend, in. (mm)
 - R_m = mean radius of run pipe, in. (mm)
 - θ = one-half angle between adjacent miter axes, deg
 - s = miter spacing at center line, in. (mm)
 - t_b = thickness in reinforcement zone of branch, in. (mm)
 - t_c = pad or saddle thickness, in. (mm)
 - t_n = nominal wall thickness of pipe, in. (mm) [matching pipe for tees and elbows, see Note (2)]
 - T'_b = nominal wall thickness of branch pipe, in. (mm)
 - T_r = nominal wall thickness of run pipe, in. (mm)
- For Figure ND-3673.2(b)-2, sketches (a) and (b):
 - $t_b = T_b$ if $L_1 \geq 0.5(2r'_m T_b)^{1/2}$
 - $= T'_b$ if $L_1 < 0.5(2r'_m T_b)^{1/2}$
- For Figure ND-3673.2(b)-2, sketch (c):
 - $t_b = T'_b + (t'_b/3)^{1/2}$ if $\theta \leq 30$ deg
 - $= T'_b + 0.385L_1$ if $\theta > 30$ deg
- For Figure ND-3673.2(b)-2, sketch (d):
 - $t_b = T'_b = T_b$
- For branch connection nomenclature, refer to Figs. ND-3643.2(b)-2 and ND-3673.2(b)-2.
- b) The flexibility factors *k*, stress intensification factors *i*, and stress indices *B*₂ apply to moments in any plane for fittings and shall in no case be taken as less than 1.0. Flexibility factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees.
- c) Primary stress indices are applicable to $D_o/t_n \leq 50$ and stress intensification factors are applicable to $D_o/t_n \leq 100$. For products and joints with $50 < D_o/t_n \leq 100$, the *B*₁ index in Table ND-3673.2(b)-1 is valid. The *B*₂ index shall be multiplied by the factor 1/(XY), where:
 - $X = 1.3 - 0.006(D_o/t_n)$, not to exceed 1.0
 - $Y = 1.033 - 0.00033T$ for Ferritic Material, not to exceed 1.0; *T* = Design temperature (°F)
 - $Y = 1.0224 - 0.0005947T$ for Ferritic Material, not to exceed 1.0; *T* = Design temperature (°C)
 - $Y = 1.0$ for other materials

NOTES:

- 1) Where flanges are attached to one or both ends, the values of *k* and *i* shall be corrected by the factor *c* given below.
 - (a) One end flanged, $c = h^{1/4}$
 - (b) Both ends flanged, $c = h^{1/2}$
 But after such multiplication, values of *k* and *i* shall not be taken as less than 1.0.
- 2) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

ASME Section III, Subsection ND - Class 3 (2017)

**Table ND-3673.2(b)-1
Stress Indices, Flexibility, and Stress Intensification Factors (Cont'd)**

NOTES (CONT'D):

- 3) Also includes single miter joints.
- 4) For checking branch leg stress:

$$Z = \pi (r'_m)^2 T_b^2$$

For checking run leg stress:

$$Z = \pi (R_m)^2 T_r$$

- 5) When $t_e > 1.5 t_n$, $h = 4.05 t_n / r$.
- 6) The equation applies only if the following conditions are met:
 - (a) The reinforcement area requirements of ND-3643 are met.
 - (b) The axis of the branch pipe is normal to the surface of the run pipe wall.
 - (c) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or not less than two times the sum of their inside radii along the circumference of the run pipe.
 - (d) The run pipe is a straight pipe.
- 7) r'_m / r shall be taken as 0.5 for $r'_m / r > 0.5$.
 r'_m / r_{ps} shall not be taken as less than 0.5.

 The definition of r_{ps} is:
 $r_{ps} = (r'_m + r_e) / 2$ for $t_e \geq 0.8 t_n$
 $r_{ps} = r'_m + (T_b / 2)$ for $t_e < 0.8 t_n$
- 8) The definition of t'_e is:
 $t'_e = t_e [(r_e / r'_m) - 1]$ but not greater than $1.0 t_n$
- 9) If an r_2 radius is provided [Figure ND-3673.2(b)-2] that is not less than the larger of $T_b / 2$, $(T'_b + y) / 2$ [sketch (c)], or $T_r / 2$, then the calculated values of i_b and i_r may be divided by 2, but with $i_b \geq 1.5$ and $i_r \geq 1.5$. For $r'_m / R_m \leq 0.5$, the i factors for checking run ends are independent of whether r_2 is provided or not.
- 10) The equations apply only if $r'_m / R_m \leq 0.5$.
- 11) In Figure ND-4427-1 sketches (c-1) and (c-2), C_x shall be taken as X_{m1n} and $C_x \geq 1.25 t_n$. In Figure ND-4427-1 sketch (c-3), $C_x \geq 0.75 t_n$. For unequal leg lengths, use the smaller leg length for C_x .
- 12) The equation applies only if the following conditions are met:
 - (a) Cone angle α does not exceed 60 deg.
 - (b) The larger of D_1 / t_1 and D_2 / t_2 does not exceed 100.
 - (c) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2 .
 - (d) For eccentric reducers, α is the maximum cone angle.

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from 4.2(4).

$$P = \frac{2fet_f}{D - 2t_f}$$

where

P = allowable pressure

f = allowable stress

e = joint factor (input as material property)

t_f = minimum required thickness, including mechanical and corrosion allowances

= nominal pipe thickness \times (1 – mill tolerance/100) – corrosion allowance

D = outside diameter

$$P = \frac{fe}{X(1 + 0.6427 \tan \alpha \sqrt{X})}$$

where

α = miter angle

$X = (D - 2t_f)/2t_f$

Stresses

Stresses are calculated according to 4.11.

Sustained stresses are due to pressure, weight and other sustained mechanical loads. Maximum value is 0.8 \times proof stress value or rupture stress value in hot condition.

Expansion stresses are due to thermal (including specified displacements) and pressure loadings. Maximum value is lower of

- 1) 0.9 \times proof stress at room temperature plus 0.9 \times proof stress at design temperature.
- 2) 0.9 \times proof stress at room temperature plus rupture stress at design temperature.

Hot stresses are due to pressure, deadweight, other sustained mechanical loads, thermal and cold pull loadings. Maximum value is the rupture stress at design temperature.

Occasional stresses (which are due to seismic, dynamic or wind loadings) are not calculated. If these are to be evaluated, ASME B31.1 code should be used according to Inquiry Case 806/2 : November 1986 to BS 806 : 1986.

Stresses on Straight Pipes and Bends (4.11.4)

The combined stress f_c on straight pipes and bends including miter bends is calculated from (28).

$$F_c = F^2 + 4f_s^2$$

where

F = greater of f_T or f_L

f_T = transverse stress (4.11.4.2)

= transverse pressure stress + transverse bending stress

f_L = longitudinal stress (4.11.4.3)

= longitudinal pressure stress + longitudinal bending stress

f_s = torsional stress (4.11.4.4)

Transverse Stress f_T (4.11.4.2)

The transverse pressure stress on both straight pipes and bends excluding miter bends is calculated from (29).

$$\frac{pd}{2t} + 0.5p$$

The transverse pressure stress on miter bends is calculated from (30)

$$\left(\frac{pd}{2t} + 0.5p\right) \left(1 + 0.6427 \tan \alpha \sqrt{\frac{d+t}{2t}}\right)$$

The transverse bending stress on straight pipe is zero.

The transverse bending stress on bends including miter bends is calculated from (31)

$$\frac{r}{I} (M_i F_{Ti})^2 + (M_o F_{To})^2$$

where

d = inside diameter

t = thickness

p = pressure

M_i = in-plane bending moment

M_o = out-of-plane bending moment

F_{Ti} = in-plane transverse stress intensification factor

F_{To} = out-of-plane transverse stress intensification factor

r = mean radius of pipe

I = moment of inertia

D = outside diameter

α = miter angle

Longitudinal Stress f_L (4.11.4.3)

The longitudinal pressure stress on both straight pipes and bends including miter bends is calculated from (32)

$$\frac{pd^2}{4t(d+t)}$$

The longitudinal bending stress on straight pipe is calculated from (33).

$$\frac{d+2t}{2I} \sqrt{M_i^2 + M_o^2}$$

The longitudinal bending stress on bends including miter bends is calculated from (34).

$$\frac{r}{I} \sqrt{(M_i F_{Li})^2 + (M_o F_{Lo})^2}$$

where

F_{Li} = in-plane longitudinal stress intensification factor

F_{Lo} = out-of-plane longitudinal stress intensification factor

Torsional Stress f_s (4.11.4.4)

The torsional stress for both straight pipes and bends including miter bends is calculated from (35).

$$f_s = M_t \frac{d+2t}{4I}$$

where

M_t = torsional moment

Stress at Branch Junction (4.11.5)

The combined stress at a branch junction is calculated from (36)

$$f_{CB} = f_B^2 + 4f_{SB}^2$$

where

f_B = transverse pressure stress at the junction plus nondirectional bending stress

f_{SB} = torsional stress at the junction

Transverse Pressure Stress at Branch Junction (4.11.5.2)

The transverse pressure stress at branch junction is calculated from (37)

$$pm \left(\frac{d_1 + t_a}{2t_a} \right)$$

where

d_1 = mean radius of main pipe

t_a = minimum thickness of main pipe

p = design pressure

m = stress multiplier, or equal to:

(a) for branch junctions where both r_2/r_1 and t_2/t_1 are less than or equal to 0.3

$$m = 1.8 + \frac{2.8r_2}{r_1} \sqrt{\frac{r_1}{t_1}}$$

(b) for branch junctions where either r_2/r_1 and t_2/t_1 are greater than 0.3

$$m = 2.5Z_1^{0.2042} \text{ for } d_2/d_1 \leq 0.7$$

$$m = 2.5Z_1^{0.2415} \text{ for } d_2/d_1 > 0.7$$

$$Z_1 = (r_2/t_2)^2 t_1/r_1$$

r_1 = mean radius of main pipe

r_2 = mean radius of branch pipe

t_1 = thickness of main pipe

t_2 = thickness of branch pipe

Non-directional Bending Stress at Branch Junction (4.11.5.3)

For the main pipe, the bending stress is calculated from (40)

$$\frac{r_1}{I} \sqrt{(M_i B_i)^2 + (M_o B_o)^2}$$

where

r_1 = mean radius of pipe

I = moment of inertia of main pipe

M_i = in-plane bending moment

M_o = out-of-plane bending moment

B_i = in-plane branch stress intensification factor (Fig.4.11.1(6))

B_o = out-of-plane branch stress intensification factor (Fig.4.11.1(6))

For the branch pipe, the bending stress is calculated from

$$\frac{r_2}{I} \sqrt{(M_i B_i)^2 + (M_o B_o)^2}$$

where

r_2 = mean radius of branch pipe

I = calculated from $\pi r_2^3 B_o t_2$ or $\pi r_2^3 t_1$ whichever gives the lower value

Allowable Internal Pressure

For straight pipes and bends, the allowable pressure is calculated using the equation provided in para. 5.2.1 for straight pipes and bends.

$$P_a = \frac{2fS_{yt}t_a}{DX}$$

where

P_a = allowable pressure

S_{yt} = specified minimum yield strength

t_a = available thickness for pressure design

$$= t_n \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance "c"} \text{ (as per para. 8.3.3)}$$

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

t_n = nominal pipe thickness

D = outside diameter

f = design factor from Table 2.

Stress from Normal Sustained Loads

The von Mises equivalent stress (S_L) due to Normal Sustained Loads (pressure, weight and other sustained loads inclusive of snow/ice loading) is calculated as per para. 6.3, para. 8.5.2 and Appendix 3 for all components in CAEPIPE and compared with the acceptance limit given in para. 8.5.3, as given below.

$$S_L = \sqrt{(S_h - S_a)^2 + (S_h S_a) + 3S_q^2} \leq S_s$$

where

For Bends, Miter Bends and Welding Elbows

$$S_a = i_t \left[\frac{PD_o}{4t_s} + \frac{4F}{\pi[D_o^2 - D_i^2]} \right] \pm \frac{i_t 32M_b D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_h = i_p \left[\frac{PD_o}{2t_s} \right] \pm \frac{i_b 32M_b D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_q = i_q \left[\frac{16D_o M_q}{\pi[D_o^4 - D_i^4]} \right] + i_s \frac{4V_T}{\pi[D_o^2 - D_i^2]}$$

For Other components such as Straight Pipes, Reducers, Branch Pipes, Header Pipes, etc.

$$S_a = i_t \left[\frac{PD_o}{4t_s} + \frac{4F}{\pi[D_o^2 - D_i^2]} \right] \pm \frac{i_b 32M_b D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_h = i_p \left[\frac{PD_o}{2t_s} \right]$$

$$S_q = i_q \left[\frac{16D_o M_q}{\pi[D_o^4 - D_i^4]} \right] + i_s \frac{4V_T}{\pi[D_o^2 - D_i^2]}$$

P = maximum of CAEPIPE input pressures P1 through P10 (inclusive of any overpressure as per para. 5.2.3)

D_o = outside diameter

D_i = inside diameter

t_s = nominal thickness – corrosion allowance in CAEPIPE, as per para. 8.3.3

i_p, i_b, i_t, i_q, i_s = sustained stress concentration factor (SCF) for pressure, bending, thrust, torsion and shear computed as per Appendix 4.

S_h = sustained hoop stress

S_a = sustained axial stress

S_q = sustained shear stress

F = axial force due to sustained loads

M_b = bending moment due to sustained loads = $\sqrt{M_i^2 + M_o^2}$

M_q = torsional moment due to sustained loads

V_T = shear force due to sustained loads = $\sqrt{V_i^2 + V_o^2}$

M_i = in-plane bending moment due to sustained loads

M_o = out-of-plane bending moment due to sustained loads

V_i = in-plane shear force (local fy from CAEPIPE) due to sustained loads

V_o = out-of-plane shear force (local fz from CAEPIPE) due to sustained loads

S_s = allowable equivalent stress for Normal condition from Table 3 (given below).

Note:

In CAEPIPE, any wind load input is always considered as an “Abnormal” sustained load (and NOT as a Normal sustained load).

In addition, CAEPIPE always considers snow/ice loading as a “Normal” sustained load (and NOT as an Abnormal sustained load).

In CAEPIPE, the effect of cold-pull/cold spring is included only in support loads and not included in stress calculations as many piping codes do not allow credit for any reduction in stresses due to cold spring since the displacement range is unaffected. On the other hand, piping codes allow reduction in support loads due to cold spring (which can be helpful at the equipment).

Stress from Abnormal Sustained Loads

The von Mises equivalent stress (S_{Lo}) due to Abnormal Sustained Loads is calculated as per para. 6.4, para. 8.5.2 and Appendix 3 for all components as the Sum of stress (S_L) due to Normal Sustained Loads (pressure, weight and other sustained loads) and stress (S_o) due to Abnormal Sustained Loads (i.e., occasional loads) such as earthquake or wind. Wind and earthquake are not considered as acting concurrently. The resulting stress S_{Lo} is compared with the acceptance limit given in para. 8.5.3.

$$S_{Lo} \leq S_{sab}$$

where

$S_{Lo} = S_L + S_o$, where S_L is computed as above.

$$S_o = \sqrt{(S_{ho} - S_{ao})^2 + (S_{ho}S_{ao}) + 3S_{qo}^2}$$

For Bends, Miter Bends and Welding Elbows

$$S_{ao} = i_t \left[\frac{P_{peak}D_o}{4t_s} + \frac{4F_o}{\pi[D_o^2 - D_i^2]} \right] \pm \frac{i_t 32M_{b0}D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_{ho} = i_p \left[\frac{P_{peak}D_o}{2t_s} \right] \pm \frac{i_b 32M_{b0}D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_{qo} = i_q \left[\frac{16D_o M_{qo}}{\pi[D_o^4 - D_i^4]} \right] + i_s \frac{4V_{To}}{\pi[D_o^2 - D_i^2]}$$

For Other components such as Straight Pipes, Reducers, Branch Pipes, Header Pipes, etc.,

$$S_{ao} = i_t \left[\frac{P_{peak}D_o}{4t_s} + \frac{4F_o}{\pi[D_o^2 - D_i^2]} \right] \pm \frac{i_b 32M_{b0}D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_{ho} = i_p \left[\frac{P_{peak}D_o}{2t_s} \right]$$

$$S_{qo} = i_q \left[\frac{16D_o M_{qo}}{\pi[D_o^4 - D_i^4]} \right] + i_s \frac{4V_{To}}{\pi[D_o^2 - D_i^2]}$$

P_{peak} = peak pressure = (peak pressure factor in CAEPIPE – 1.0) x P

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

D_i = inside diameter

t_s = nominal thickness – corrosion allowance in CAEPIPE, as per para. 8.3.3

i_p, i_b, i_t, i_q, i_s = sustained stress concentration factor (SCF) for pressure, bending, thrust, torsion and shear computed as per Appendix 4.

S_{ho} = occasional hoop stress

S_{ao} = occasional axial stress

S_{qo} = occasional shear stress

F_o = axial force due to occasional loads

M_{bo} = bending moment due to occasional loads = $\sqrt{M_{io}^2 + M_{oo}^2}$

M_{qo} = torsional moment due to occasional loads

V_{To} = shear force due to occasional loads = $\sqrt{V_{io}^2 + V_{oo}^2}$

M_{io} = in-plane bending moment due to occasional loads

M_{oo} = out-of-plane bending moment due to occasional loads

V_{io} = in-plane shear force (local fy from CAEPIPE) due to occasional loads

V_{oo} = out-of-plane shear force (local fz from CAEPIPE) due to occasional loads

S_{sab} = allowable equivalent stress for Abnormal condition from Table 3 (given below).

Note:

In CAEPIPE, any ground settlement input is considered in computing “Shakedown Stress” (which is covered next) and NOT as an Abnormal sustained load.

Table 3: Allowable Stress for Normal and Abnormal Sustained Loads

f	NORMAL (S_s)		ABNORMAL ($S_{sab1}, S_{sab2}, \dots, S_{sabi}$)	
	$\frac{SMYS}{UTS} \leq 0.74$	$\frac{SMYS}{UTS} > 0.74$	$\frac{SMYS}{UTS} \leq 0.74$	$\frac{SMYS}{UTS} > 0.74$
0.67	0.80 SMYS	0.34 (SMYS +UTS)	0.90 SMYS	0.38 (SMYS +UTS)
0.50	0.60 SMYS	0.25 (SMYS +UTS)	0.67 SMYS	0.28 (SMYS +UTS)
0.30	0.36 SMYS	0.15 (SMYS +UTS)	0.40 SMYS	0.17 (SMYS +UTS)

Expansion Stress (Shakedown Stress)

The von Mises equivalent stress (S_E) range due to thermal expansion is calculated as per para. 8.5.4 and Appendix 3 for all components in CAEPIPE and compared with the acceptance limit given in para. 8.5.5, as given below.

$$S_E \leq 0.5K_{SD}(S_y + S_{YT})$$

where

$$S_E = \sqrt{(S_{he} - S_{ae})^2 + (S_{he}S_{ae}) + 3S_{qe}^2}$$

For Bends, Miter Bends and Welding Elbows

$$S_{ae} = i_t \left[\frac{PD_o}{4t_s} + \frac{4F_e}{\pi[D_o^2 - D_i^2]} \right] \pm \frac{i_t 32M_{be}D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_{he} = i_p \left[\frac{PD_o}{2t_s} \right] \pm \frac{i_b 32M_{be}D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_{qe} = i_q \left[\frac{16D_o M_{qe}}{\pi[D_o^4 - D_i^4]} \right] + i_s \frac{4V_{Te}}{\pi[D_o^2 - D_i^2]}$$

For Other components such as Straight Pipes, Reducers, Branch Pipes, Header Pipes, etc.,

$$S_{ae} = i_t \left[\frac{PD_o}{4t_s} + \frac{4F_e}{\pi[D_o^2 - D_i^2]} \right] \pm \frac{i_b 32M_{be}D_o}{\pi[D_o^4 - D_i^4]}$$

$$S_{he} = i_p \left[\frac{PD_o}{2t_s} \right]$$

$$S_{qe} = i_q \left[\frac{16D_o M_{qe}}{\pi[D_o^4 - D_i^4]} \right] + i_s \frac{4V_{Te}}{\pi[D_o^2 - D_i^2]}$$

P = operating pressure corresponding to the temperature considered for displacement cycle under analysis. For example, $P = P1$ from CAEPIPE for Expansion T1.

D_o = outside diameter

D_i = inside diameter

t_s = nominal thickness – corrosion allowance in CAEPIPE, as per para. 8.3.3

i_p, i_b, i_t, i_q, i_s = cyclic stress concentration factor (SCF) for pressure, bending, thrust, torsion and shear computed as per Appendix 4.

S_{he} = thermal expansion hoop stress

S_{ae} = thermal expansion axial stress

S_{qe} = thermal expansion shear stress

F_e = axial force due to thermal expansion

M_{be} = bending moment due to thermal expansion = $\sqrt{M_{ie}^2 + M_{oe}^2}$

M_{qe} = torsional moment due to thermal expansion

V_{Te} = shear force due to thermal expansion = $\sqrt{V_{ie}^2 + V_{oe}^2}$

M_{ie} = in-plane bending moment due to thermal expansion

M_{oe} = out-of-plane bending moment due to thermal expansion

V_{ie} = in-plane shear force (local f_y from CAEPIPE) due to thermal expansion

V_{oe} = out-of-plane shear force (local f_z from CAEPIPE) due to thermal expansion

K_{SD} = shakedown factor for the material from Table 4.

$K_{SD} = 1.8$ for Carbon Steel (CS) and 2.0 for Austenitic Steel (AS). For other materials, it is assumed to be 1.8.

$S_y =$ yield stress of material at room temperature (reference temperature in CAEPIPE).

$S_{yT} =$ yield stress of material at maximum of CAEPIPE input temperatures T1 through T10.

Fatigue Analysis

Fatigue compliance checks as described in para. 6.7, para. 8.5.6, para. 8.5.7 and Appendix 5 are not included in CAEPIPE analysis.

Stress Concentration Factors (SCF)

CONCENTRIC AND ECCENTRIC REDUCERS

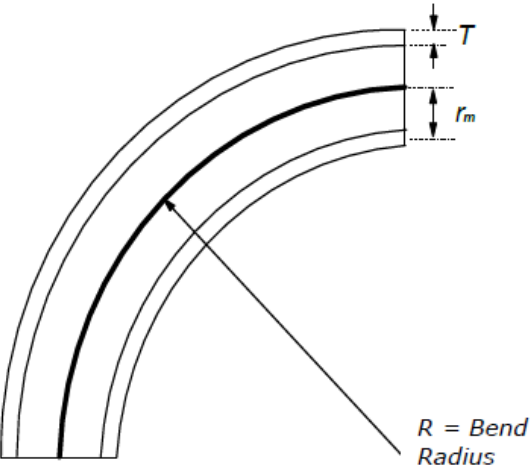
Sketch	Validity limits	k
	<p>Cone angle $\alpha < 60^\circ$</p> <p>Wall thickness throughout the body of the reducer is not less than the minimum thicknesses required to resist the design pressure.</p>	1.0

For reducers meeting the validity limits, take the sustained SCF for all loadings as 1.0 for cone angles $< 30^\circ$, and 2.0 for cone angles from 30° to 60° .

Take the cyclic SCF for the pressure, bending, thrust, torsion and shear loadings as those given in Table 8.

TYPE	CYCLIC SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
Reducer with R_1 and $R_2 \geq 0.1 D_1$	$1.0 + 0.0058\alpha \sqrt{\frac{D_n}{T_n}}$	$1.0 + 0.36\alpha^{0.4} \left(\frac{D_n}{T_n}\right)^{0.4} \left(\frac{D_2}{D_1}\right)^{-0.5}$	1.0	1.0	2.0

BEND & WELDING ELBOWS

Sketch	h	k <i>Never less than 1.0</i>
 <p style="text-align: right; margin-right: 50px;"><i>R = Bend Radius</i></p>	$\frac{TR}{r_m^2}$	$\frac{1.65}{h}$

TYPE	SUSTAINED SCF					CYCLIC SCF				
	<i>i_p</i> Pressure	<i>i_b</i> Bending <i>Never less than 1.0</i>	<i>i_t</i> Thrust	<i>i_q</i> Torsion	<i>i_s</i> Shear	<i>i_p</i> Pressure	<i>i_b</i> Bending <i>Never less than 1.5</i>	<i>i_t</i> Thrust	<i>i_q</i> Torsion	<i>i_s</i> Shear
Seam welded	1.0	$\frac{1.3}{h^{2/3}}$	1.0	1.0	1.0	2.0	$\frac{1.95}{h^{2/3}}$	1.3	1.0	2.0

Notes:

1. For large diameter, thin walled elbows and bends pressure stiffening effects can significantly affect the magnitudes of *k* and *i_b*. For the application of this effect, satisfy the following criteria;
 - a. No flanges at either end
 - b. $R/r_m < 1.7$
 - c. $R\alpha > 2r_m$, where α is the arc angle of the bend in radians.

Where the above criteria are satisfied, to correct values from the above tables,

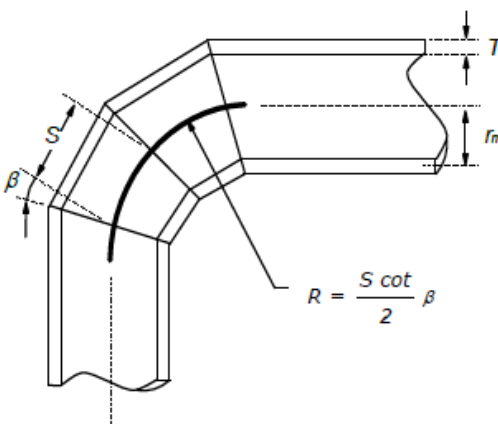
Divide *k* by $\left[1 + 6\left(\frac{P}{E}\right)\left(\frac{r_m}{T}\right)^{7/3}\left(\frac{R}{r_m}\right)^{1/3} \right]$ and divide *i_b* by

$$\left[1 + 3.25\left(\frac{P}{E}\right)\left(\frac{r_m}{T}\right)^{5/2}\left(\frac{R}{r_m}\right)^{2/3} \right]$$

2. Where flanges are attached to one or both ends, multiply the values of *k* and *i_b* in by the factor *C*.

- a. For one end flanged, $C = h^{1/6}$
- b. For both ends flanged, $C = h^{1/3}$.

CLOSELY SPACED MITRE BEND

Sketch	Validity limits	h	k
			<i>Never less than 1.0</i>
	$S < r_m$ $(1 + \tan \beta)$	$\frac{TR}{r_m^2}$	$\frac{1.52}{h^{5/6}}$

TYPE	SUSTAINED SCF					CYCLIC SCF				
	i_p	i_b	i_t	i_q	i_s	i_p	i_b	i_t	i_q	i_s
	Pressure	Bending <i>Never less than 1.0</i>	Thrust	Torsion	Shear	Pressure	Bending <i>Never less than 1.5</i>	Thrust	Torsion	Shear
Seam welded	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0	2.0	$\frac{1.8}{h^{2/3}}$	1.3	1.0	2.0

Note: Where flanges are attached to one or both ends, multiply the values of k and i_b by the factor C.

- a. For one end flanged, $C = h^{1/6}$
- b. For both ends flanged, $C = h^{1/3}$.

SINGLE OR WIDELY SPACED MITRE BEND

Sketch	Validity limits	h	k
			Never less than 1.0
<p style="text-align: center;">$R = \frac{r_m (1 + \cot \beta)}{2}$</p>	$S \geq r_m (1 + \tan \beta)$	$\frac{TR}{r_m^2}$	$\frac{1.52}{h^{5/6}}$

TYPE	SUSTAINED SCF					CYCLIC SCF				
	i_p Pressure	i_b Bending <i>Never less than 1.0</i>	i_t Thrust	i_q Torsion	i_s Shear	i_p Pressure	i_b Bending <i>Never less than 1.5</i>	i_t Thrust	i_q Torsion	i_s Shear
Seam welded	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0	2.0	$\frac{1.8}{h^{2/3}}$	1.3	1.0	2.0

Notes: Where flanges are attached to one or both ends, multiply the values of k and i_b in by the factor C.

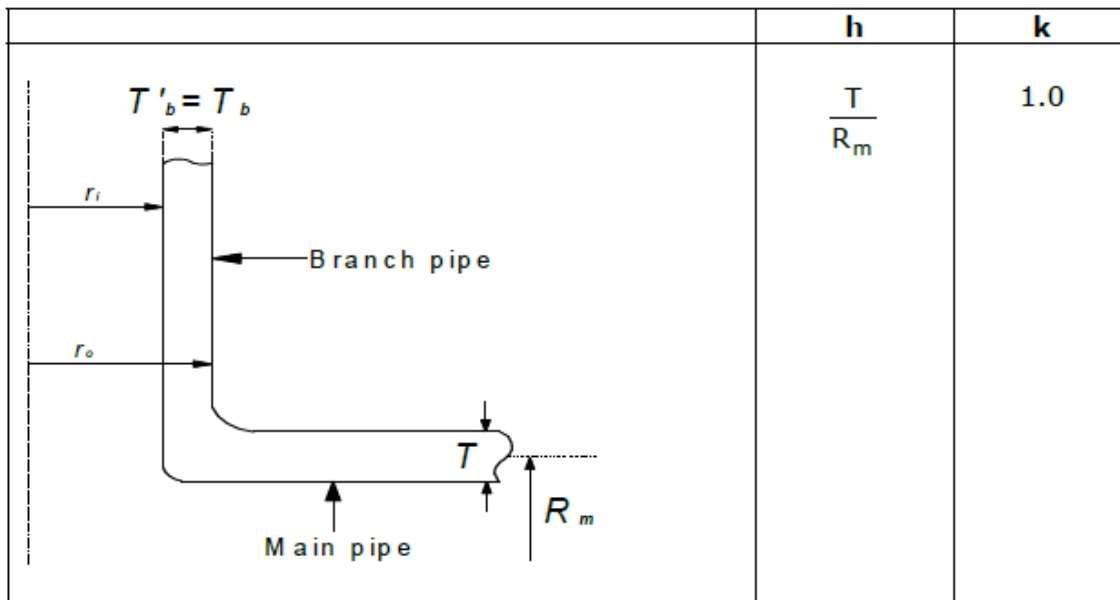
- a. For one end flanged, $C = h^{1/6}$
- b. For both ends flanged, $C = h^{1/3}$.

WELDOLET

	h $3.3 \frac{T}{R_m}$	k 1.0
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TYPE	SUSTAINED SCF				
	i _p Pressure	i _b Bending	i _t Thrust	i _q Torsion	i _s Shear
		Never less than 1.0 (See Notes)			
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
TYPE	CYCLIC SCF				
	i _p Pressure	i _b Bending	i _t Thrust	i _q Torsion	i _s Shear
		Never less than 1.5 (See Notes)			
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^{-2} \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^{-2} \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^{-2} \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^{-2} \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.3437}$	1.0	2.0

FABRICATED TEE



TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
		Never less than 1.0 (See Note 1)			
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
TYPE	CYCLIC SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
		Never less than 1.5 (See Note 1)			
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{-0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{-0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{-0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{-0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.3437}$	1.0	2.0

Welding TEE

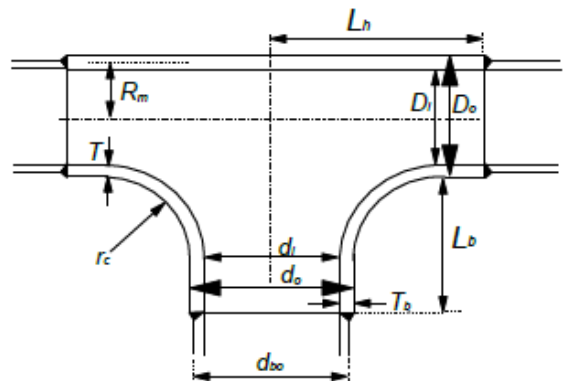
Sketch	Validity limits	k
	$r_c \geq 0.125 d_{bo}$ $T_c \geq 1.5 T_p$ (See Note 1)	1.0

TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending <i>Never less than 1.0</i> <i>(See Note 2)</i>	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	1.0	$0.5 \left(\frac{R_m}{T_p} \right)^{2/3}$	1.0	1.0	1.0
Branch pipe	1.0	$0.4 \left(\frac{R_m}{T_p} \right)^{2/3}$	1.0	1.0	1.0
TYPE	CYCLIC SCF				
	i_p Pressure	i_b Bending <i>Never less than 2.0</i> <i>(See Note 2)</i>	i_t Thrust	i_q Torsion	i_s Shear
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$0.67 \left(\frac{R_m}{T_p} \right)^{2/3}$	$1.29 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$0.67 \left(\frac{R_m}{T_p} \right)^{2/3}$	$0.89 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.3437}$	1.0	2.0

Notes:

- T_p is the pipe wall thickness not the tee thickness.
- The product $i_b \cdot w$ (see Appendix 3) is never less than 1.0 for sustained or 2.0 for cyclic assessments.

Extruded TEE

	Validity limits $0.05d_{bo} \leq r_c \leq (0.1d_{bo} + 12.5)$ $L_b \geq 0.7\sqrt{d_o T_b}$ $L_h \geq d_i$	h $\frac{T}{R_m} \left(1 + \frac{T_b}{R_m}\right)$	k 1.0
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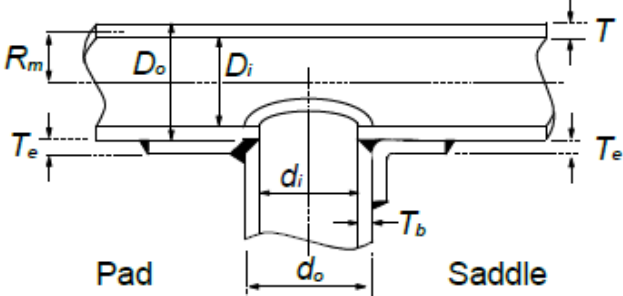
TYPE	SUSTAINED SCF				
	ip Pressure	ib Bending	it Thrust	iq Torsion	is Shear
		Never less than 1.0 (See Note)			
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
TYPE	CYCLIC SCF				
	ip Pressure	ib Bending	it Thrust	iq Torsion	is Shear
		Never less than 1.5 (See Note)			
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{-0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{-0.3437}$	1.0	2.0

SWEEPOLET & WELDED-IN CONTOUR INSERT

	<p>Validity limits</p> $r_c \geq 0.125 d_o$ $T_c \geq 1.5T$	<p>h</p> $4.4 \frac{T}{R_m}$	<p>k</p> <p style="text-align: center;">1.0</p>
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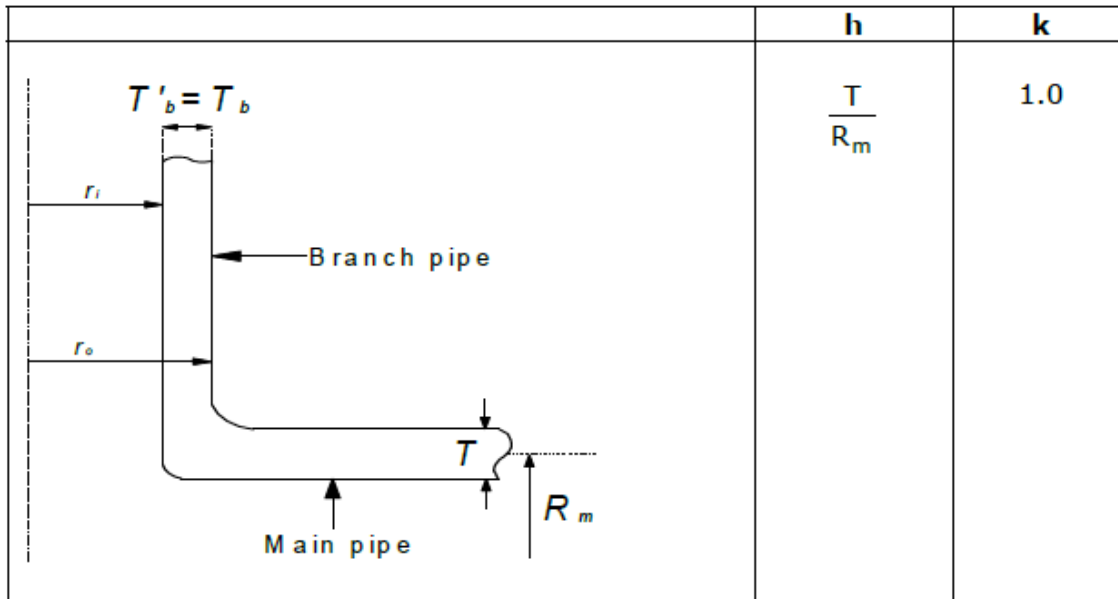
TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
		<i>Never less than 1.0 (See Notes)</i>			
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
		<i>Never less than 1.5 (See Notes)</i>			
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.3437}$	1.0	2.0

Reinforced Fabricated TEE

	h $\frac{(T + 0.5T_e)^{5/2}}{R_m(T)^{3/2}}$	k 1.0
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TYPE	SUSTAINED SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
		<i>Never less than 1.0 (See Note 1)</i>			
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i_p Pressure	i_b Bending	i_t Thrust	i_q Torsion	i_s Shear
		<i>Never less than 1.5 (See Note 1)</i>			
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89 \left[\frac{d_o T_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.3437}$	1.0	2.0

Unreinforced Fabricated TEE



TYPE	SUSTAINED SCF				
	i _p Pressure	i _b Bending	i _t Thrust	i _q Torsion	i _s Shear
		<i>Never less than 1.0 (See Note 1)</i>			
Main pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
Branch pipe	1.0	$\frac{1.8}{h^{2/3}}$	1.0	1.0	1.0
	CYCLIC SCF				
	i _p Pressure	i _b Bending	i _t Thrust	i _q Torsion	i _s Shear
		<i>Never less than 1.5 (See Note 1)</i>			
Main pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T'_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T'_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$1.29 \left[\frac{d_o T'_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.1439}$	1.0	2.0
Branch pipe	For $d_i/D_i \leq 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T'_b} \right]^2 \right]^{0.2042}$ For $d_i/D_i > 0.7$ $2.5 \left[\frac{2T}{D_o} \left[\frac{d_o}{2T'_b} \right]^2 \right]^{0.241}$	$\frac{1.8}{h^{2/3}}$	$0.89 \left[\frac{d_o T'_b}{D_o T} \left(\frac{D_o}{T} \right)^2 \right]^{0.3437}$	1.0	2.0

Sustained and Cyclic SCF for Welds and Threaded Joints in CAEPIPE

Type	Ip Pressure	Ib Bending	It Thrust	Iq Torsion	Is Shear
Buttweld	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	2.00	1.30	1.30	1.00	2.00
Tapered Transition	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	1.80	2.10	2.00	1.00	2.00
Filletweld	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	2.00	1.30	1.30	1.00	2.00
Concave Filletweld	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	2.00	1.30	1.30	1.00	2.00
Threaded Joint	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	1.00	2.30	2.30	1.00	1.00

Sustained and Cyclic SCF for Flanges in CAEPIPE

Type	Ip Pressure	Ib Bending	It Thrust	Iq Torsion	Is Shear
Weldneck	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	1.00	1.00	1.00	1.00	1.00
Double Welded	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	1.00	1.20	1.20	1.00	1.00
Single, Fillet & Socket Welded	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	2.00	1.30	1.30	1.00	1.00
Lap Joint	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	2.00	1.60	1.60	1.00	1.00
Threaded	Sustained SCF				
	1.00	1.00	1.00	1.00	1.00
	Cyclic SCF				
	2.00	2.30	2.30	1.00	1.00

Allowable Pressure

The allowable pressure for straight pipes is calculated from equation (6.1-1) or (6.1-3) depending on the ratio between outer and inner diameters.

For $D_o/D_i \leq 1.7$

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

For $D_o/D_i > 1.7$

$$P = fz \frac{(1 - a^2)}{(1 + a^2)}$$

where

P = allowable pressure

f = allowable stress at Design Temperature as input into CAEPIPE Material properties

z = joint factor (input as material property in CAEPIPE)

e = pipe wall thickness without allowances and tolerances

= nominal pipe thickness \times (1 – mill tolerance/100 – corrosion allowance “c”)

(In the pipe section where higher nominal thickness is ordered in order to accommodate either threading or grooving or erosion or any other thinning allowance, then such additional thickness required for threading/grooving/erosion/thinning etc. should be included in corrosion allowance “c” in CAEPIPE to compute allowable pressure for that pipe section.)

D_o = outer diameter

D_i = un-corroded inner diameter

$$a = 1 - \frac{2e}{D_o}$$

For pipe bends, the pipe wall thickness “e” in the above equation should be replaced by e_{ext} to calculate the allowable pressure.

e_{ext} = bend extrados wall thickness without allowances and tolerances = nominal bend thickness $\times t_f \times$ (1 – mill tolerance/100 – corrosion allowance “c”)

where

$$t_f = \left(\frac{R/D_o + 0.25}{R/D_o + 0.50} \right)$$

R = radius of bend

For closely spaced miter bends, the allowable pressure is calculated from equations (6.3.4-1) and (6.3.4-2).

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

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)

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

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

where

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

R_s = effective bend radius of the miter

θ = miter half angle

Sustained Stress

The primary stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from equation (12.3.2-2)

$$\sigma_1 = \sqrt{\left[\frac{i_{QA}Q_{xA}}{A_c} + \frac{\sqrt{(0.75i_iM_{iA})^2 + (0.75i_oM_{oA})^2}}{Z_c} \right]^2 + \left[\frac{i_tM_{tA}}{Z_c} \right]^2} \leq f_f$$

where

$$Q_{xA} = \max \left[|Q_{xS}|, \left| \frac{P_c \pi d_{ic}^2}{4} + Q_{xS} \right| \right]$$

$\frac{P_c \pi d_{ic}^2}{4}$ = internal pressure forces due to unrelieved axial expansion joints etc.

Q_{xS} = axial force from other sustained mechanical loads (such as pipe weight, fluid weight etc.) [excluding that from pressure]

P_c = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

d_{ic} = corroded inside diameter = $d_o - (2.e_c)$

d_o = outside diameter

e_c = corroded thickness = $e_n - \text{corrosion allowance}$

e_n = nominal pipe thickness

A_c = area of cross section of the corroded pipe = $\frac{\pi}{4} (d_o^2 - d_{ic}^2)$

M_{iA} = in-plane bending moment from the sustained mechanical loads [excluding that from pressure]

M_{oA} = out-of-plane bending moment from the sustained mechanical loads [excluding that from pressure]

M_{tA} = torsional moment from the sustained mechanical loads [excluding that from pressure]

i_{QA} = stress intensification factor for axial forces for sustained mechanical loads = 1.0

i_i = In-plane stress intensification factor from the Tables given at the end of this section

i_o = Out-of-plane stress intensification factor from the Tables given at the end of this section

i_t = stress intensification factor for torsional moments = 1.0

Z_c = corroded section modulus for pipe = $\frac{\pi}{32d_o} (d_o^4 - d_{ic}^4)$;

for branch connections/reduced outlets, as per Table H.3 of EN 13480-3:2017/A2:2020,

$$Z_c = \min \left[i \frac{\pi((d_{m,b}+e_{n,b})^4 - (d_{m,b}+e_{n,b}-2e_{c,b})^4)}{32(d_{m,b}+e_{n,b})}, \frac{\pi}{4} (d_{m,b} + e_{n,b})^2 e_c \right]$$

where i is taken as In-plane SIF i_i

$f_f = \min(f; f_{cr})$ = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

$f = \min(Rp0.2t/1.5 ; Rm/2.4)$ at max(T1 through T10); f is input into CAEPIPE material properties

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into CAEPIPE material properties

$Rp0.2t$ = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note: Starting Version 7.50 of CAEPIPE, the value of “ f_f ” is no longer input in the material properties table. Instead, the value of “ f ” which is calculated as $\min(Rp0.2t/1.5; Rm/2.4)$ is input for each temperature.

If a stress model created using CAEPIPE version earlier than 7.50 is read into CAEPIPE Version 7.50 or later version, the material properties should be updated appropriately by the CAEPIPE User.

Sustained plus Occasional Stress

The primary stress (σ_2) due to sustained and occasional loads is calculated from equation (12.3.3-4) as the combined stress due to (a) sustained loads such as pressure, weight and other sustained mechanical loads and (b) occasional loads such as earthquake or wind. Wind and earthquake are not considered to act concurrently.

$$\sigma_2 = \sqrt{\left[\frac{i_{QA} Q_x}{A_c} + \frac{\sqrt{[0.75 i_i (M_{iA} + M_{iB})]^2 + [0.75 i_o (M_{oA} + M_{oB})]^2}}{Z_c} \right]^2 + \left[\frac{i_t M_{tA} + i_t M_{tB}}{Z_c} \right]^2} \leq k f_f$$

where

M_{iB} = in-plane bending moment from occasional or exceptional loads

M_{oB} = out-of-plane bending moment from occasional or exceptional loads

M_{tB} = torsional moment from occasional or exceptional loads

For reversing loads (unsigned occasional load cases, e.g. earthquake)

$$Q_x = \max\left[|Q_{xA}| + |Q_{xB}|, \left|\frac{P_b \pi d_{ic}^2}{4} + Q_{xA}\right| + |Q_{xB}|\right] \text{ as per equation (12.3.3-2)}$$

Both signs of M_{tB} and M_{oB} are considered

For non-reversing loads (signed occasional load cases, e.g. wind)

$$Q_x = \max\left[|Q_{xA}|, |Q_{xA} + Q_{xB}|, \left|\frac{P_b \pi d_{ic}^2}{4} + Q_{xA}\right|, \left|\frac{P_b \pi d_{ic}^2}{4} + Q_{xA} + Q_{xB}\right|\right] \text{ as per equation (12.3.3-3)}$$

P_b = Peak pressure during occasional loading = Peak Pressure Factor x P_c

P_c = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

Q_{xA} = axial force due to sustained mechanical loads [excluding that from pressure]

Q_{xB} = axial force due to occasional loads [excluding that from pressure]

A_c = area of cross section of the corroded pipe = $\frac{\pi}{4} (d_o^2 - d_{ic}^2)$

Z_c = corroded section modulus = $\frac{\pi}{32d_o} (d_o^4 - d_{ic}^4)$;

for branch connections/reduced outlets, as per Table H.3 of EN 13480-3:2017/A2:2020,

$$Z_c = \min \left[i \frac{\pi((d_{m,b} + e_{n,b})^4 - (d_{m,b} + e_{n,b} - 2e_{c,b})^4)}{32(d_{m,b} + e_{n,b})}, \frac{\pi}{4} (d_{m,b} + e_{n,b})^2 e_c \right]$$

where i is taken as In-plane SIF i_i

$f_r = \min(f; f_{cr})$ = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

$f = \min(Rp0.2t/1.5 ; Rm/2.4)$ at max(T1 through T10); f is input into CAEPIPE material properties

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into CAEPIPE material properties

$Rp0.2t$ = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

$k=1.2$ if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE, the default value for $k=1.2$; user can change this default value through Layout window > Options > Analysis > Code > EN13480.

Note: Starting Version 7.50 of CAEPIPE, the value of “ f_r ” is no longer input in the material properties table. Instead, the value of “ f ” which is calculated as $\min(Rp0.2t/1.5; Rm/2.4)$ is input for each temperature.

If a stress model created using CAEPIPE version earlier than 7.50 is read into CAEPIPE Version 7.50 or later version, the material properties should be updated appropriately by the CAEPIPE User.

Expansion Stress

The secondary stress (σ_3) due to thermal expansion is calculated from equation (12.3.4-3)

$$\sigma_3 = \sqrt{\left[\frac{i_{QC} Q_{xC}}{A} + \frac{\sqrt{(i_i M_{iC})^2 + (i_o M_{oC})^2}}{Z} \right]^2 + \left[\frac{i_t M_{tC}}{Z} \right]^2} \leq f_a$$

where

M_{iC} = in-plane moment range due to thermal expansion and alternating loads

M_{oC} = out-of-plane moment range due to thermal expansion and alternating loads

M_{tC} = torsional moment range due to thermal expansion and alternating loads

i_{QC} = stress intensification factor for axial forces due to thermal expansion and alternating loads = 1.0

Q_{xC} = range of axial force due to thermal expansion and alternating loads

e_n = nominal pipe thickness

d_o = outside diameter

d_i = inside diameter = $d_o - 2 e_n$

A = un-corroded nominal area of cross-section = $\frac{\pi}{4} (d_o^2 - d_i^2)$

Z = un-corroded section modulus for pipe = $\frac{\pi}{32 d_o} (d_o^4 - d_i^4)$;

for branch connections/reduced outlets, as per Table H.3 of EN 13480-3:2017/A2:2020,

$$Z = \min \left[i \frac{\pi ((d_{m,b} + e_{n,b})^4 - (d_{m,b} - e_{n,b})^4)}{32 (d_{m,b} + e_{n,b})}, \frac{\pi}{4} (d_{m,b} + e_{n,b})^2 e_n \right]$$

where i is taken as In-plane SIF i_i

$f_a = U(1.25f_c + 0.25f_h) \frac{E_h}{E_c}$ as per equation (12.1.3-1)

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

E_c = modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

E_h = modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

$f_c = \min(R_m/3; f)$, where $f = \min(R_{p0.2t}/1.5; R_m/2.4)$ at room temperature (T_{ref}) as per equation (12.1.3-2)

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration = $\min(f_c; f; f_{cr})$ as per equation (12.1.3-3), with f_c determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration.

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into CAEPIPE material properties

For example, for the thermal range (T1-T2), with T1 = 300⁰ C, T2 = 100⁰ C and T_{ref} = 21⁰C, E_c is determined at T2 = 100⁰C and E_h is determined at T1 = 300⁰C.

f_c as per Equation (12.1.3-2) listed above is determined at T_{ref} = 21⁰C.

The value of f_c used in calculating f_h is determined at T2 = 100⁰C [= min(100, 300)]; the value of f used in calculating f_h is determined at T1 = 300⁰ C [= max(100, 300)] and the value of f_{cr} is taken at T1 = 300⁰C (if available)

If the above condition in equation (12.3.4-3) is not met, equation (12.3.4-2) as listed below may be used.

$$\sigma_4 = \sigma_1 + \sigma_3 \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_5), due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-2) below.

$$\sigma_5 = \sigma_1 + \sqrt{\left[\frac{i_{QC} Q_{xc}}{3A} + \frac{\sqrt{(0.75i_i M_{ic})^2 + (0.75i_o M_{oc})^2}}{3Z} \right]^2} + \left[\frac{i_t M_{tc}}{3Z} \right]^2 \leq f_{cr}$$

where

f_{cr} = design stress in creep range at max(T1 through T10); f_{cr} is input into material properties.

Stresses due to a single non-repeated Support Movement (settlement)

The stress (σ_6) due to a single non-repeated support movement (settlement) is calculated from equation (12.3.6-2)

$$\sigma_6 = \sqrt{\left[\frac{i_{QD} Q_{xD}}{A} + \frac{\sqrt{(i_i M_{iD})^2 + (i_o M_{oD})^2}}{Z} \right]^2} + \left[\frac{i_t M_{tD}}{Z} \right]^2 \leq f_D$$

where

M_{iD} = in-plane moment due to non-repeated anchor/restraint movement

M_{oD} = out-of-plane moment due to non-repeated anchor/restraint movement

M_{tD} = torsional moment due to non-repeated anchor/restraint movement

i_{QD} = stress intensification factor for axial forces due to non-repeated anchor/restraint movement = 1.0

Q_{xD} = axial force due to non-repeated anchor/restraint movement

A and Z are the same as defined under Expansion Stress given above

$$f_D = \text{allowable stress} = \min(2R_{p0.2}; R_m)$$

Since only f and R_m are input into CAEPIPE, the above allowable stress criterion can be rewritten as follows.

$$f_D = 3f, \text{ if } [f < (R_m/2.4)]; \text{ otherwise}$$

$$f_D = R_m, \text{ if } [f = (R_m/2.4)]$$

where

f = allowable stress @ Reference Temperature (T_{ref}) entered in CAEPIPE.

Stresses on Buried Piping as per EN 13480-6 (2017)

The axial stress (S_L) due to combined pressure and temperature change effects is calculated from equation 1 of Clause 5.2.4 of EN 13480-6 (2017).

$$S_L = \eta S_p - E\alpha(\Delta_T) \leq 0.9S_y$$

where

S_p = circumferential stress due to maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

η = Poisson's ratio

Δ_T = maximum temperature range

S_y = Yield Strength = 1.5 x f

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

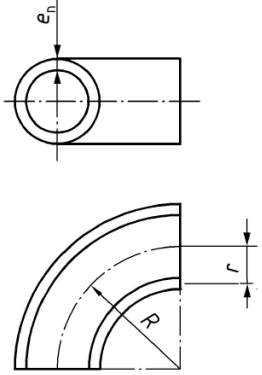
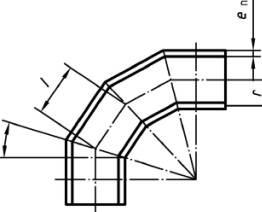
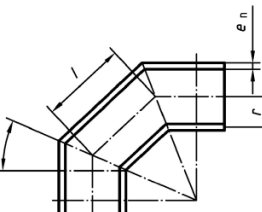
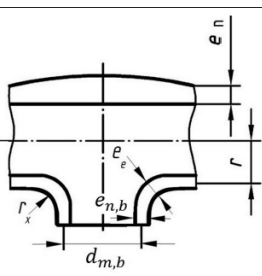
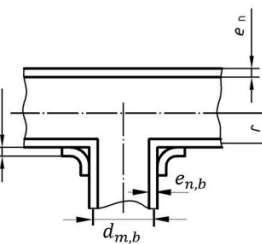
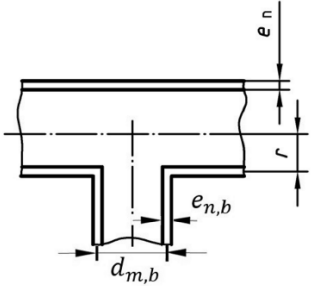
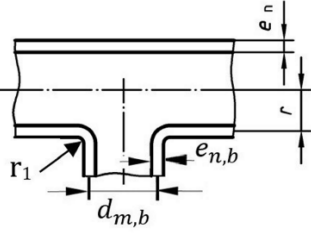
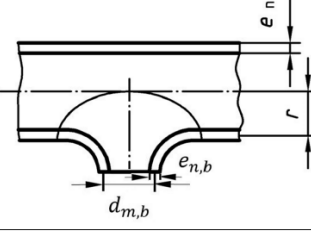
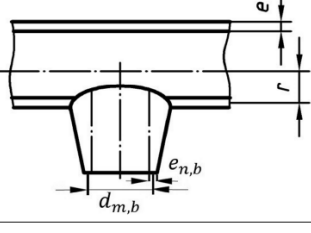
N°	Component designation	Sketch	Flexibility characteristic h	Stress intensification factor	
				Out-of-plane i_o	In-plane I_i
1	Welding elbow or pipe bend		$\frac{e_n R}{r^2}$	$\frac{0,75}{h^{2/3}}$ a b c j	$\frac{0,9}{h^{2/3}}$ a b c j
2	Closely spaced mitre bend $l < r(1 + \tan\theta)$ ($l = 2 R \tan\theta$)		$\frac{\cot\theta e_n l}{2 r^2}$	$\frac{0,9}{h^{2/3}}$ a b c j	$\frac{0,9}{h^{2/3}}$ a b c j
3	Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$		$\frac{e_n}{r} \left(\frac{1 + \cot\theta}{2} \right)$	$\frac{0,9}{h^{2/3}}$ a b c j	$\frac{0,9}{h^{2/3}}$ a b c j
4	Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes		$\frac{4,4e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a e f g i k	$0,75 i_o + 0,25$ a e f g i k
5	Reinforced fabricated tee with pad or saddle		$\frac{(e_n + 0,5e_r)^{5/2}}{r(e_n^{3/2})}$	$\frac{0,9}{h^{2/3}}$ a d e i k	$0,75 i_o + 0,25$ a d e i k

Table H.3 (continued)

N°	Component designation	Sketch	Flexibility characteristic h	Stress intensification factor	
				Out-of-plane I_o	In-plane i_i
6	Unreinforced fabricated tee		$\frac{e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a d e i k	$0,75 i_o + 0,25$ a d e i k
7	Extruded welding tee		$\left(1 + \frac{r_1}{r}\right) \frac{e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a e i k	$0,75 i_o + 0,25$ a e i k
8	Welded in contour insert		$\frac{4,4e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a e f g i k	$0,75 i_o + 0,25$ a e f g i k
9	Branch welded on fitting (integrally reinforced)		$\frac{3,3e_n}{r}$	$\frac{0,9}{h^{2/3}}$ a d f h k	$\frac{0,9}{h^{2/3}}$ a d f h k

(to be continued)

Table H.3 (concluded)

a	The factors i_o and i_i apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.
b	If these components are fitted with: <ul style="list-style-type: none"> - flange at one extremity, i_o and i_i are multiplied by $h^{1/6}$; - flange at each of the extremities, i_o and i_i are multiplied by $h^{1/3}$.
c	If the pressure is likely to correct ovality (large diameter, small thickness), the factors i_o and i_i shall be divided by: $1 + 3,25 \left(\frac{p_o}{E_c} \right) \left(\frac{r}{e_n} \right)^{5/2} \left(\frac{R}{r} \right)^{2/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).
d	For a nozzle with a ratio of branch diameter to pipe diameter exceeding 0,5, the out-of-plane stress intensification factor may be non-conservative. In addition a smooth transition by a concave shaped weld is proved to reduce the value of this factor. Consequently the selection of an appropriate value for this factor remains the responsibility of the designer.
e	The stress intensification factors regarding the branch connections are based on tests carried out with at least two diameters of straight pipe on either side of the branch axis. The case of closer branches requires a particular attention.
f	The forgings shall be suitable with regard to the operating conditions.
g	When the limitations with respect to radius ($r_x \geq r_{mb} / 4$) and thickness ($e_e \geq 1,5 e_n$) are not met and reliable data are not available, the flexibility characteristic is taken as $h = \frac{3,1 e_n}{r}$.
h	The designer shall check that the design against pressure is at least equivalent to that for a straight pipe.
i	The factors only apply to nozzles with convergent axes, and is not applicable for instance for configurations according to Figure 8.4.3-5.
j	The relevant wall thickness of bends should be taken at the crown (neutral axis). If unspecified, the average wall thickness of intrados and extrados may be used. For elbows, the wall thickness series from EN 10253 may be used. If the pressure is likely to reduce ovality (large diameter, small thickness), the factor k shall be divided by: $1 + 6 \left(\frac{p_o}{E_c} \right) \left(\frac{r}{e_n} \right)^{7/3} \left(\frac{R}{r} \right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).
k	The sectional modulus for the branch shall be calculated as: $Z = \min \left(i \frac{\pi((d_{m,b} + e_{n,b})^4 - (d_{m,b} - e_{n,b})^4)}{32(d_{m,b} + e_{n,b})}, \frac{\pi}{4} (d_{m,b} + e_{n,b})^2 e_n \right)$ or for corrosion $Z_c = \min \left(i \frac{\pi((d_{m,b} + e_{n,b})^4 - (d_{m,b} + e_{n,b} - 2e_{c,b})^4)}{32(d_{m,b} + e_{n,b})}, \frac{\pi}{4} (d_{m,b} + e_{n,b})^2 e_c \right)$

SIFs for Reducer and Welds are computed as per Table H.1 as given below.

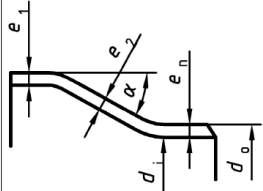
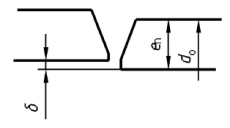
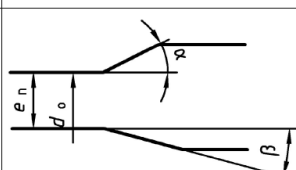
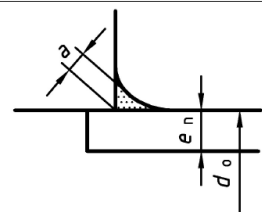
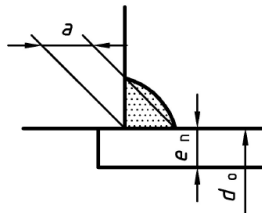
5	forged welded-in reducer		Shape conditions: $\alpha \leq 60^\circ$ $e_n \geq d_o/100$ $e_2 \geq e_1$	1	$0,5 + \frac{\alpha}{100} \left(\frac{d_o}{e_n} \right)^{1/2}$ max. 2,0 (α in deg.) d
9	butt weld		$e_n \geq 5 \text{ mm}$ and $\delta \leq 0,1 e_n$ $e_n < 5 \text{ mm}$ or $\delta > 0,1 e_n$	1 1	1,0 ^f 1,8 ^f

Table H.1 (concluded)

N°	Component designation	Sketch	Flexibility characteristic h	Flexibility factor k_B^a	Stress intensification factor i
10	wall thickness transitions		$\alpha \leq 30^\circ$ $\beta \leq 15^\circ$ (without circumferential weld at transitions $\delta = 0$)	1	$1,3 + 0,0036 \frac{d_o}{e_n} + 3,6 \frac{\delta}{e_n}$ max 1,9 ^f
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3 ^k
12				1	2,1 ^k

See Notes given at the end of this Section

SIFs for Flanges and Threaded Joints are computed as given below.

Sl. No.	Designation	Flexibility factor	Stress intensification factor i
1	Weld Neck Flange	1	1.0
2	Double Welded Slip on Flange	1	1.2
3	Single Welded Slip on Flange	1	1.3
4	Fillet Welded Flange	1	1.3
5	Socket Welded Flange	1	1.3
6	Lap Joint Flange	1	1.6
7	Threaded Flange	1	2.3
8	Threaded Joint	1	2.3

Note:

In-plane and out-of-plane SIF values are the same for Reducers, Welds, Flanges and Threaded Joints (computed as per Table H.1 as well as the Table provided above).

CAEPIPE internally incorporates the SIF values and Flexibility factors as given by the above three (3) Tables for any stress model.

Allowable Pressure

The allowable pressure for straight pipes is calculated from equation 6.1-1 or 6.1-3 depending on the ratio between inner and outer diameter.

For $D_o/D_i \leq 1.7$

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

For $D_o/D_i > 1.7$

$$P = fz \frac{(1 - a^2)}{(1 + a^2)}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness \times (1 – mill tolerance %/100 – corrosion allowance)“c”

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

D_o = outer diameter

D_i = inner diameter

$a = 1 - \frac{2e}{D_o}$

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi} –

$$e_{equi} = \frac{e}{t_f}$$

where

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

R = radius on bend

For closely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1 and 6.3.4-2.

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

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

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

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

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)

$$\sigma_1 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} \leq f_f$$

where

P = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

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

$f_f = \min(f; f_{cr})$ = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

$f = \min(Rp0.2t/1.5 ; Rm/2.4)$

f_{cr} = design stress in creep range at max(T1 through T10)

$Rp0.2t$ = minimum 0.2% proof strength at max(T1 through T10)

Rm = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note: Starting Version 7.50 of CAEPIPE, the value of “ff” is no longer input in the material properties table. Instead, the value of “f” which is calculated as $\min(Rp0.2t/1.5; Rm/2.4)$ is input for each temperature.

If a stress model created using an earlier version of CAEPIPE is read into Version 7.50 of CAEPIPE, then in the 7.50 model file, the material properties should be updated appropriately.

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated from equation (12.3.3-1) as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently

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

where

M_B = resultant bending moment due to occasional load

$k=1.2$ if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE $k=1.2$; user can change this input in Layout window > Options > Analysis > Code > EN13480.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from equation (12.3.4-1)

$$\sigma_3 = \frac{iM_C}{Z} \leq f_a$$

where

M_C = resultant moment due to thermal expansion and alternating loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

$$f_a = U(1.25f_c + 0.25f_h) \frac{E_h}{E_c} \text{ as per Equation (12.1.3-1)}$$

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

E_C = modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

E_h = modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

f_c = $\min(R_m/3; f)$, where $f = \min(R_{p0.2t}/1.5; R_m/2.4)$ at room temperature (T_{ref}) as per Equation (12.1.3-2)

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration = $\min(f_c; f; f_{cr})$ as per Equation 12.1.3-3, with f_c determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration.

For example, for the thermal range (T_1 - T_2), with $T_1 = 300^\circ\text{C}$, $T_2 = 100^\circ\text{C}$ and $T_{ref} = 21^\circ\text{C}$, E_c is determined at $T_2 = 100^\circ\text{C}$ and E_h is determined at $T_1 = 300^\circ\text{C}$

f_c as per Equation (12.1.3-2) listed above is determined at $T_{ref} = 21^\circ\text{C}$, the value of f_c used in calculating f_h is determined at $T_2 = 100^\circ\text{C}$ the value of f used in calculating f_h is determined at $T_1 = 300^\circ\text{C}$ and the value of f_{cr} is taken at $T_1 = 300^\circ\text{C}$ (if available)

If the above condition in equation (12.3.4-1) is not met, equation (12.3.4-2) may be used.

$$\sigma_4 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_3), due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-1) below.

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

where

f_{cr} = design stress in creep range at max(T1 through T10)

Stresses due to single non-repeated Support Movement (settlement)

The stress (σ_6) due to a single non-repeated support movement (settlement) is calculated from equation (12.3.6-1)

$$\sigma_6 = \frac{iM_D}{3Z} \leq \sigma_{6a}$$

where

M_D = resultant moment from a single non-repeated anchor movement (settlement)

σ_{6a} = allowable stress = min($2R_{p0.2}$; R_m)

Since only f and R_m are input into CAEPIPE, the above allowable stress criterion can be rewritten as follows.

$\sigma_{6a} = 3f$, if [$f < (R_m/2.4)$]; otherwise

$\sigma_{6a} = R_m$, if [$f = (R_m/2.4)$]

where

f = allowable stress @ Reference Temperature (T_{ref}) entered in CAEPIPE.

Stresses on Buried Piping as per EN 13480-6 (2017)

The axial stress (S_L) due to combined pressure and temperature change effects is calculated from equation 1 of Clause 5.2.4 of EN 13480-6 (2017).

$$S_L = \eta S_p - E\alpha(\Delta_T) \leq 0.9S_y$$

where

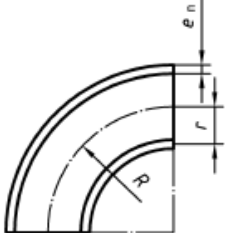
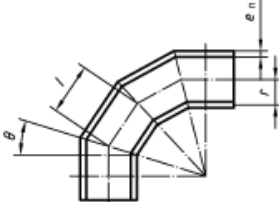
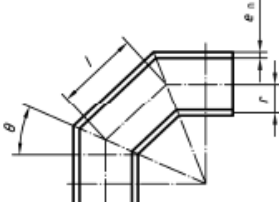
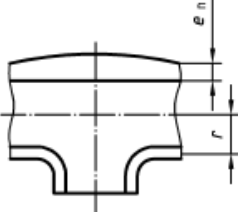
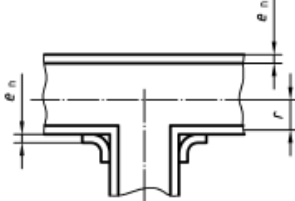
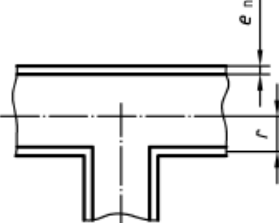
S_p = circumferential stress due to maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

η = Poisson's ratio

Δ_T = maximum temperature range

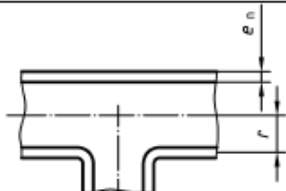
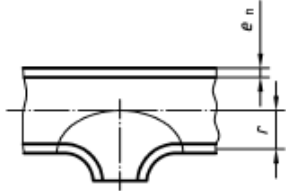
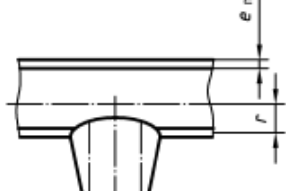
S_y = Yield Strength = 1.5 x f

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0,75}{h^{2/3}} \text{ a b c j}$	$\frac{0,9}{h^{2/3}} \text{ a b c j}$	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r(1 + \tan\theta)$ ($l = 2 R \tan\theta$)	$\frac{0,9}{h^{2/3}} \text{ a b c j}$	$\frac{0,9}{h^{2/3}} \text{ a b c j}$	$\frac{\cot\theta}{2} \frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$	$\frac{0,9}{h^{2/3}} \text{ a b c j}$	$\frac{0,9}{h^{2/3}} \text{ a b c j}$	$\frac{e_n}{r} \left(\frac{1 + \cot\theta}{2} \right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0,9}{h^{2/3}} \text{ a e f g i}$	$0,75 i_o + 0,25 \text{ a e f g i}$	$\frac{4,4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0,9}{h^{2/3}} \text{ a d e i}$	$0,75 i_o + 0,25 \text{ a d e i}$	$\frac{(e_n + 0,5 e_r)^{5/2}}{r (e_n^{3/2})}$	
Unreinforced fabricated tee	$\frac{0,9}{h^{2/3}} \text{ a d e i}$	$0,75 i_o + 0,25 \text{ a d e i}$	$\frac{e_n}{r}$	

(to be continued)

Table H.3 (continued)

Component description	Out-of plane i_0	In-plane \bar{h}	Flexibility characteristic	Sketch
Extruded welding tee	$\frac{0,9}{h^{2/3}} a e_i$	$0,75i_0 + 0,25$ $a e_i$	$\left(1 + \frac{r_1}{r}\right) \frac{e_n}{r}$	
Welded in contour insert	$\frac{0,9}{h^{2/3}} a e f g i$	$0,75i_0 + 0,25$ $a e f g i$	$\frac{4,4e_n}{r}$	
Branch welded on fitting (integrally reinforced)	$\frac{0,9}{h^{2/3}} a d f h$	$0,75i_0 + 0,25$ $a d f h$	$\frac{3,3e_n}{r}$	

SIFs for Reducer and Welds are computed as per Table H.1 as given below.

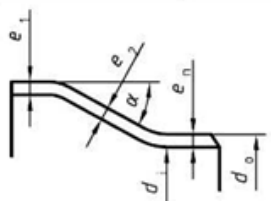
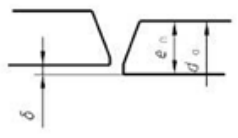
N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B^a	Stress intensification factor i	Section modulus Z
5	forged welded-in reducer		Shape conditions : $\alpha \leq 60^\circ$ $e_n \geq d_o/100$ $e_2 \geq e_1$	1	$0,5 + \frac{\alpha}{100} \left(\frac{d_o}{e_n}\right)^{1/2}$ max. 2,0 (α in deg.) ^d	
9	butt weld		$e_n \leq 5\text{mm}$ and $\delta \leq 0,1e_n^f$	1	1,0 ^f	
			$e_n < 5\text{mm}$ and $\delta > 0,1e_n^f$	1	1,8 ^f	

Table H.1 (concluded)

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B^a	Stress intensification factor i	Section modulus Z
10	wall thickness transitions		$\alpha \leq 30^\circ$ $\beta \leq 15^\circ$ (without circumferential weld at transitions $\delta = 0$)	1	$1,3 + 0,0036 \frac{d_o}{e_n} + 3,6 \frac{\delta}{e_x}$ $\max 1,9^f$	$\frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o}$
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3	smaller value of $\frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o}$ and
12				1	2,1	$\frac{\pi}{4} d_o^2 a$

SIFs for Flanges and Threaded Joints are computed as given below.

Sl. No.	Designation	Flexibility factor	Stress intensification factor i
1	Weld Neck Flange	1	1.0
2	Double Welded Slip on Flange	1	1.2
3	Single Welded Slip on Flange	1	1.3
4	Fillet Welded Flange	1	1.3
5	Socket Welded Flange	1	1.3
6	Lap Joint Flange	1	1.6
7	Threaded Flange	1	2.3
8	Threaded Joint	1	2.3

Note:

In-plane and out-of-plane SIF values are the same for Reducers, Welds, Flanges and Threaded Joints (computed as per Table H.1 as well as the Table provided above).

CAEPIPE internally incorporates the SIF values and Flexibility factors as given by the above three (3) Tables in any stress model.

Allowable Pressure

The allowable pressure for straight pipes is calculated from equation 6.1-1 or 6.1-3 depending on the ratio between inner and outer diameter.

For $D_o/D_i \leq 1.7$

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

For $D_o/D_i > 1.7$

$$P = fz \frac{(1 - a^2)}{(1 + a^2)}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness \times (1 – mill tolerance %/100 – corrosion allowance)“c”

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

D_o = outer diameter

D_i = inner diameter

$a = 1 - \frac{2e}{D_o}$

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi} –

$$e_{equi} = \frac{e}{t_f}$$

where

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

R = radius on bend

For closely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1 and 6.3.4-2.

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

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

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

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

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)

$$\sigma_1 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} \leq f_f$$

where

P = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

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

f_f = min(f ; f_{cr}) = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

f = min($R_{p0.2t}/1.5$; $R_m/2.4$)

f_{cr} = design stress in creep range at max(T1 through T10)

$R_{p0.2t}$ = minimum 0.2% proof strength at max(T1 through T10)

R_m = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note: Starting Version 7.50 of CAEPIPE, the value of “ff” is no longer input in the material properties table. Instead, the value of “f” which is calculated as min($R_{p0.2t}/1.5$; $R_m/2.4$) is input for each temperature.

If a stress model created using an earlier version of CAEPIPE is read into Version 7.50 of CAEPIPE, then in the 7.50 model file, the material properties should be updated appropriately.

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated from equation (12.3.3-1) as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently

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

where

M_B = resultant bending moment due to occasional load

$k=1.2$ if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE $k=1.2$; user can change this input in Layout window > Options > Analysis > Code > EN13480.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from equation (12.3.4-1)

$$\sigma_3 = \frac{iM_C}{Z} \leq f_a$$

where

M_C = resultant moment due to thermal expansion and alternating loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

$$f_a = U(1.25f_c + 0.25f_h) \frac{E_h}{E_c} \text{ as per Equation (12.1.3-1)}$$

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

E_C = modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

E_h = modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

f_c = $\min(R_m/3; f)$, where $f = \min(R_{p0.2t}/1.5; R_m/2.4)$ at room temperature (T_{ref}) as per Equation (12.1.3-2)

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration = $\min(f_c; f; f_{cr})$ as per Equation 12.1.3-3, with f_c determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration.

For example, for the thermal range (T_1-T_2), with $T_1 = 300^\circ\text{C}$, $T_2 = 100^\circ\text{C}$ and $T_{ref} = 21^\circ\text{C}$, E_c is determined at $T_2 = 100^\circ\text{C}$ and E_h is determined at $T_1 = 300^\circ\text{C}$

f_c as per Equation (12.1.3-2) listed above is determined at $T_{ref} = 21^\circ\text{C}$, the value of f_c used in calculating f_h is determined at $T_2 = 100^\circ\text{C}$ the value of f used in calculating f_h is determined at $T_1 = 300^\circ\text{C}$ and the value of f_{cr} is taken at $T_1 = 300^\circ\text{C}$ (if available)

If the above condition in equation (12.3.4-1) is not met, equation (12.3.4-2) may be used.

$$\sigma_4 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_3), due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-1) below.

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

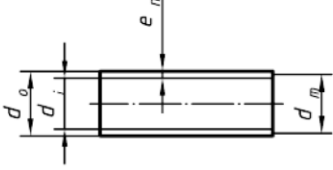
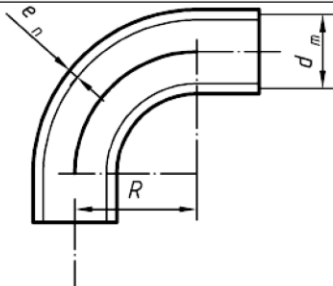
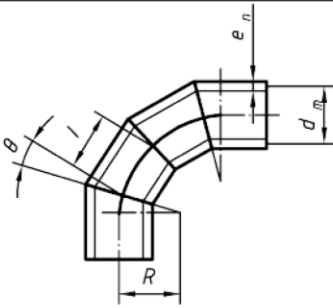
where

f_{cr} = design stress in creep range at max(T1 through T10)

Stresses due to single non-repeated Support Movement (settlement)

Settlement evaluation as per Equation (12.3.6-1) of EN 13480-3 (2012) is not yet implemented in CAEPIPE.

Table H.1 — Flexibility characteristics, flexibility and stress intensification factors and section moduli for general cases

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B^a	Stress intensification factor i	Section modulus Z
1	straight pipe		1	1	1	
2	plain bend		$\frac{4Re_n}{d_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}^{b,c}$	$\frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o}$
3	Closely spaced mitre bend $l < r(1 + \tan \theta)$ $(l = 2R \tan \theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{l \cot \theta}{2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}^{b,c}$	

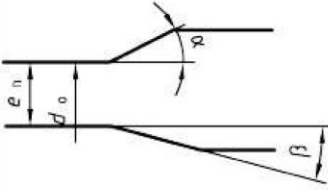
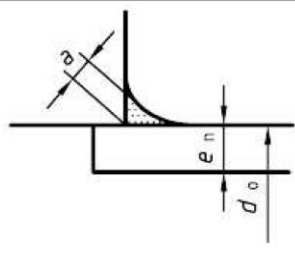
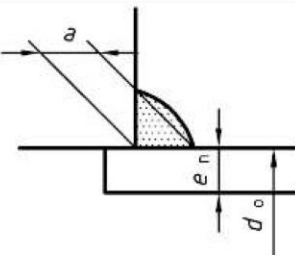
(to be continued)

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 $R = \frac{d_m(1 + \cot\theta)}{4}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}^b$	
5	forged welded-in reducer		Shape conditions : $\alpha \leq 60^\circ$ $e_n \geq d_o/100$ $e_2 \geq e_1$	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	$\frac{0,9}{h^{2/3}}^{be}$	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	$\frac{0,9}{h^{2/3}}^{be}$	Nozzle $\frac{\pi}{4} d_{n,b}^2 e_x$
8	forged welded-in tee with e_n and $e_{n,b}$ as connecting wall thickness		$\frac{8,8e_n}{d_m}$	1	$\frac{0,9}{h^{2/3}}^{bg}$	with e_x as smaller value of $e_{x1} = e_n$ and $e_{x2} = i e_{n,b}$ resp.
9	butt weld		$e_n \leq 5\text{mm}$ and $\delta \leq 0,1e_n^f$ $e_n < 5\text{mm}$ and $\delta > 0,1e_n^f$	1 1	1,0 ^f 1,8 ^f	

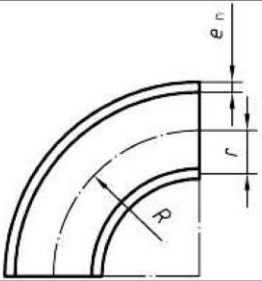
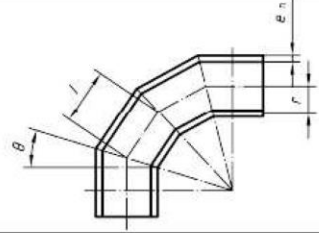
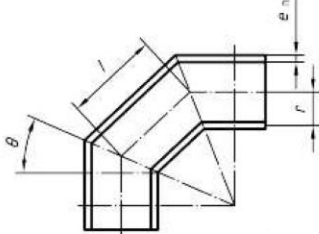
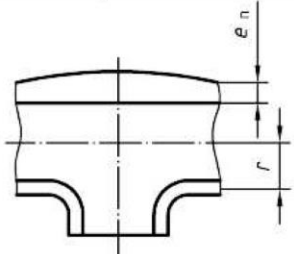
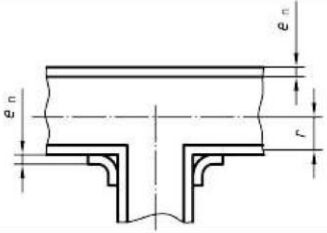
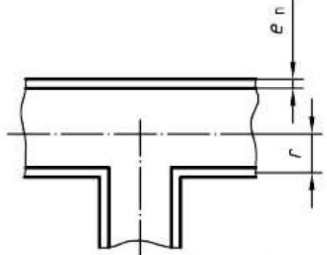
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Table H.1 (concluded)

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B^a	Stress intensification factor i	Section modulus Z
10	wall thickness transitions		$\alpha \leq 30^\circ$ $\beta \leq 15^\circ$ (without circumferential weld at transitions $\delta = 0$)	1	$1,3 + 0,0036 \frac{d_o}{e_n} + 3,6 \frac{\delta}{e_n}$ max 1,9 ^f	$\frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o}$
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3	smaller value of $\frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o}$ and
12				1	2,1	$\frac{\pi}{4} d_o^2 a$

- ^a The flexibility factor k_B applies to bending in all planes. The factor related to torsion is equal to 1 in all cases.
- ^b The factors k_B and i apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.
- ^c If these components are fitted with :
- flange at one extremity, k_B and i are multiplied by $h^{1/6}$;
 - flange at each of the extremities, k_B and i are multiplied by $h^{1/3}$.
- ^d The wall thickness of the reducer is not less than e_1 except in the vicinity of the small end where however the thickness is not less than e_n .
- ^e Other values may be used subject to justification.
- ^f The factor applies if the fabrication tolerances are met. Otherwise the determination of the factors is the responsibility of the designer.
- ^g The factors only apply to nozzles with convergent axes.

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0,75}{h^{2/3}}_{abc}$	$\frac{0,9}{h^{2/3}}_{abc}$	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r(1 + \tan\theta)$ ($l = 2R \tan\theta$)	$\frac{0,9}{h^{2/3}}_{abc}$	$\frac{0,9}{h^{2/3}}_{abc}$	$\frac{\cot\theta}{2} \frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$	$\frac{0,9}{h^{2/3}}_{abc}$	$\frac{0,9}{h^{2/3}}_{abc}$	$\frac{e_n}{r} \left(\frac{1 + \cot\theta}{2} \right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0,9}{h^{2/3}}_{aefgi}$	$0,75i_o + 0,25_{aefgi}$	$\frac{4,4e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0,9}{h^{2/3}}_{adei}$	$0,75i_o + 0,25_{adei}$	$\frac{(e_n + 0,5e_r)^{5/2}}{r(e_n^{3/2})}$	
Unreinforced fabricated tee	$\frac{0,9}{h^{2/3}}_{adei}$	$0,75i_o + 0,25_{adei}$	$\frac{e_n}{r}$	

(to be continued)

Table H.3 (continued)

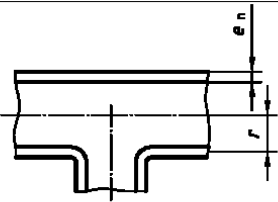
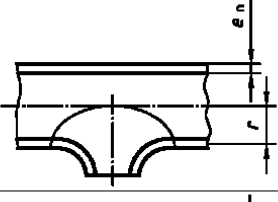
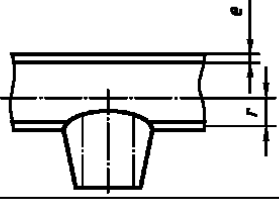
Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Extruded welding tee	$\frac{0,9}{h^{2/3}}_{aei}$	$0,75i_o + 0,25_{aei}$	$\left(1 + \frac{r_1}{r}\right) \frac{e_n}{r}$	
Welded in contour insert	$\frac{0,9}{h^{2/3}}_{aefgi}$	$0,75i_o + 0,25_{aefgi}$	$\frac{4,4e_n}{r}$	
Branch welded on fitting (integrally reinforced)	$\frac{0,9}{h^{2/3}}_{adfh}$	$0,75i_o + 0,25_{adfh}$	$\frac{3,3e_n}{r}$	

Table H.3 (concluded)

<p>a The factors i_0 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.</p> <p>b If these components are fitted with :</p> <ul style="list-style-type: none"> - flange at one extremity, i_0 and i_i are multiplied by $h^{1/6}$; - flange at each of the extremities, i_0 and i_i are multiplied by $h^{1/3}$. <p>c If the pressure is likely to correct ovality (large diameter, small thickness), the factors i_0 and i_i shall be divided by:</p> $1 + 3,25 \left(\frac{p_o}{E_c} \right) \left(\frac{r}{e_n} \right)^{5/2} \left(\frac{R}{r} \right)^{2/3}$ <p>where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).</p> <p>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.</p> <p>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.</p> <p>f The forgings shall be suitable with regard to the operating conditions.</p> <p>g When the limitations with respect to radius and thickness are not met and reliable data are not available, the flexibility characteristic is taken as $\frac{e_n}{r}$.</p> <p>h The designer shall check that the design against pressure is at least equivalent to that for a straight pipe.</p> <p>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.</p> <p>j If the pressure is likely to correct ovality (large diameter, small thickness), the factor k shall be divided by:</p> $1 + 6 \left(\frac{p_o}{E_c} \right) \left(\frac{r}{e_n} \right)^{7/3} \left(\frac{R}{r} \right)^{1/3}$ <p>where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).</p>
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Norwegian (1983)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 6.3.

$$p = \frac{2fz_L T_{eff}}{Dm - T_{eff}}$$

where

p = allowable pressure

f = allowable stress

z_L = joint efficiency of longitudinal weld (input as material property)

T_{eff} = nominal pipe thickness \times (1 – mill tolerance/100) – corrosion allowance

D = outside diameter

d = inside diameter

m = pressure coefficient

= 1.0 for $D/d < 1.6$

= $0.25(D/d) + 0.6$ for $1.6 \leq D/d \leq 2.0$

Sustained Stress

Stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 9.32.

$$S_L = \frac{pD}{4T_{eff}z_C} + \frac{0.75k_1 M_A}{W} \leq f_2$$

where

p = maximum pressure

z_C = joint efficiency of circumferential weld (input as material property)

k_1 = stress intensification factor. The product $0.75k_1$ shall not be less than 1.0

M_A = resultant bending moment due to sustained loads

W = section modulus, for reduced outlets, effective section modulus

f_2 = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of the stress due to sustained loads (S_L) and the stress (S_O) due to occasional loads such as earthquake or wind from Equation 9.33. Wind and earthquake are not considered concurrently.

$$S_{LO} = \frac{pD}{4T_{eff}z_C} + \frac{0.75k_1(M_A + M_B)}{W} \leq 1.2f_2$$

where

M_B = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 9.34.

$$S_E = \frac{k_1 M_C}{W} \leq S_r$$

Alternatively, Equation 9.35 may be used.

$$S_L + S_E \leq f_2 + S_r$$

where

M_C = resultant bending moment due to thermal expansion.

$S_r = f_r(1.17R_1 + 0.17R_2)$

f_r = stress range reduction factor taken from Table 9.1.

R_1 = smaller of f_1 and $0.267R_m$

R_2 = smaller of f_2 and $0.367R_m$

f_1 = allowable stress at cold condition

f_2 = allowable stress at hot condition

R_m = tensile strength at room temperature

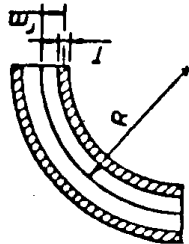
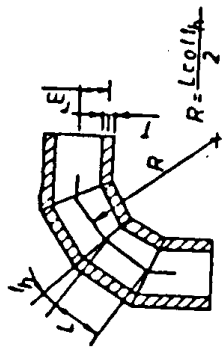
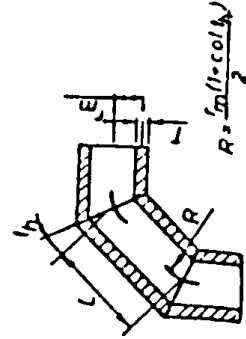
At moderate temperatures (up to 370° C) for carbon steel, low alloy steel and chromium steel (specified as CS material type) and up to 425° C for austenitic stainless steel (specified as AS material type), the limits $0.267R_m$ and $0.367R_m$ are disregarded and S_r is selected as smaller of S'_r and S''_r ,

where



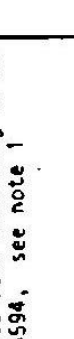
$S'_r = 1.17f_1 + 0.20f_2$

$S''_r = 290f_r - f_2$

Table 9.2 Stress and flexibility coefficients for pipe and pipe components (fittings)

Item	Type of pipe component	Characteristic value h	Flexibility coefficient k	Stress coefficient k_1	Figure
1	Pipe bend, see notes 1 and 2	$\frac{T \cdot R}{r_m^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h \sqrt{2/3}}$	
2	Pipe bend of welded segments with a segment length $L < r_m (1 + \tan t_h)$ see notes 1 and 2	$\frac{L \cdot T \cdot \cot t_h}{2 r_m^2}$	$\frac{1.52}{h \sqrt{6}}$	$\frac{0.9}{h \sqrt{2/3}}$	
3	Pipe bend of welded segments with a segment length $L \geq r_m (1 + \tan t_h)$ or inclined circumferential welds, see notes 1 and 3	$\frac{T (1 + \cot t_h)}{2 r_m}$	1	$\frac{0.9}{h \sqrt{2/3}}$	

Stress and flexibility coefficients for pipe and pipe components (fittings)

Item	Type of pipe component	Characteristic value h	Flexibility coefficient k	Stress coefficient k_1	Figure
4	Tee bend according to NS 5594, see note 1	$4,4 \frac{T_h}{r_h}$	1	$\frac{0,9}{h} \frac{273}{h}$	
5	Branch without local reinforcement of the main pipe, see note 1	$\frac{T_h}{r_h}$	1	$\frac{0,9}{h} \frac{273}{h}$	
6	Branch or main pipe with raised edges radiused at joint between main pipe and branch, see note 1	$\frac{T_e}{T_h} \frac{3}{2} \frac{T_e \cdot R_e}{r_h}$	1	$\frac{0,9}{h} \frac{273}{h}$	

Stress and flexibility coefficients for pipe and pipe components (fittings)

Item	Type of pipe component	Characteristic value h	Flexibility coefficient k	Stress coefficient k_1	Figure
7	Branch on locally thickened main pipe, see note 1	$\frac{T_h + T}{2} \cdot \frac{5/2}{r_h \cdot T_h}$	1	$\frac{0.9}{h} \frac{5/2}{3/2}$	
	$L < \frac{d_1}{2} + 1.8 \sqrt{0 \cdot T_f}$ $L \geq \frac{d_1}{2} + 1.8 \sqrt{0 \cdot T_f}$	$\frac{T_f^{5/2}}{r_h \cdot T_h} \cdot \frac{3/2}{3/2}$	1	$\frac{0.9}{h} \frac{5/2}{3/2}$	
8	Branch with plate reinforcement, see notes 1 and 4	$\frac{T_p^{5/2}}{(T_h + \frac{T_p^2}{2})} \cdot \frac{5/2}{r_h \cdot T_h}$	1	$\frac{0.9}{h} \frac{5/2}{3/2}$	

Symbols (items 4 - 8)

r = fillet radius (mm)

r_g = mean radius of branch = $(\frac{d - t_g}{2})(mm)$

R_e = effective radius = $r + r_h$ (mm)

r_h = mean radius of main pipe = $(\frac{D - T_h}{2})(mm)$

T_g = specified wall thickness of branch (mm)

T_h = specified wall thickness of main (mm)

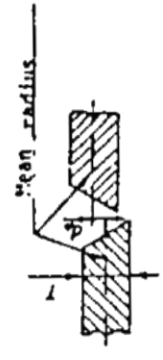
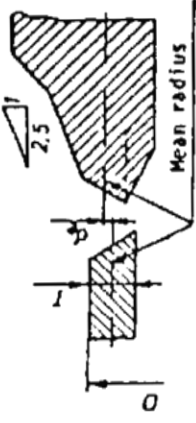
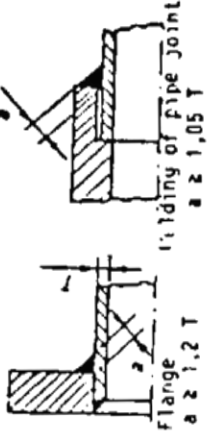
T_e = effective wall thickness = $1/2 (T_p + T_s)$ (mm)

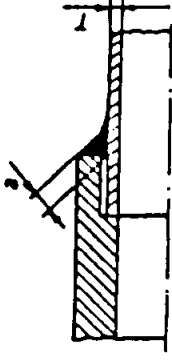
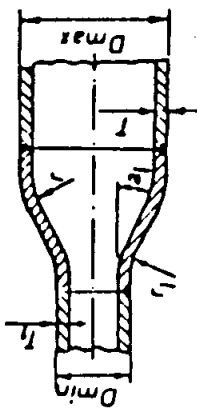
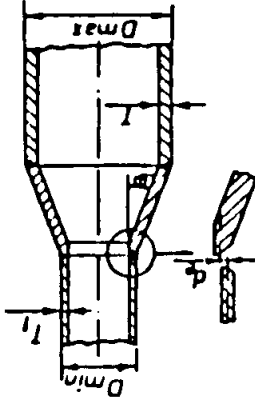
T_f = wall thickness at fillet radius (see item 5) (mm)

T_s = wall thickness of main pipe at a point located diametrically opposite of the branch (see item 5) (mm)

T_f = wall thickness of locally thickened main pipe (mm)

T_p = thickness of plate reinforcement (mm)

Item	Type of pipe component	Flexibility coefficient k	Stress coefficient k_1	Figure
9	Butt weld $T > 4,5$ mm and $d_e/T_{nom} \leq 0,1$ $T \leq 4,5$ mm or $d_e/T_{nom} > 0,1$	1	1,0 1,8 (If the weld is ground flush inside and out, the value 1,0 may be used)	
10	Butt weld between components of unequal thickness	1	$1,3 - 0,0036 \frac{D}{T} + 3,6 \frac{d_e}{T}$ but not over 1,9	
11	Fillet weld (spigot type)	1	2,1	

Item	Type of pipe component	Flexibility coefficient k	Stress coefficient k_1	Figure
12	Concave fillet weld (spigot type) with even transition to the pipe. (no undercut permitted)	1	1,3	 <p>$a \geq 1,05 T$</p>
13	Conical reducer with defined knuckles r and r_1	1	$0,5 + 0,01 \cdot a \sqrt{\frac{D_{\min}}{r_1}}$ but not over 2,0	
14	Conical reducer without knuckles, see notes 1 and 5 $T_1 > 4,5$ mm and $d_e/T_1 \leq 0,1$ $T_1 \leq 4,5$ mm or $d_e/T_1 > 0,1$		$0,9 + 0,17 \cdot a \sqrt{\frac{D_{\min}}{r_1}}$ $1,25 + 0,023 \cdot a \sqrt{\frac{D_{\min}}{r_1}}$ but not less than 1,8	

Norwegian (1983)

Item	Type of component	Flexibility coefficient k	Stress coefficient k ₁
15	Threaded joint or connection to threaded flange	1	2,3

Symbols (items 13 - 14)

D_{min} , D_{maks} , α_1 see clause 6.5

T_1 = specified wall thickness of the smaller pipe (mm)

T = specified wall thickness of the larger pipe (mm)

d_e = difference in mean radius at each side of the welding groove (mm)

Notes relating to illustrations shown in table 9.2

All dimensions are nominal

- The coefficients k and k₁ apply to bending in any plane and shall never be given a value less than 1. For plain bends and bends made of welded segments, the coefficients shall be applied to the effective length of the arc (shown by a heavy centreline in the illustrations). For branches and tees, they shall be applied up to the intersection point between the main pipe and the branch, see fig. 9.3.

k and k₁ as functions of h can be taken from fig. 9.4.

- If a flange is joined to one end or both, the coefficients k and k₁ shall be multiplied by the factor F as shown below.

$F = h^{1/6}$ if one end has a flange

$F = h^{1/3}$ if both ends have flanges

F as function of h can be taken from fig. 9.5.

- An inclined circumferential weld at the angle t_h degrees so that

$$t_h \leq 9 \cdot \sqrt{\frac{T}{r_m}}$$

may be considered as a perpendicular circumferential weld.

- When $T_p \geq 2.5 T_h$ is set to $h = 4.05 \cdot \frac{T_h}{r_h}$

- The formula for k₁ applies only when the following conditions are satisfied:

- the reducer is concentric
- the angle α_1 does not exceed 60°
- neither D_{max}/T nor D_{min}/T_1 exceeds 100.

Norwegian (1990)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 6.3.

$$p = \frac{2fz_L T_{eff}}{Dm - T_{eff}}$$

where

p = allowable pressure

f = allowable stress

z_L = joint efficiency of longitudinal weld (input as material property)

T_{eff} = nominal pipe thickness \times (1 – mill tolerance/100) – corrosion allowance

D = outside diameter

d = inside diameter

m = pressure coefficient

= 1.0 for $D/d < 1.6$

= $0.25(D/d) + 0.6$ for $1.6 \leq D/d \leq 2.0$

Sustained Stress

Stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 10.7.

$$S_L = \frac{pD}{4T_{eff}z_C} + \frac{0.75k_1 M_A}{W} \leq f_2$$

where

p = maximum pressure

z_C = joint efficiency of circumferential weld (input as material property)

k_1 = stress intensification factor. The product $0.75k_1$ shall not be less than 1.0

M_A = resultant bending moment due to sustained loads

W = section modulus, for reduced outlets, effective section modulus

f_2 = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of the stress due to sustained loads (S_L) and the stress (S_O) due to occasional loads such as earthquake or wind from Equation 10.8. Wind and earthquake are not considered concurrently.

$$S_{LO} = \frac{pD}{4T_{eff}z_C} + \frac{0.75k_1(M_A + M_B)}{W} \leq 1.2f_2$$

where

M_B = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 10.9.

$$S_E = \frac{k_1 M_C}{W} \leq S_r$$

Alternatively, Equation 10.10 may be used.

$$S_L + S_E \leq f_2 + S_r$$

where

M_C = resultant bending moment due to thermal expansion.

S_r = smaller of S_r' and S_r''

S_r' = $1.25f_1 + 0.25f_2$

S_r'' = $f_r R_s - f_2$

f_r = stress range reduction factor

f_1 = allowable stress at cold condition

f_2 = allowable stress at hot condition

R_s = permissible extent of stress for 7000 load cycles for different materials

R_s is determined by material type as follows:

Material	Type	R_s
Carbon and low alloy steel	CS	290
Austenitic stainless steel	AS	400
Copper alloys, annealed	CA	150
Copper alloys, cold worked	CC	100
Aluminum	AL	130
Titanium	TI	200

The stress range reduction factor f_r depends on the number of thermal cycles (NE). For moderate high temperatures ($\leq 370^\circ$ C for carbon, low alloy and chromium steel and $\leq 425^\circ$ C for austenitic stainless steel), f_r is calculated from

$$f_r = (7000/N_E)^{0.2} N_E > 100 \text{ (i.e., } f_r \leq 2.34)$$

At higher temperatures, S_r shall not be greater than $f_r(1.25R_1 + 0.25R_2)$ and f_r shall not be greater than 1.0.

where

R_1 = smaller of f_1 and $0.25R_m$

R_2 = smaller of f_2 and $0.25R_m$

R_m = tensile strength at room temperature

Norwegian (1990)

Tabell 10.1 Spennings- og fleksibilitets-
koeffisient for rør og rørdeler

Table 10.1 Stress and flexibility coefficients for
pipe and pipe components (fittings)

Betegnelser (detalj 4 - 8)

Symbols (item 4-8)

r	= hulkeilradius (mm)
r_g	= grenens middelradius = $(d - T_g)/2$ (mm)
r_h	= hovedrørets middelradius = $(d - T_h)/2$ (mm)
R_e	= $r + r_h$ (mm)
T_e	= $0,5 \times (T_r + T_s)$ (mm)
T_f	= veggtykkelse i lokalt tykkere hovedrør (mm)
T_g	= grenens nominelle veggtykkelse (mm)
T_h	= hovedrørets nominelle veggtykkelse (mm)
T_p	= tykkelsen av plateforsterkning (mm)
T_r	= veggtykkelse ved hulkeilradien (se detalj 6) (mm)
T_s	= veggtykkelse i hovedrørets side rett ovenfor grenen (se detalj 6) (mm)

r	= fillet radius (mm)
r_g	= mean radius of branch = $(d - T_g)/2$ (mm)
r_h	= mean radius of main pipe = $(d - T_h)/2$ (mm)
R_e	= $r + r_h$ (mm)
T_e	= $0,5 \times (T_r + T_s)$ (mm)
T_f	= wall thickness of locally thickened main pipe
T_g	= nominal wall thickness of branch (mm)
T_h	= nominal wall thickness of main pipe (mm)
T_p	= thickness of plate reinforcement (mm)
T_r	= wall thickness at fillet radius (see item 6) (mm)
T_s	= wall thickness of pipe at a point located diametrically opposite of the branch (see item 6) (mm)

Betegnelser (detalj 13 -14)

Symbols (item 13-14)

D_{\min} og D_{\max} , se punkt 7.5

D_{\min} and D_{\max} , see clause 7.5.

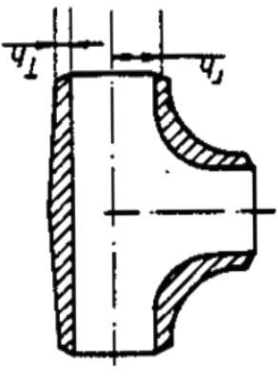
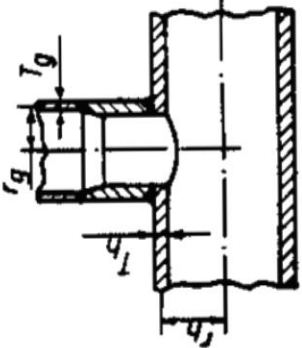
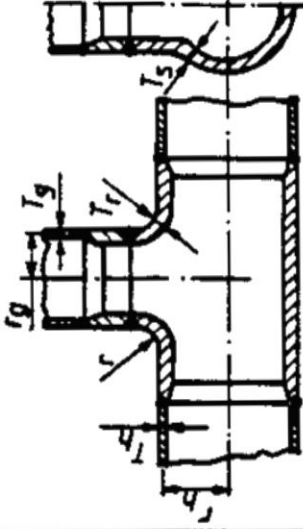
d_e	= forskjell i middelradius på hver side av sveisefuge (mm)
T	= nominell veggtykkelse i det største røret (mm)
T_1	= nominell veggtykkelse i det minste røret (mm)
α	= vinkel, i grader

d_e	= difference in mean radius on each side of the welding groove (mm)
T	= nominal wall thickness of the larger pipe (mm)
T_1	= nominal wall thickness of the smaller pipe (mm)
α	= angle, in degrees

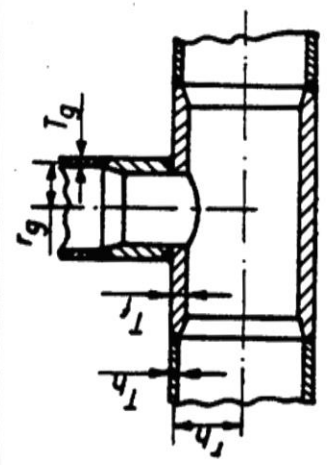
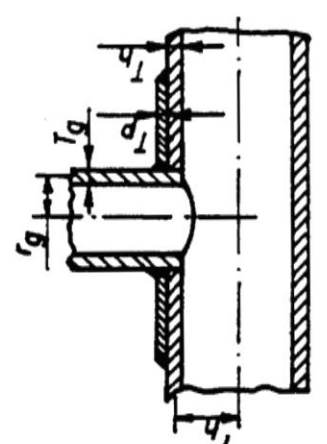
Tabell 10.1 Spennings- og fleksibilitetskoeffisient for rør og rørdeler
 Table 10.1 Stress and flexibility coefficient for pipe and pipe components (fittings)

Detailj Item	Type rørdel Type of pipe component	Karakteristisk verdi h Characteristic value h	Fleksibilitets- koeffisient k Flexibility coefficient k	Spennings- koeffisient k ₁ Stress coefficient	Figur Figure
1	Rørbend, se fotnote 1, 2 og 3 Pipe bend, see notes 1, 2 and 3	$\frac{T \cdot R}{r_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$	
2	Segmentsteikt rørbend med segmentlengde $L < r_m \cdot (1 + \tan \theta)$ se fotnote 1, 2 og 3 Pipe bend of welded segments with a segment length $L < r_m \cdot (1 + \tan \theta)$ see notes 1, 2 and 3	$\frac{L \cdot T \cdot \cot \theta}{2 \cdot r_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$	
3	Segmentsteikt rørbend med segmentlengde $L \geq r_m \cdot (1 + \tan \theta)$ eller skrå rundsveis, se fotnote 1 og 4 Pipe bend of welded segments with a segment length $L \geq r_m \cdot (1 + \tan \theta)$ or inclined circumferential welds, see notes 1 and 4	$\frac{T \cdot (1 + \cot \theta)}{2 \cdot r_m}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$	

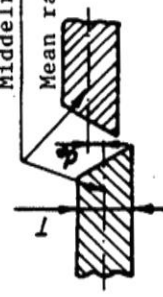
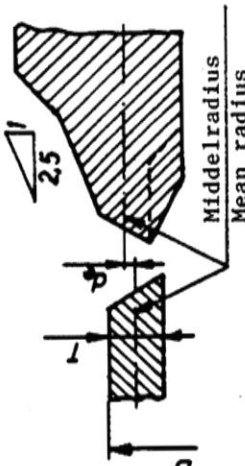
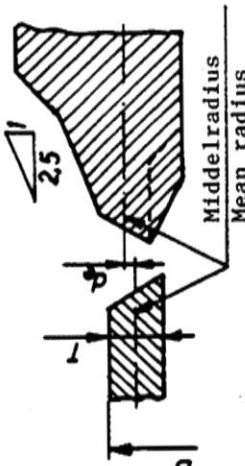
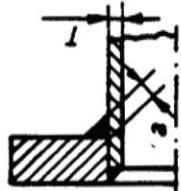
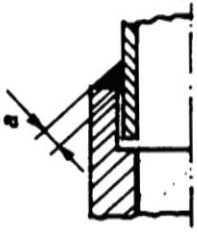
Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Karakteristisk verdi h Characteristic value h	Flexibilitets- koeffisient k Flexibility coefficient k	Spennings- koeffisient k ₁ Stress coefficient k ₁	Figur Figure
4	T-rør etter NS 5594, se fotnote 1 Tee bend according to NS 5594, see note 1	$4,4 \cdot \frac{T_h}{r_h}$	1	$\frac{0,9}{h^{2/3}}$	
5	Gren uten lokal forsterkning av hovedrøret, se fotnote 1 Branch without local reinforcement of the main pipe, see note 1	$\frac{T_h}{r_h}$	1	$\frac{0,9}{h^{2/3}}$	
6	Gren eller utkraging med radius i overgang mellom hovedrør og grenrør, se fotnote 1 Branch or main pipe with raised edges radius at joint between main pipe and branch, see note 1	$\left(\frac{T_e}{T_h}\right)^{3/2} \cdot \frac{T_e \cdot R_e}{r_h^2}$	1	$\frac{0,9}{h^{2/3}}$	

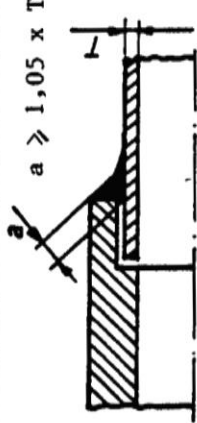
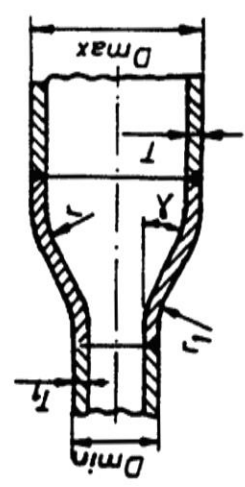
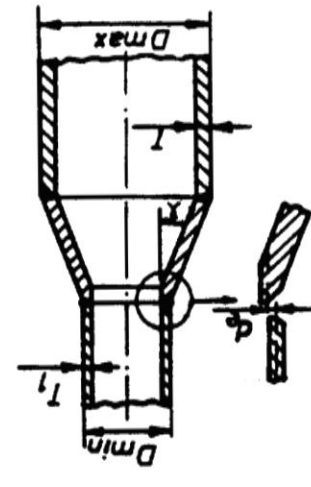
Tabell 10.1 fortsatt
Table 10.1 continued

Detailj Item	Type rørdel Type of pipe component	Karakteristisk verdi h Characteristic value h	Flexibilitets- koeffisient k Flexibility coefficient k	Spennings- koeffisient k ₁ Stress coefficient k ₁	Figur Figure
7	Gren med lokalt tykkere hoved- rør, se fotnote 1 Branch on locally thickened main pipe, see note 1 $L < \frac{d_1}{2} + 1,8 \sqrt{D \cdot T_f}$ $L \geq \frac{d_i}{2} + 1,8 \sqrt{D \cdot T_f}$	$\frac{(\frac{T_h}{2} + \frac{T_f}{2})^{5/2}}{r_h \cdot T_h^{3/2}}$ $\frac{T_f^{5/2}}{r_h \cdot T_h^{3/2}}$	1 1	$\frac{0,9}{h^{2/3}}$ $\frac{0,9}{h^{2/3}}$	
8	Gren med plateforsterkning, se fotnote 1 og 5 Branch with plate reinforcement, see notes 1 and 5	$\frac{(\frac{T_h}{2} + \frac{T_p}{2})^{5/2}}{r_h \cdot T_h^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	

Tabell 10.1 fortsatt
Table 10.1 continued

Delalj Item	Type rørdel Type of pipe component	Flleksibilitets-koeffisient k	Spenningskoeffisient k_1 Stress coefficient k_1	Figur Figure
9	Buttsveis/Butt weld $T > 4,5$ mm og/and $d_e/T \leq 0,1$ $T \leq 4,5$ mm eller/or $d_e/T > 0,1$	1 1	1,0 1,8 (Slipes sveisen jevn inn-vendig og utvendig kan verdien 1,0 brukes) (If the weld is ground flush inside and out, the value 1,0 may be used)	 
10	Buttsveis ved ulik godstykkelse etter avsnitt 11.3.6 Butt weld between components of unequal thickness according to clause 11.3.6	1	$1,3 - 0,0036 \cdot \frac{D}{T} + 3,6 \cdot \frac{d_e}{T}$ men maks/but max. 1,9	
11	Kilsvéis (Innstikksveis) Fillet weld (spigot type)	1	2,1	  <p>Flens/Flange $a \geq 1,2 \times T$</p> <p>Fugesveis/ Welding of pipe joint $a \geq 1,05 \times T$</p>

Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type of pipe component	Flexibilitets-koeffisient k	Spenningskoeffisient k_1 Stress coefficient k_1	Figur Figure
12	Konkav kilsveis (innstikkveis) med jevn overgang til røret (smelte "diken" ikke tillatt) Concave fillet weld (spigot type) with even transition to the pipe. (no undercut permitted)	1	1,3	
13	Konisk rørovergang med definerte hulkeiler r og r_1 , se fotnote 1 og 4 Conical reducer with defined knuckles r and r_1 , see note 1 and 4	1	$0,5 + 0,01 \cdot \alpha \cdot \sqrt{\frac{D_{\min}}{T_1}}$ men maks./but max. 2,0	
14	Konisk rørovergang uten hulkeiler, se fotnote 1 og 4 Conical reducer without knuckles, see notes 1 and 4 $T_1 > 4,5$ mm og/and $d_e/T_1 \leq 0,1$ $T_1 \leq 4,5$ mm eller/or $d_e/T_1 > 0,1$	1	$0,9 + 0,017 \cdot \alpha \cdot \sqrt{\frac{D_{\min}}{T_1}}$ $1,25 + 0,023 \cdot \alpha \cdot \sqrt{\frac{D_{\min}}{T_1}}$ men min./but min. 1,8	

Tabell 10.1 fortsatt
Table 10.1 continued

Detalj Item	Type rørdel Type of pipe component	Fleksibilitetskoeffisient k Flexibility coefficient k	Spenningskoeffisient k_1 Stress coefficient k_1
15	Gjengeforbindelse eller tilslutning til gjengeflens Threaded joint or connection to threaded flange	1	2,3

Fotnoter til figurene i tabell 10.1

Notes relating to illustrations shown in table 10.1

Alle dimensjoner er nominelle.

All dimensions are nominal.

- 1) Koeffisientene k og k_1 gjelder for bøyning i vilkårlig plan og skal aldri være mindre enn 1. For glatte og segmentsveiste rørbend skal koeffisientene gjelde over den effektive buelengde (markert med tykk senterlinje i figurene). For gren og T-rør skal de gjelde frem til skjæringspunktet mellom hovedrør og gren, se figur 10.5.

- 1) The coefficients k and k_1 apply to bending in any plane and shall never be given a value less than 1. For plain bends and bends made of welded segments, the coefficients shall be applied to the effective length of the arc (shown by a heavy centre-line in the illustrations). For branches and tees, they shall be applied up to the intersection point between the main pipe and the branch, see figure 10.5.

k og k_1 som funksjon av h kan tas fra figur 10.3. Tillatte verdier for h er angitt i figur 10.3.

k and k_1 as functions of h can be taken from figure 10.3. Permissible values for h is given in figure 10.3.

- 2) Hvis en eller begge ender har standard flenstilslutning skal koeffisientene k og k_1 multipliseres med faktoren F som vist nedenfor

- 2) If a standard flange is joined to one end or both, the coefficients k and k_1 shall be multiplied by the factor F as shown below.

$F = h^{1/6}$ om en ende har flens

$F = h^{1/6}$ if one end has a flange

$F = h^{1/3}$ om begge ender har flens

$F = h^{1/3}$ if both ends have flanges

F som funksjon av h kan tas fra figur 10.4. Tillatte verdier for h er angitt i figur 10.4.

F as function of h can be taken from figure 10.4. Permissible values for h is given in figure 10.4.

- 3) For albuer under innvendig trykk kan k endres på følgende måte:

- 3) For elbows under internal pressure k may be changed in the following way:

Under innvirkning av det innvendige overtrykk p minsker koeffisienten k til k_p .

The coefficient k is reduced to k_p due to the effect of the internal pressure, p :

$$k_p = \frac{k}{1 + \frac{R_t}{E} \cdot 6 \left(\frac{r_m}{T}\right)^{4/3} \cdot \left(\frac{R}{r_m}\right)^{1/3}}$$

der

where

E = elastisitetmodul (N/mm²)

E = modulus of elasticity (N/mm²)

p = innvendig overtrykk (MPa)

p = internal pressure (MPa)

<p>$r_m = (D - T)/2$, rørtverrsnittets middelradius (mm)</p> <p>$R_t = (p \times r_m)/T$, tangentiell spenning</p> <p>Minste verdi for k_p er 1.</p> <p>4) Skrårundsveis med vinkelen θ i grader slik at</p>	<p>$r_m = (D-T)/2$, mean radius of the pipe section (mm)</p> <p>$R_t = (p \times r_m)/T$, tangential stress (mm)</p> <p>The minimum value of k_p is 1.</p> <p>4) An inclined circumferential weld with the angle θ in degrees so that</p>
$\theta \leq 9 \cdot \sqrt{\frac{T}{r_m}}$	
<p>kan betraktes som rett roundsveis.</p> <p>5) Når $T_p \geq 2,5 \times T_h$ settes $h = 4,05 \times (T_h/r_h)$</p> <p>6) Formelen for k_1 gjelder bare under forutsetning av at følgende krav er oppfylt:</p> <ul style="list-style-type: none"> - overgangsstykket er konsentrisk - vinkelen $\alpha \leq 60^\circ$ - D_{maks}/T respektive D_{min}/T_1 ikke er større enn 100. 	<p>may be considered as a perpendicular cir- cumferential weld.</p> <p>5) When $T_p \geq 2,5 \times T_h$ is set $h = 4,05 \times (T_h/r_h)$</p> <p>6) The formula for k_1 applies only when the following conditions are satisfied:</p> <ul style="list-style-type: none"> - the reducer is concentric - the angle $\alpha \leq 60^\circ$ - neither D_{maks}/T nor D_{min}/T_1 exceeds 100

RCC-M (1985)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 2 of C 3641.1.

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

where

P = allowable pressure

S = allowable stress

E = joint factor (input as material property)

t_m = minimum required thickness, including mechanical and corrosion allowance
= $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

t = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

= 0.4 for $t < D/6$

= $d/(D + d)$ for $t \geq D/6$

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 6 of C 3652.

$$S_L = \frac{PD}{4t} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum pressure

D = outside diameter

t = nominal wall thickness

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

M_A = resultant bending moment due to sustained loads = $\sqrt{M_x^2 + M_y^2 + M_z^2}$

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

S_h = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained loads (S_L) and stress due to occasional loads (S_O), such as earthquake or wind from Equation 10 of C 3654. Wind and earthquake are not considered concurrently.

$$S_{LO} = S_L + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 7 of C 3653.2.

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

where

M_C = resultant moment due to thermal expansion

$S_A = f(1.25S_c + 0.25S_h)$

S_c = allowable stress at cold temperature

f = stress range reduction factor from Table C 3653.3

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation 8 of C 3653.2.

$$S_{TE} = S_L + S_E \leq S_h + S_A$$

FIGURE C 3680.1
 FLEXIBILITY AND STRESS INTENSIFICATION FACTORS ($D_o/t_n \leq 100$)

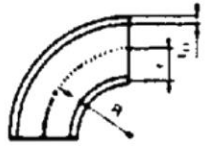
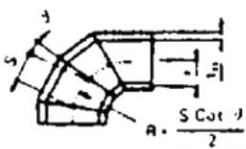
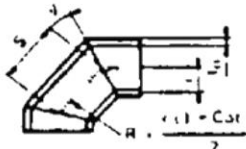
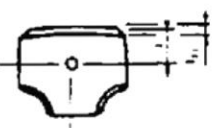
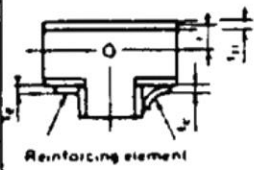
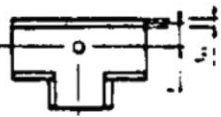
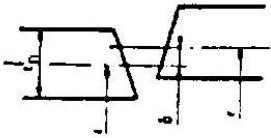
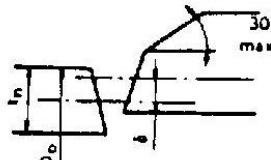
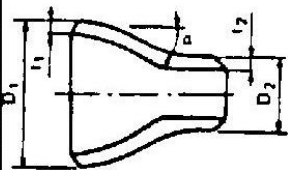
Description	Flexibility characteristic h	Flexibility factor k	Stress intensification factor i	Sketch
Welding elbow or pipe bend. (Notes (1), (2), (3)).	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2.3}}$	
Closely spaced miter bend. (Notes (1), (2), (3)) $s < r(1 + \tan \theta)$	$\frac{\pi t_n \cot \theta}{2r^2}$	$\frac{1.52}{h^{2.6}}$	$\frac{0.9}{h^{2.3}}$	
Widely spaced miter bend. (Notes (1), (2), (4)) $s \geq r(1 + \tan \theta)$	$\frac{t_n (1 + \cot \theta)}{2r}$	$\frac{1.52}{h^{2.6}}$	$\frac{0.9}{h^{2.3}}$	
Welding tee per ANSI B.16.9 (Notes (1), (2)).	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2.3}}$	
Reinforced fabricated tee (Notes (1), (2), (5)).	$\frac{(t_n + \frac{t_b}{2})^{3/2}}{\pi t_n^{3/2}}$	1	$\frac{0.9}{h^{2.3}}$	
Unreinforced fabricated tee (Notes (1), (2)).	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2.3}}$	

FIGURE C 3680.1
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS (cont'd)

Description	Flexibility factor K	Stress intensification factor i	Sketch
Branch connections [Note (6)]	1	- Analysis of run pipe: $Z = r (R_m)^2 T_r$ $i = 0,4 \left(\frac{R_m}{T_r} \right)^{1/2} \left(\frac{r'_m}{R_m} \right)$ with a minimum value of 1,5 - Analysis of branch pipe $Z = r (r'_m)^2 T'_b$ $i = 1,5 \left(\frac{R_m}{T_r} \right)^{1/2} \left(\frac{r'_m}{R_m} \right)^{1/2} \left(\frac{T'_b}{T_r} \right) \left(\frac{r'_m}{r_p} \right)$	Fig. C 3680.2
Butt welds [Note (1)] $t_n > 4,75 \text{ mm}$ and $\frac{\delta}{t_n} < 0,1$	1	1,0	
Butt weld [Note (1)] $t_n \leq 4,75 \text{ mm}$ or $\frac{\delta}{t_n} > 0,1$	1	for flush weld 1,0 for as-welded 1,8	
Fillet welded joint, socket welded flange or single welded slip-on flange	1	2,1	Figure C 3661.2 Sketches (C), (D), (E), (F) and (G)
Braze joint	1	2,1	Conformity to C 3671.4.b)
Full fillet weld	1	1,3	Figure C 3661.2 Sketch (H)
Tapered transition $\leq 30^\circ$ [ANSI B 16.25] [Note (1)]	1	1,8 max. or $1,3 + 0,0036 \frac{D_n}{t_n} + 3,6 \frac{\delta}{t_n}$	
Concentric reducers [ANSI B 16.9 or MSS SP 48] [Note (7)]	1	2,0 max. or $0,5 + 0,01 \left(\frac{D_2}{t_2} \right)^{1/2}$	
Threaded pipe joint or threaded flange	1	2,3	—
Corrugated straight pipe or corrugated or creased bend [Note (8)]	5	2,5	—

NOTES TO FIGURE C 3680.1:

- (1) The following nomenclature applies
- r = mean radius of pipe (matching pipe for tees and elbows)
 - t_n = nominal wall thickness of pipe (matching pipe for tees and elbows see note (9))
 - R = bend radius of elbow or pipe bend
 - θ = one-half angle between adjacent miter axes
 - s = miter spacing at centreline
 - t_e = reinforced thickness
 - δ = mismatch
 - D_o = outside diameter
- (2) The flexibility factors k and stress intensification factors i apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centrelines in the sketches) for curved and miter elbows and to the intersection point for tees.
- (3) Where flanges are attached to one or both ends the values of k and i shall be corrected by the factors given below
- one end flanged $c = h/\delta$
 - both ends flanged $c = r/\delta$
- (4) Also includes single miter joints
- (5) When $t_e > 1.5 t_n$ $h = 4.05 t_n/r$
- (6) The equation applies only if the following conditions are met
- a) The reinforcement area requirements of C 3643 are met
 - b) The axis of the branch pipe is normal to the surface of run pipe wall
 - c) For branch connections in a pipe the arc distance measured between the centres of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their inside radii along the circumference of the run pipe
 - d) The inside corner radius r_1 (figure C 3680.2) is between 10% and 50% of T_r
 - e) The outer radius r_2 is not less than the larger of $T_b/2$ ($T_b + y/2$) (fig. C 3680.2 sketch (c)) or $T_r/2$
 - f) The outer radius r_3 is not less than the larger of
 - (1) $0.002 \theta D_o$
 - (2) $2 (\sin \theta)^2$ times the offset for the configurations shown in fig. C 3680.2 sketches (a) and (b)
 - g) $R_m/T_r \leq 50$ and $t_m/R_m \leq 0.5$
- (7) The equations apply only if the following conditions are met
- a) Cone angle α does not exceed 60° and the reducer is concentric
 - b) The larger of D_1/t_1 and D_2/t_2 does not exceed 100
 - c) The wall thickness is not less than t_1 throughout the body of the reducer except in and immediately adjacent to the cylindrical portion on the small end where the thickness shall not be less than t
- (8) Factors shown apply to bending flexibility factor for tension equals 0.9
- (9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

Allowable Pressure

For straight pipes and bends, the allowable pressure is calculated using Eq. (C2.2.2-2) for straight pipes and Eq. (C2.3.2-1) for bends from paras. C2.2.2. and C2.3.2. respectively

$$P = \frac{2fze}{D - e}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness \times (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 = outside diameter

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}

$$e_{equi} = \frac{e}{t_f}$$

Where

$$t_f = \left[\frac{R/D - 0.25}{R/D - 0.50} \right]$$

For closely spaced miter bends, the allowable pressure is calculated from

$$P = \min \left[\left(\frac{2fze}{D_m} \cdot \frac{e}{e + 0.643 \tan \theta \sqrt{0.5D_m e}} \right), \left(\frac{2fze}{D_m} \cdot \frac{R - 0.5D_m}{R - 0.25D_m} \right) \right] \text{ with } \theta \leq 22.5$$

For widely spaced miter bends, the allowable pressure is calculated from

$$P = \min \left[\left(\frac{2fze}{D_m} \cdot \frac{e}{e + 0.643 \tan \theta \sqrt{0.5D_m e}} \right), \left(\frac{2fze}{D_m} \cdot \frac{R - 0.5D_m}{R - 0.25D_m} \right) \right] \text{ with } \theta \leq 22.5$$

$$P = \left(\frac{2fze}{D_m} \cdot \frac{e}{e + 1.25 \tan \theta \sqrt{0.5D_m e}} \right) \text{ with } \theta \leq 22.5$$

Where

D_m = mean diameter of pipe = $D - t_n$

R = effective bend radius of the miter

θ = miter half angle

t_n = nominal thickness

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated using Eq. (C10.3.2) from para. C10.3.2.

$$\sigma_1 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} \leq f_h$$

Where

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance “c”

i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0

M_A = resulting bending moment due to sustained loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

f_h = hot allowable stress

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently (see para. C10.3.3)

$$\sigma_2 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kf_h$$

where,

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

M_B = resultant bending moment due to occasional load

k = 1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE $k = 1.2$ is used for occasional loading.

e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance “c”

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from Eq. C10.3.4-1 from para. C10.3.4.

$$\sigma_3 = \frac{iM_C}{Z} \leq f_a$$

where,

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of thermal anchor movements

- Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
 $f_a = U(1.25f_c + 0.25f_h) \frac{E_h}{E_c}$ Eq. (C10.2.4.2-1) of para. C10.2.4.2.
 i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0
 U = cyclic stress range reduction factor from Table C10.2.4.3 and are mentioned below.

Number of cycle	Stress range reduction factor U
$f_a \leq 7000$	1.0
7001 to 140000	0.9
14001 to 220000	0.8
22001 to 0.7	0.7
45001 to 100000	0.6
100001 to 2000000	0.5

- f_c = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis
 f_h = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis
 E_c = elastic modulus at cold temperature
 E_h = elastic modulus at hot temperature

Sustained + Expansion Stress

The stress due to pressure, weight, other sustained loads and thermal expansion is calculated from Equation C10.3.4-2 of para. C10.3.4.

$$\sigma_4 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_H + f_a$$

where,

- P = maximum of CAEPIPE input pressures P1 through P10
 D_o = outside diameter
 e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance “c”
 M_A = resulting bending moment due to sustained loads
 M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of thermal anchor movements
 Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus
 i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0
 $f_a = U(1.25f_c + 0.25f_h) \frac{E_h}{E_c}$ Eq. (C10.2.4.2-1) of para. C10.2.4.2.
 f_c = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis
 f_h = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis
 E_c = elastic modulus at cold temperature

E_h = elastic modulus at hot temperature

f_H = allowable stress at Maximum of CAEPIPE input temperatures T1 through T10

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, (σ_5), due to sustained, thermal and alternating loadings shall satisfy the Eq. C10.3.4-3 of para. C10.3.4.

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

where,

P = maximum of CAEPIPE input pressures P1 through P10

D_o = outside diameter

e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance "c"

M_A = resulting bending moment due to sustained loads

M_C = range of resultant moments due to displacement cycle between two thermal states inclusive of thermal anchor movements

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

i = stress intensification factor from Table C10.2.6-1; the product of 0.75i shall not be less than 1.0

f_{cr} = allowable creep stress value

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte

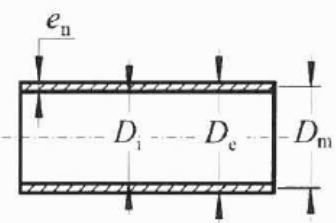
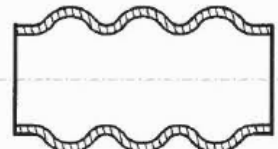
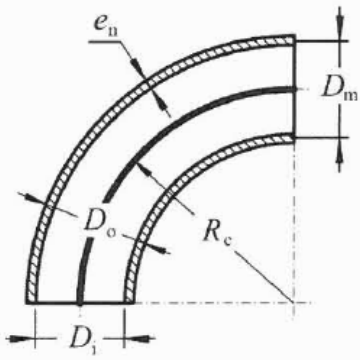
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_1 dans le plan	
<p>1. Tuyau droit soudé bout-à-bout</p> 		1	1	1	1	$\frac{\pi}{32} \frac{D_e^4 - D_i^4}{D_e}$
<p>2. Tuyau droit ondulé ou coude ondulé</p> 		5	2,5	2,5	2,5	
<p>3. Coude ou cintre soudé bout-à-bout</p>  <p>Note : Pour les intersections tubulure-coude voir § C5.5.4.</p>	$\frac{4 e_n R_c}{D_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$ Notes (2) & (3)	$\frac{0,75}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0,9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{\pi}{32} \frac{D_e^4 - D_i^4}{D_e}$

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

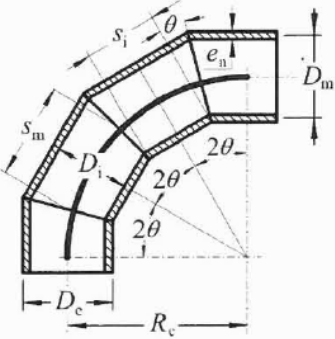
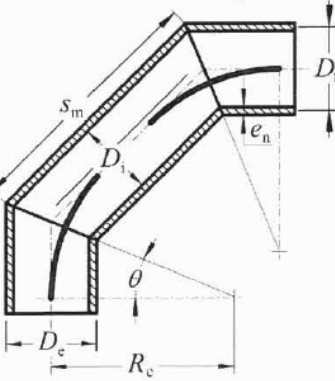
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_i dans le plan	
<p>4.1. Coude à sections rapprochées ou à sections multiples</p>  <p> $s_m \leq \frac{D_m}{2} (1 + \tan \theta)$ $R_c = \frac{s_m \cot \theta}{2}$ </p>	$\frac{4 R_c e_n}{D_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ $s_i \geq 6 e_n$ $\theta \leq 22,5^\circ$ Notes (2) & (3)	$\frac{0,9}{h^{2/3}}$ Notes (2),(3) & (4)	$\frac{0,9}{h^{2/3}}$ Notes (2),(3) & (4)	$\frac{\pi D_o^4 - D_i^4}{32 D_o}$
<p>4.2. Coude à sections espacées et coude à un onglet</p>  <p> $s_m > \frac{D_m}{2} (1 + \tan \theta)$ $R_c = \frac{D_m (1 + \cot \theta)}{4}$ </p>	$\frac{4 R_c e_n}{D_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ $\theta \leq 22,5^\circ$ Note (2)	$\frac{0,9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0,9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{\pi D_o^4 - D_i^4}{32 D_o}$

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

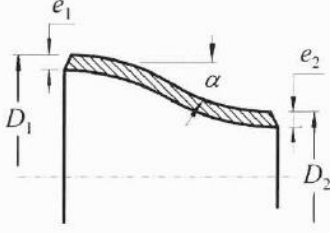
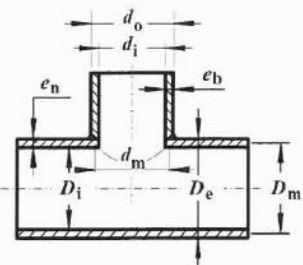
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_i dans le plan	
<p>5.1. Réduction forgée</p> 		1		$0,5 + \frac{\alpha}{100} \left(\frac{D_2}{e_2} \right)^{1/2}$ MAX = 2,0 (α en °) $\alpha \leq 60^\circ$ $D_1/e_1 \leq 100$ $D_2/e_2 \leq 100$ Note (5)		
<p>5.2. Réduction chaudronnée voir Figure C2.5</p>				Note (14)		
<p>6. Té reconstitué non renforcé avec tubulure posée ou pénétrante</p> 	$\frac{2 e_n}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ Notes (2), (12) & (16)	$\frac{0,9}{h^{2/3} (\sin \alpha)^{3/2}}$ $\alpha =$ angle d'inclinaison de la tubulure par rapport au collecteur $\frac{3 i_0}{4} + 0,25$ Notes (2), (6), (7) & (11)	Collecteur $\frac{\pi D_e^4 - D_i^4}{32 D_e}$ Dérivation $\frac{\pi}{4} d_m^2 e_x$ $e_x = \text{MIN}(e_f; i e_b)$	

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_i dans le plan	
<p>7. Té reconstitué avec tubulure posée ou pénétrante et renforcé par anneau ou selle de renfort</p> <p>avec anneau renfort avec selle de renfort</p>	<p>si $e_r \leq 1,5 e_n$</p> $\frac{2(e_n + 0,5 e_r)^{5/2}}{e_n^{3/2} D_m}$ <p>si $e_r > 1,5 e_n$</p> $8 \frac{e_r}{D_m}$	<p>1</p>	<p>$\frac{0,9}{h^{2/3}}$</p> <p>Notes (2), (12) & (16)</p>	<p>$\frac{0,9}{h^{2/3} (\sin \alpha)^{3/2}}$</p> <p>$\alpha =$ angle d'inclinaison de la tubulure par rapport au collecteur</p> <p>$\frac{3 i_0}{4} + 0,25$</p> <p>Notes (2), (6), (7) & (11)</p>	<p>Collecteur</p> $\frac{\pi D_e^4 - D_i^4}{32 D_e}$ <p>Dérivation</p> $\frac{\pi d_m^2 e_x}{4}$ <p>$e_x = \text{MIN}(e_r; i e_b)$</p>	
<p>8. Piquage avec pièces forgées</p> <p>Type manchon forgé Type weldolets® etc.</p>	$6,6 \frac{e_n}{D_m}$	<p>1</p> <p>Type manchon forgé</p> <p>1</p> <p>Type weldolets® etc.</p>	<p>$\frac{0,9}{h^{2/3}}$</p> <p>Notes (2), (6), (8) & (10)</p>	<p>2,1</p> <p>2,1</p> <p>$\frac{3 i_0}{4} + 0,25$</p>		

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

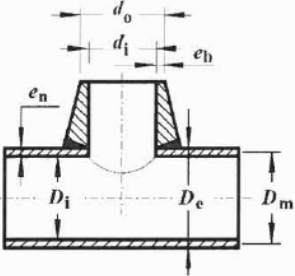
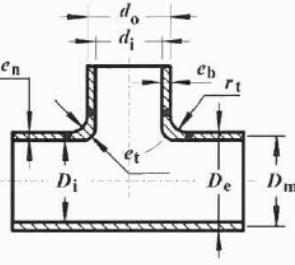
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte		Module d'inertie Z	
			i	i_0 hors du plan i_1 dans le plan		
<p>9. Piquage posé intégralement renforcé</p> 	$6,6 \frac{e_n}{D_m}$	1		$\frac{0,9}{h^{2/3}}$	$\frac{0,9}{h^{2/3}}$	Notes (2), (6), (8) & (10)
<p>10. Piquage avec selle de renfort insérée</p> 	$\frac{8,8 e_n}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ et Tableau C10.2.6-2 Note 16	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$	$r_t \geq d_o / 8$ $e_t \geq 1,5 e_n$ Notes (2), (7), (8), (9) & (11)

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

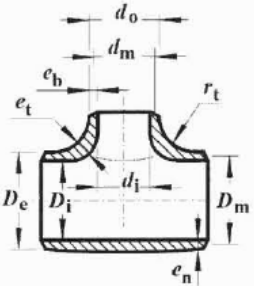
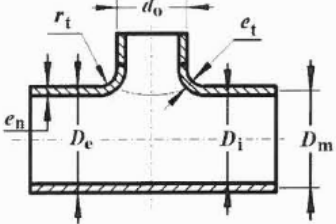
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_1 dans le plan	
<p>11. Té forgé</p> 	$\frac{8,8 e_n}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ Notes (2) & (12)	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$ $e_t \geq 1,5 e_n$	Collecteur $\frac{\pi D_e^4 - D_i^4}{32 D_e}$ Dérivation $\frac{\pi d_m^2 e_x}{4}$ $e_x = \text{MIN}(e_t; i e_b)$
<p>12. Té à souder extrudé</p> 	$\left(1 + \frac{2 r_t}{D_m}\right) \frac{2 e_n}{D_m}$	1	Note (13)	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$ $r_t \geq 0,05 d_0$ $e_t \leq 1,5 e_n$	Notes (2) & (7)

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

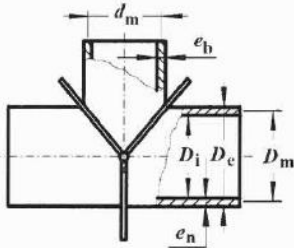
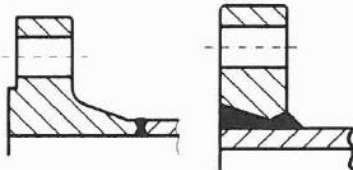
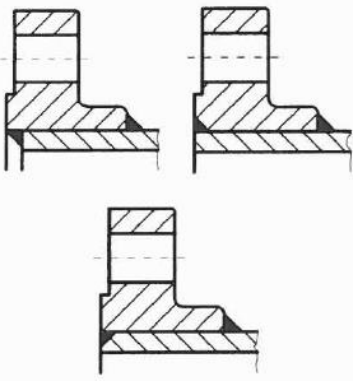
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_1 dans le plan	
<p>13. Triform</p> 	$\frac{2 e_n}{D_m}$	1	Note (13)	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$	<p>Collecteur $\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$</p> <p>Dérivation $\frac{\pi}{4} d_m^2 e_x$</p> <p>$e_x = \text{MIN}(e_r; i e_b)$</p>
<p>14.1. Bride à assembler bout-à-bout</p> 		1		1		
<p>14.2. Bride à emmancher et à souder (soudée des deux côtés)</p> 		1		1,2		

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

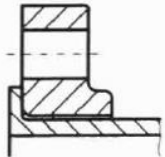
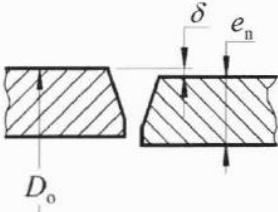
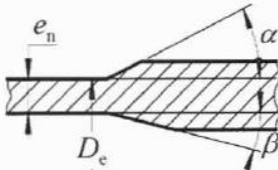
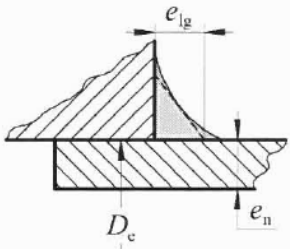
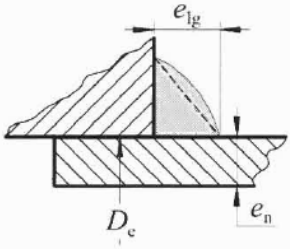
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie Z
			i	i_0 hors du plan	i_1 dans le plan	
14.3. Bride tournantes 		1	1,6			
14.4 Bride à visser Voir Figure C6.3.7-2		1	2,3			
15.1 Soudure bout-à-bout 			1 $e_n \geq 5 \text{ mm}$ et $\delta \leq 0,1 e_n$ Note (15)			$\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$
			1,8 $e_n < 5 \text{ mm}$ ou $\delta > 0,1 e_n$ Note (15)			
15.2. Transition d'épaisseur de paroi  $\alpha \leq 30^\circ$ $\beta \leq 15^\circ$			$1,3 + 0,0036 D_o / e_n + 3,6 \delta / e_n$ avec un maximum de 1,9 Note (15)			$\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$
			sans soudure circonférentielle au niveau de la transition $\delta = 0$			

Tableau C10.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte. (suite)

Composant	Caractéristique de flexibilité <i>h</i>	Coefficient de flexibilité <i>k</i> Note (1)	Coefficients d'intensification de contrainte			Module d'inertie <i>Z</i>
			<i>i</i>	<i>i</i> ₀ hors du plan	<i>i</i> ₁ dans le plan	
<p>15.3 Composant emmanché-soudé</p>  <p>forme concave avec raccordement régulier au tuyau</p>		1	1,3	$\frac{2,1 e_n}{e_{lg}}$ <p>avec un minimum de 1,3 et un maximum de 2,1</p>	$\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$	
<p>15.4 Composant emmanché-soudé</p>  <p>forme convexe</p>		1	2,1	$\frac{2,1 e_n}{e_{lg}}$ <p>avec un minimum de 1,3 et un maximum de 2,1</p>	$\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$	

Notes du Tableau C10.2.6-1.

(1) Le coefficient de flexibilité k s'applique à la flexion dans tous les plans. Le coefficient pour la torsion est égal à 1 dans tous les cas à l'exception du cas 2 (tuyau droit et coude ondulé) pour lequel il est égal à 0,9.

(2) Les coefficients k, i, i_0, i_1 s'appliquent sur toute la longueur effective des coudes et des cintres (ligne épaissie sur les schémas) et à l'intersection des axes pour les tés et les piquages.

(3) Si ces composants sont munis :

- d'une bride à l'une de leurs extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/6}$,
- d'une bride à leurs deux extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/3}$.

(4) Si la pression est susceptible d'apporter une correction d'ovalisation (grand diamètre, petite épaisseur), les coefficients sont divisés par :

$$- 1 + 6 \left(\frac{P}{E} \right) \left(\frac{r_m}{e_r} \right)^{7/3} \left(\frac{R_c}{r_m} \right)^{1/3} \quad \text{pour le coefficient } k.$$

$$- 1 + 3,25 \left(\frac{P}{E} \right) \left(\frac{r_m}{e_r} \right)^{5/2} \left(\frac{R_c}{r_m} \right)^{2/3} \quad \text{pour les coefficients } i, i_0, i_1.$$

P étant la pression de service et E le module d'élasticité à 20°C.

(5) L'épaisseur de la paroi de la réduction ne doit pas être inférieure à e_1 sauf au voisinage de l'extrémité de petit diamètre où, toutefois, l'épaisseur de la paroi ne doit pas être inférieure à e_s .

(6) Le coefficient d'intensification de contrainte « hors du plan », pour un piquage dont le rapport des diamètres de la tubulure et du collecteur est supérieur à 0,5, peut être non-conservatif. Par ailleurs, il a été démontré qu'un raccordement régulier par une soudure de forme concave réduit la valeur de ce coefficient. Le choix d'une valeur appropriée pour ce coefficient reste donc de la responsabilité du Concepteur.

(7) Les coefficients d'intensification de contrainte pour les raccords de tubulures sont basés sur des essais avec au moins deux diamètres de tuyau droit de chaque côté de l'axe de la tubulure. Le cas de tubulures plus proches requiert une attention particulière.

(8) Les pièces forgées utilisées doivent être appropriées aux conditions de service.

(9) Lorsque les limitations portant sur le rayon et l'épaisseur ne sont pas respectées et en l'absence de données fiables la caractéristique de flexibilité doit être prise égale à $\frac{2 e_n}{D_m}$.

(10) Le Concepteur doit vérifier que le dimensionnement en fonction de la pression est au moins équivalent à celui du tuyau droit.

(11) Les coefficients ne s'appliquent qu'aux piquages à axes concourants.

(12) D'autres valeurs peuvent être utilisées sous réserve de justification.

(13) En l'absence de données fiables, la détermination des coefficients est de la responsabilité du Concepteur.

(14) En l'absence de données plus précises, les coefficients d'intensification de contrainte peuvent être pris égaux à 2,5.

(15) Le coefficient s'applique dans le cas où les tolérances de fabrication (voir Partie F) sont respectées. Dans le cas contraire, la détermination des coefficients est de la responsabilité du Concepteur.

(16) Pour des rapports $\frac{d_m}{D_m} \leq 0,5$, le coefficient d'intensification de contrainte peut être déterminé à partir de la formulation ci-dessous :

$$i = \text{MIN} \left[0,45 \left\{ \frac{D_m}{2 e_n} \right\}^{\frac{2}{3}} \left\{ \frac{d_m}{D_m} \right\}^{\frac{1}{2}} \left\{ \frac{e_b}{e_n} \right\} F ; \left(0,17 \left\{ \frac{D_m}{2 e_n} \right\}^{\frac{2}{3}} + 0,25 \right) \left\{ \frac{e_b}{e_n} \right\} F \right]$$

avec :

$F = 1$ pour une soudure meulée arasée

$F = 1,6$ dans les autres cas

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from

$$P = \frac{2fze}{D - e}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness \times (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 = outside diameter

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}

$$e_{equi} = \frac{e}{t_f}$$

Where

$$t_f = \left[\frac{R/D - 0.25}{R/D - 0.50} \right]$$

For closely spaced miter bends, the allowable pressure is calculated from

$$P = \min \left[\left(\frac{2fze}{D_m} \cdot \frac{e}{e + 0.643 \tan \theta \sqrt{0.5D_m e}} \right), \left(\frac{2fze}{D_m} \cdot \frac{R - 0.5D_m}{R - 0.25D_m} \right) \right] \text{ with } \theta \leq 22.5$$

For widely spaced miter bends, the allowable pressure is calculated from

$$P = \min \left[\left(\frac{2fze}{D_m} \cdot \frac{e}{e + 0.643 \tan \theta \sqrt{0.5D_m e}} \right), \left(\frac{2fze}{D_m} \cdot \frac{R - 0.5D_m}{R - 0.25D_m} \right) \right] \text{ with } \theta \leq 22.5$$

$$P = \left(\frac{2fze}{D_m} \cdot \frac{e}{e + 1.25 \tan \theta \sqrt{0.5D_m e}} \right) \text{ with } \theta \leq 22.5$$

Where

D_m = mean diameter of pipe = $D - t_n$

R = effective bend radius of the miter

θ = miter half angle

t_n = nominal thickness

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from

$$\sigma_1 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} \leq f_h$$

Where

P = maximum of CAEPIPE input pressures P1, P2 and P3

D_o = outside diameter

e = nominal pipe thickness x [1 - mill tolerance%/100] - corrosion allowance "c"

i = stress intensification factor; the product of 0.75i shall not be less than 1.0

M_A = resulting bending moment due to sustained loads

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

f_h = hot allowable stress

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently

$$\sigma_2 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \leq kf_h$$

M_B = resultant bending moment due to occasional load

k = 1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE $k=1.2$ is used for occasional loading.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from

$$\sigma_3 = \frac{iM_C}{Z} + \leq f_a$$

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

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

U = cyclic stress range reduction factor as mentioned below

Number of cycle	Stress range reduction factor U
$f_a \leq 7000$	1.0
7001 to 140000	0.9
14001 to 220000	0.8
22001 to 0.7	0.7
45001 to 100000	0.6
100001 to 2000000	0.5

- f_c = allowable stress at cold temperature
 f_h = allowable stress at hot temperature
 E_c = elastic modulus at cold temperature
 E_h = elastic modulus at hot temperature

$$\sigma_4 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_h + f_a$$

Additional Conditions for the Creep Range

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

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

Where

- f_{cr} = allowable creep stress value

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte et coefficients d'intensification de contrainte

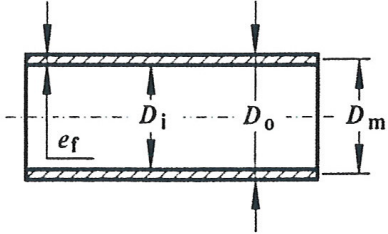
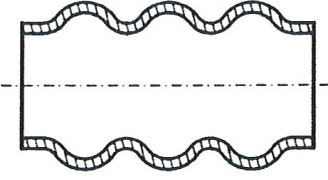
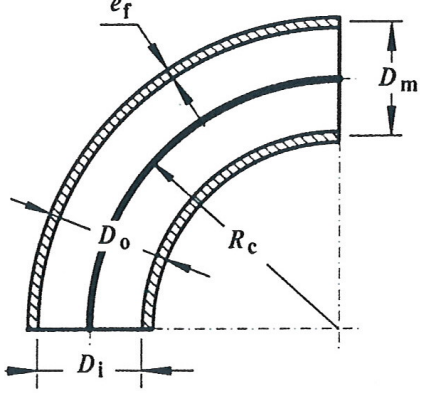
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie
			i	i_0 hors du plan	i_i dans le plan	
<p>1. Tuyau droit soudé bout-à-bout</p> 		1	1	1	1	$\frac{\pi}{32} \frac{D_e^4 - D_i^4}{D_e}$
<p>2. Tuyau droit ondulé ou coude ondulé</p> 		5	2,5	2,5	2,5	
<p>3. Coude ou cintre soudé bout-à-bout</p>  <p>Note : Pour les intersections tubulure-coude voir § C2.2.7.4.4.</p>	$\frac{4 e_f R_c}{D_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$ Notes (2) & (3)	$\frac{0,75}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{0,9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{\pi}{32} \frac{D_e^4 - D_i^4}{D_e}$

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

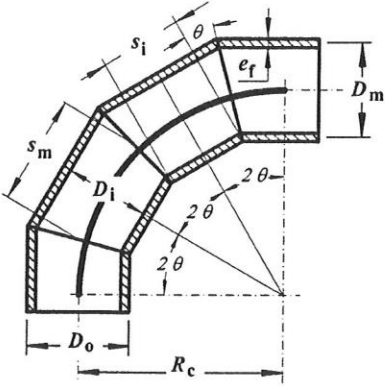
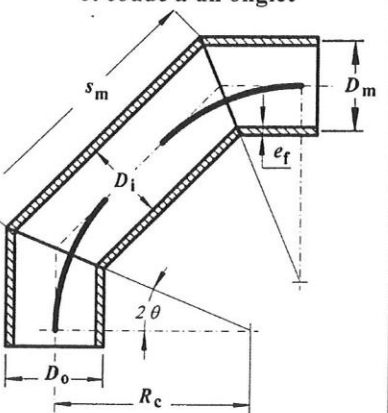
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte		Module d'inertie
			i	i_0 hors du plan i_i dans le plan	
<p>4.1 Coude à sections rapprochées ou à sections multiples</p>  <p> $s_m \leq \frac{D_m}{2} (1 + \tan \theta)$ $R_c = \frac{s_m \cot \theta}{2}$ </p>	$\frac{4 R_c e_f}{D_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ $s_i \geq 6 e_f$ $\theta \leq 22,5^\circ$ Notes (2) & (3)	$\frac{0,9}{h^{2/3}}$ $\frac{0,9}{h^{2/3}}$ Notes (2),(3) & (4)	$\frac{\pi D_o^4 - D_i^4}{32 D_o}$
<p>4.2 Coude à sections espacées et coude à un onglet</p>  <p> $s_m > \frac{D_m}{2} (1 + \tan \theta)$ $R_c = \frac{D_m (1 + \cot \theta)}{4}$ </p>	$\frac{4 R_c e_f}{D_m^2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ $\theta \leq 22,5^\circ$ Note (2)	$\frac{0,9}{h^{2/3}}$ $\frac{0,9}{h^{2/3}}$ Notes (2), (3) & (4)	$\frac{\pi D_o^4 - D_i^4}{32 D_o}$

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

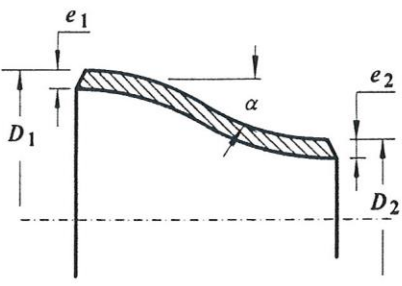
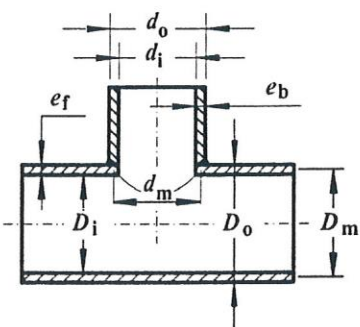
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie
			i	i_0 hors du plan	i_i dans le plan	
<p>5.1 Réduction forgée</p> 		1		$0,5 + \frac{\alpha}{100} \left(\frac{D_2}{e_2} \right)^{1/2}$ MAX = 2,0 (α en °) $\alpha \leq 60^\circ$ $d_1/e_1 \leq 100$ $d_2/e_2 \leq 100$ Note (5)		
<p>5.2 Réduction chaudronnée voir figure C2.2.4</p>				Note (14)		
<p>6. Té reconstitué non renforcé avec tubulure posée ou pénétrante</p> 	$\frac{2 e_f}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ Notes (2) & (12)	$\frac{0,9}{h^{2/3} (\sin \alpha)^{3/2}}$ $\alpha =$ angle d'inclinaison de la tubulure par rapport au collecteur $\frac{3 i_0}{4} + 0,25$ Notes (2), (6), (7) & (11)	$\frac{\pi D_e^4 - D_i^4}{32 D_e}$ Dérivation $\frac{\pi}{4} d_m^2 e_x$ $e_x = \text{MIN}(e_f ; i e_b)$	

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

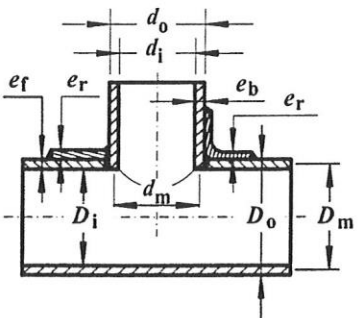
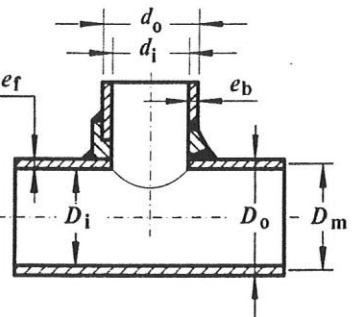
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte		Module d'inertie
			i	i_0 hors du plan i_i dans le plan	
<p>7. Té reconstitué avec tubulure posée ou pénétrante et renforcé par anneau ou selle de renfort</p>  <p>avec anneau renfort avec selle de renfort</p>	<p>si $e_r \leq 1,5 e_f$</p> $\frac{2(e_f + 0,5 e_r)^{5/2}}{e_f^{3/2} D_m}$ <p>si $e_r > 1,5 e_f$</p> $8 \frac{e_r}{D_m}$	1	$\frac{0,9}{h^{2/3}}$ <p>Notes (2) & (12)</p>	$\frac{0,9}{h^{2/3} (\sin \alpha)^{3/2}}$ <p>$\alpha =$ angle d'inclinaison de la tubulure par rapport au collecteur</p> $\frac{3 i_0}{4} + 0,25$ <p>Notes (2), (6), (7) & (11)</p>	<p>Collecteur</p> $\frac{\pi D_e^4 - D_i^4}{32 D_e}$ <p>Dérivation</p> $\frac{\pi}{4} d_m^2 e_x$ <p>$e_x = \text{MIN}(e_f; i e_b)$</p>
<p>8. Piquage avec pièces forgées</p>  <p>Type manchon forgé Type weldolets etc.</p>	$6,6 \frac{e_f}{D_m}$	<p>1 Type manchon forgé</p> <p>1 Type weldolets etc.</p>	$\frac{0,9}{h^{2/3}}$ <p>Notes (2), (6), (8) & (10)</p>	<p>2,1 2,1</p> $\frac{3 i_0}{4} + 0,25$	

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

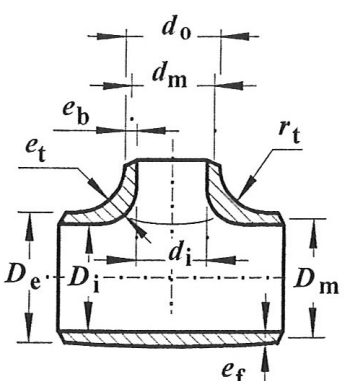
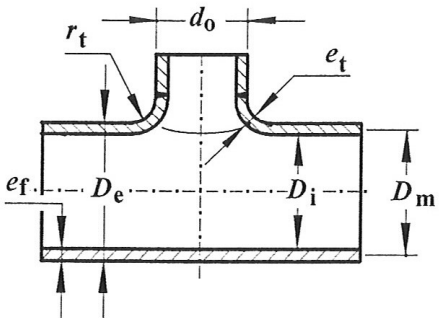
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie
			i	i_0 hors du plan	i_i dans le plan	
<p>11. Té forgé</p> 	$\frac{8,8 e_f}{D_m}$	1	$\frac{0,9}{h^{2/3}}$	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$	<p>Collecteur</p> $\frac{\pi D_e^4 - D_i^4}{32 D_e}$ <p>Dérivation</p> $\frac{\pi d_m^2 e_x}{4}$ <p>$e_x = \text{MIN}(e_f; i e_b)$</p> <p>Notes (2), (7), (8), (9) & (11)</p> <p>$e_t \geq 1,5 e_f$</p>
<p>12. Té à souder extrudé</p> 	$\left(1 + \frac{2 r_t}{D_m}\right) \frac{2 e_f}{D_m}$	1	Note (13)	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$	<p>$r_t \geq 0,05 d_o$</p> <p>$e_t \leq 1,5 e_f$</p> <p>Notes (2) & (7)</p>

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie
			i	i_0 hors du plan	i_i dans le plan	
<p>13. Triform</p>	$\frac{2 e_f}{D_m}$	1	Note (13)	$\frac{0,9}{h^{2/3}}$	$\frac{3 i_0}{4} + 0,25$	<p>Collecteur $\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$</p> <p>Dérivation $\frac{\pi}{4} d_m^2 e_x$</p> <p>$e_x = \text{MIN}(e_f; i e_b)$</p>
<p>14.1 Bride à assembler bout-à-bout</p>		1		1		
<p>14.2 Bride à emmancher et à souder (soudée des deux côtés)</p>		1		1,2		

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

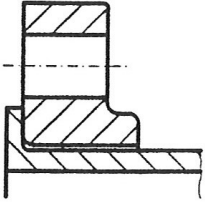
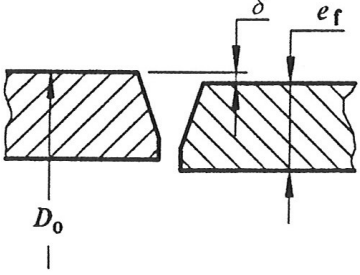
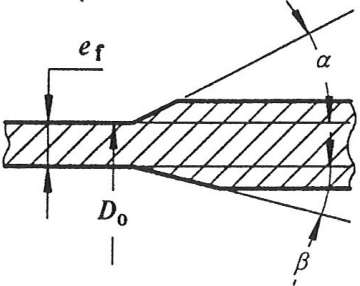
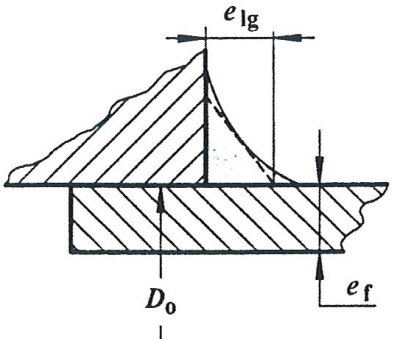
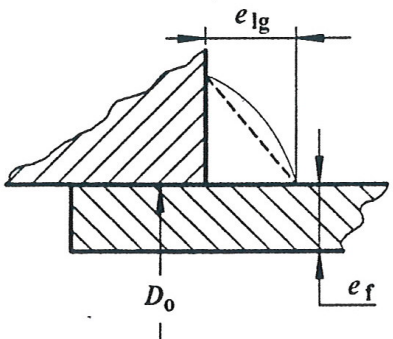
Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte		Module d'inertie
			i	i_0 hors du plan i_i dans le plan	
14.3 Bride tournantes 		1	1,6		
14.4 Bride à visser Voir figure C2.2.8.3.7-2		1	2,3		
15.1 Soudure bout-à-bout 			1 $e_n \geq 5 \text{ mm}$ et $\delta \leq 0,1 e_f$ Note (15)	$\frac{\pi D_o^4 - D_i^4}{32 D_o}$	
			1,8 $e_n < 5 \text{ mm}$ ou $\delta > 0,1 e_f$ Note (15)		
15.2 Transition d'épaisseur de paroi  $\alpha \leq 30^\circ$ $\beta \leq 15^\circ$			$1,3 + 0,0036 D_o / e_f + 3,6 \delta / e_f$ avec un maximum de 1,9 Note (15)	$\frac{\pi D_o^4 - D_i^4}{32 D_o}$	
			sans soudure circonférentielle au niveau de la transition $\delta = 0$		

Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)

Composant	Caractéristique de flexibilité h	Coefficient de flexibilité k Note (1)	Coefficients d'intensification de contrainte			Module d'inertie
			i	i_0 hors du plan	i_i dans le plan	
<p>15.3 Composant emmanché-soudé</p>  <p>forme concave avec raccordement régulier au tuyau</p>		1	1,3	$\frac{2,1 e_f}{e_{lg}}$ <p>avec un minimum de 1,3 et un maximum de 2,1</p>	$\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$	
<p>15.4 Composant emmanché-soudé</p>  <p>forme convexe</p>		1	2,1	$\frac{2,1 e_f}{e_{lg}}$ <p>avec un minimum de 1,3 et un maximum de 2,1</p>	$\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$ $\frac{\pi}{4} D_o^2 e_f$	

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CODETI 2006 Division 1 • Partie C – CONCEPTION ET CALCULS
Section C3 – ANALYSE ET CRITÈRES D'ACCEPTATION

Notes du tableau C3.2.6-1

- (1) Le coefficient de flexibilité k s'applique à la flexion dans tous les plans. Le coefficient pour la torsion est égal à 1 dans tous les cas à l'exception du cas 2 (tuyau droit et coude ondulé) pour lequel il est égal à 0,9.
- (2) Les coefficients k, i, i_0, i_1 s'appliquent sur toute la longueur effective des coudes et des cintres (ligne épaissie sur les schémas) et à l'intersection des axes pour les tés et les piquages.
- (3) Si ces composants sont munis :
 - d'une bride à l'une de leurs extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/6}$,
 - d'une bride à leurs deux extrémités, k, i, i_0, i_1 sont à multiplier par $h^{1/3}$.
- (4) Si la pression est susceptible d'apporter une correction d'ovalisation (grand diamètre, petite épaisseur), les coefficients sont divisés par :

$$- 1 + 6 \left(\frac{P}{E} \right) \left(\frac{r_m}{e_r} \right)^{7/3} \left(\frac{R_c}{r_m} \right)^{1/3} \quad \text{pour le coefficient } k.$$

$$- 1 + 3,25 \left(\frac{P}{E} \right) \left(\frac{r_m}{e_r} \right)^{5/2} \left(\frac{R_c}{r_m} \right)^{2/3} \quad \text{pour les coefficients } i, i_0, i_1.$$

P étant la pression de service et E le module d'élasticité à 20 °C.

- (5) L'épaisseur de la paroi de la réduction ne doit pas être inférieure à e_1 sauf au voisinage de l'extrémité de petit diamètre où, toutefois, l'épaisseur de la paroi ne doit pas être inférieure à e_2 .
- (6) Le coefficient d'intensification de contrainte « hors du plan », pour un piquage dont le rapport des diamètres de la tubulure et du collecteur est supérieur à 0,5, peut être non-conservatif. Par ailleurs, il a été démontré qu'un raccordement régulier par une soudure de forme concave réduit la valeur de ce coefficient. Le choix d'une valeur appropriée pour ce coefficient reste donc de la responsabilité du Concepteur.
- (7) Les coefficients d'intensification de contrainte pour les raccords de tubulures sont basés sur des essais avec au moins deux diamètres de tuyau droit de chaque côté de l'axe de la tubulure. Le cas de tubulures plus proches requiert une attention particulière.
- (8) Les pièces forgées utilisées doivent être appropriées aux conditions de service.
- (9) Lorsque les limitations portant sur le rayon et l'épaisseur ne sont pas respectées et en l'absence de données fiables la caractéristique de flexibilité doit être prise égale à $\frac{2 e_f}{D_m}$.
- (10) Le Concepteur doit vérifier que le dimensionnement en fonction de la pression est au moins équivalent à celui du tuyau droit.
- (11) Les coefficients ne s'appliquent qu'aux piquages à axes concourants.
- (12) D'autres valeurs peuvent être utilisées sous réserve de justification.
- (13) En l'absence de données fiables, la détermination des coefficients est de la responsabilité du Concepteur.
- (14) En l'absence de données plus précises, les coefficients d'intensification de contrainte peuvent être pris égaux à 2,5.
- (15) Le coefficient s'applique dans le cas où les tolérances de fabrication (voir partie F) sont respectées. Dans le cas contraire, la détermination des coefficients est de la responsabilité du Concepteur.

Sustained Stress

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

$$S_L = \frac{P(D - t)}{4t} + \frac{0.75iM_A}{Z} \leq S_h$$

where

P = maximum pressure

D = outside diameter

t = nominal wall thickness

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

M_A = resultant bending moment due to sustained loads = $\sqrt{M_X^2 + M_Y^2 + M_Z^2}$

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

S_h = hot allowable stress: smaller of:

0.67 yield stress at temperature

0.44 tensile strength at 20° C

0.67 rupture stress (after 100,000 hours at temperature)

Occasional Stress

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

$$S_{LO} = S_L + \frac{0.75iM_B}{Z} \leq 1.2S_h$$

where

M_B = resultant moment due to occasional loads

Expansion Stress

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

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

where


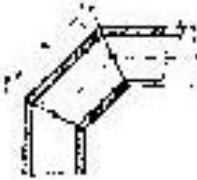
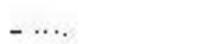
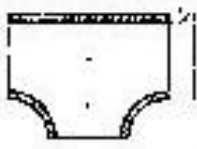
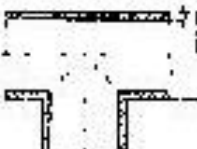

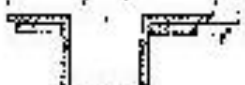

M_C = resultant moment due to thermal expansion

S_A = smaller of:

C_f (0.8 yield strength at 20° C + 0.13 hot yield strength)

C_f (0.8 yield strength at 20° C + 0.2 x 0.67 rupture stress)

C_f = stress range reduction factor

		14-42 element			
		Pipe Component	σ	k	i
	gladde bocht met $m (\leq 2)$ knopen smooth pipe bend or elbow with $m (\leq 2)$ flanged ends		$\frac{4L \cdot R}{(D_e - d)^2}$	$1,65m^{-1/2}$	$0,9; \frac{m-1}{k}$
	klein segmentbocht met $m (\leq 2)$ knopen closely spaced mitre bend with $m (\leq 2)$ flanged ends $r < \frac{D_e - d}{2} (1 + 10\phi)$		$\frac{2d \cdot s}{(D_e - d)^2} \cos \phi$	$1,22m^{-1/2}$	$0,72m^{-1/2}$
	large segmentbocht widely spaced mitre bend $r > \frac{D_e - d}{2} (1 + 10\phi)$		$\frac{d}{D_e - d} (1 - \cos \phi)$	$1,22m^{-1/2}$	$0,72m^{-1/2}$
	geamod of gepresd forged or pressed		$\frac{1,8L}{D_e - d}$		
	opgebouwd, onversterkt fabricated, unreinforced		$\frac{1L}{D_e - d}$		
7-ruik en s'laak lingen Tees and branches	opgebouwd met ringversterking fabricated, with pad or saddle reinforcement $d_1 \leq 1,2d$		$\frac{2(d + 0,5d_1)^2}{(D_e - d) \cdot d^2}$	1	$0,9m^{-1/2}$
	$d_1 > 1,2d$		$\frac{8,1d}{D_e - d}$		
	opgebouwd, versterkt fabricated, reinforced		$\frac{1L}{D_e - d}$		
Pijpverbindingen pipe connection	stompe las butt weld	-	-	1	1
	schroefverbinding screwed connection	-	-	1	1,3
	blinkflens met twee boeklussen double welded slip-on flange	-	-	1	1,3

Swedish (1978)

Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from Equation 6.3.

$$p = \frac{2\sigma_{tn}z_L s_{eff}}{D_y m - s_{eff}}$$

where

p = allowable pressure

σ_{tn} = allowable stress

z_L = joint efficiency of longitudinal weld (input as material property)

s_{eff} = nominal pipe thickness \times (1 – mill tolerance/100) – corrosion allowance

D_y = outside diameter

D_i = inside diameter = $D_y - s_{eff}$

m = pressure coefficient

= 1.0 for $D_y/D_i < 1.6$

= $0.25(D_y/D_i) + 0.6$ for $1.6 \leq D_y/D_i \leq 2.0$

Sustained Stress

Stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation 9.37.

$$S_L = \frac{p_{max} D_y}{4s_{eff} z_C} + \frac{0.75k_1 M_A}{W_y} \leq \sigma_{tn2}$$

where

p_{max} = maximum pressure

z_C = joint efficiency of circumferential weld (input as material property)

k_1 = stress intensification factor. The product $0.75k_1$ shall not be less than 1.0

M_A = resultant bending moment due to sustained loads

W_y = section modulus, for reduced outlets, effective section modulus

σ_{tn2} = hot allowable stress

Occasional Stress

The stress (S_{LO}) is calculated as the sum of the stress due to sustained loads (S_L) and the stress (S_O) due to occasional loads such as earthquake or wind from Equation 9.38. Wind and earthquake are not considered concurrently.

$$S_{LO} = \frac{p_{max} D_y}{4s_{eff} z_C} + \frac{0.75k_1 (M_A + M_B)}{W_y} \leq 1.2\sigma_{tn2}$$

where

M_B = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Equation 9.39.

$$S_E = \frac{k_1 M_C}{W_y} \leq S_r$$

where

M_C = resultant bending moment due to thermal expansion

S_r = $f(1.17\sigma_1 + 0.17\sigma_2)$ from Equation 9.43

f = stress range reduction factor taken from Table 9.1

σ_1 = smaller of σ_{tn1} and $0.267R_m$

σ_2 = smaller of σ_{tn2} and $0.367R_m$

σ_{tn1} = allowable stress at cold condition

σ_{tn2} = allowable stress at hot condition

R_m = tensile strength at room temperature

At moderate temperatures (up to 370° C) for carbon steel, low alloy steel and chromium steel (specified as CS material type) and up to 425° C for austenitic stainless steel (specified as AS material type), the limits $0.267R_m$ and $0.367R_m$ are disregarded and S_r is selected as smaller of S'_r and S''_r ,

where

$$S'_r = 1.17\sigma_{tn1} + 0.20\sigma_{tn2}$$

$$S''_r = 290f - \sigma_{tn2}$$

Table 9:2 k and k_1

Item	Type of fitting	h	k	k_1	Figure
1	Bend, see notes 1 and 2	$\frac{s_{nom} \cdot R}{r_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$	
2	Mitre bend of segment length L smaller than $r_m (1 + \tan \theta)$; see notes 1 and 2	$\frac{L \cdot s_{nom} \cdot \cot \theta}{2 r_m^2}$	$\frac{1,5}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$	
3	Mitre bend of segment length L not less than $r_m (1 + \tan \theta)$ or inclined circumferential welds; see notes 1 and 3	$\frac{s_{nom} (1 + \cot \theta)}{2 r_m}$	1	$\frac{0,9}{h^{2/3}}$	
4	Branch without local reinforcement of the main pipe; see note 1	$\frac{s_h}{r_h}$	1	$\frac{0,9}{h^{2/3}}$	
5	Raised edges on main pipe or branch radiused at joint; see note 1	$\left(\frac{s_h}{s_n}\right)^{3/2} \cdot \frac{s_p \cdot R_p}{r_h^2}$	1	$\frac{0,9}{h^{2/3}}$	
6	Branch on locally thickened main pipe; see note 1	$L < \frac{d_i}{2} + 1,8 \sqrt{D_v \cdot s_l}$ $\frac{\left(\frac{s_n + s_l}{2}\right)^{5/2}}{r_h \cdot s_h^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	
	$L < \frac{d_i}{2} + 1,8 \sqrt{D_v \cdot s_l}$	$\frac{s_l^{5/2}}{r_h \cdot s_h^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	
7	Branch with plate reinforcement; see notes 1 and 4	$\frac{\left(s_n - \frac{s_p}{2}\right)^{5/2}}{r_h \cdot s_n^{3/2}}$	1	$\frac{0,9}{h^{2/3}}$	

Symbols (items 4-7)

r = fillet radius
 r_m = mean radius of branch $\left[= \frac{d_o + s_n}{2} \right]$
 R_p = effective radius $= r + r_h$
 r_h = mean radius of main pipe $\left[= \frac{D_o + s_h}{2} \right]$
 s_n = nominal wall thickness of branch

s_h = nominal wall thickness of main pipe
 s_e = effective wall thickness $= 0,5 s_p + s_n$
 s_f = wall thickness in fillet (see item 5)
 s_l = wall thickness of main pipe side at branch (see item 5)
 s_j = wall thickness of locally thickened main pipe
 s_p = thickness of plate reinforcement

Table 9.2 (cont.)

Item	Type of fitting	h	k	k_1	Figure
8	Butt weld $s_{nom} > 4,5$ mm and $\delta/s_{nom} \leq 0,1$ $s_{nom} \leq 4,5$ mm or $\delta/s_{nom} > 0,1$		1 1	1,0 1,8 (If the weld is ground flush inside and out, k_1 may be set = 1,0)	
9	Butt weld between dissimilar thicknesses according to Section 11.2.2		1	$1,3 + 0,0036 \frac{D_y}{s_{nom}} + 3,6 \frac{\delta}{s_{nom}}$ but not over 1,9	
10	Fillet weld (spigot type)		1	2,1	
11	Concave fillet weld (spigot type) with even transition to the pipe (no undercut allowed)		1	1,3	
12	Conical reducer with defined knuckles r and r_1 , complying with Section 6.5.2.3; see notes 1 and 5		1	$0,5 + 0,01 \cdot a \sqrt{\frac{D_{y,min}}{s_{1,nom}}}$ but not over 2,0	
13	Conical reducer without knuckles; see notes 1 and 5 $s_{1,nom} > 4,5$ mm and $\delta/s_{1,nom} \leq 0,1$ $s_{1,nom} \leq 4,5$ mm or $\delta/s_{1,nom} > 0,1$		1	$0,9 + 0,017 \cdot a \sqrt{\frac{D_{y,min}}{s_{1,nom}}}$ $1,25 + 0,023 \cdot a \sqrt{\frac{D_{y,min}}{s_{1,nom}}}$ but not less than 1,8	
14	Thread joint or connection to threaded flange		1	2,3	

Symbols (items 12-13)

$D_{y,min}$, $D_{y,max}$, a : see Section 6.5
 $s_{1,nom}$ = nominal wall thickness of the smaller pipe
 $s_{2,nom}$ = nominal wall thickness of the larger pipe
 δ = difference in mean radius across a weld

Allowable Pressure

The allowable pressure is calculated from 5.3.2.1.

$$P = 2StFLJT/D$$

where

P = allowable pressure

S = specified minimum yield strength

t = minimum wall thickness

= nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance

F = design factor = 0.8 for steel pipe (from 5.2.3)

L = location factor (from Table 5.1)

J = joint factor (from Table 5.2), input as material property

T = temperature derating factor for steel pipe (from Table 5.3)

D = outside diameter

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) and wind loads, is calculated from (5.6.3.5)

$$S_L = \frac{PD}{4t} + i \frac{M}{Z} \leq SFLJT$$

where

P = maximum pressure

D = outside diameter

t = minimum wall thickness

i = stress intensification factor

M = resultant bending moment due to sustained loads

Z = corroded section modulus

S = specified minimum yield strength

F = design factor

L = location factor

J = joint factor

T = temperature derating factor

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained and wind loads (S_L) and stress due to occasional loads (S_O), such as earthquake. The allowable stress for occasional stress is not given in the code, therefore it is conservatively taken the same as the sustained stress allowable.

$$S_{LO} = S_L + i \frac{M}{Z} \leq SFLJT$$

where

M = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from (5.6.3.3).

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where

S_b = resultant bending stress = iM_b/Z

S_t = torsional stress = $M_t/2Z$

M_b = resultant bending moment due to expansion loads

M_t = torsional moment due to expansion loads

Z = un-corroded section modulus

Table 5.5
Flexibility and Stress Intensification Factors

Description	Flex- ibility Factor k	Stress Intens. Factor i	Description	Flex- ibility Factor k'	Stress Intens. Factor i'	Flexibility Character- istic h	See sketch
Buttwelded joint, reducer, or welding neck flange	1	1.0	Welding elbow, or pipe bend [†]	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{1R}{r^2}$	A
Double-welded slip-on or socket welding flange	1	1.2	Mitre bend with close spacing [‡] $s < r(1 + \tan \alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \alpha}{2} \cdot \frac{ts}{r^2}$	B
Fillet welded joint, or single-welded socket welding flange	1	1.3	Mitre bend with wide spacing ^{‡§} $s \geq r(1 + \tan \alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \alpha}{2} \cdot \frac{t}{r}$	C
Lap joint flange (with CSA Standard CAN3-Z245 12) (lap joint stub)	1	1.6	Welding tee per CSA Standard CAN3-Z245 11	1	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{1}{r}$	D
Screwed pipe joint, or screwed flange	1	2.3	Reinforced fabricated tee, with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2 T)^{5/2}}{t^{3/2} r}$	E
Corrugated pipe, straight or curved, or creased bend ^{**}	5	2.5	Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	F

*The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system, and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for curved and mitre elbows, and to the intersection point for tees.

Where flanges are attached to one or both ends, the values of k and i in the Table shall be multiplied by the following factors:

One end flanged: $(h)^{1/6}$

Both ends flanged: $(h)^{1/3}$

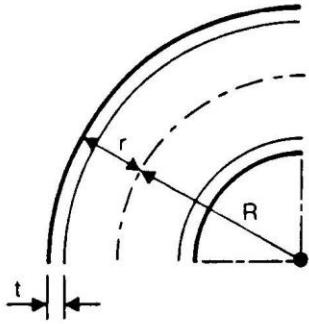
‡Subject to the limitations of Clause 5.4.2.2(d).

§Also includes single-mitre joint.

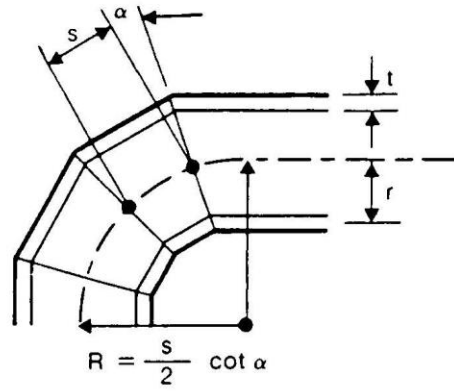
**Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Note: Designers are cautioned that specific cases may require more comprehensive analysis than that specified in Clause 5.6.

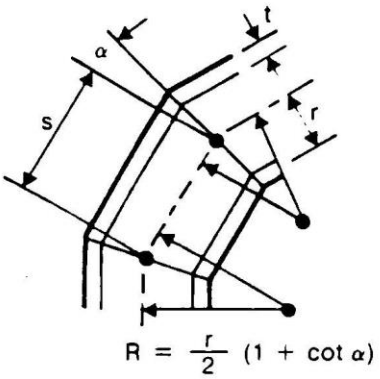
Table 5.5 (Concluded)



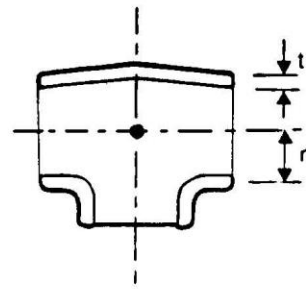
Sketch A



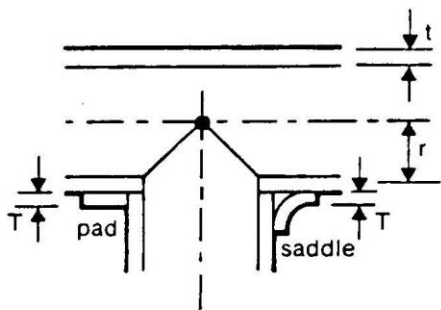
Sketch B



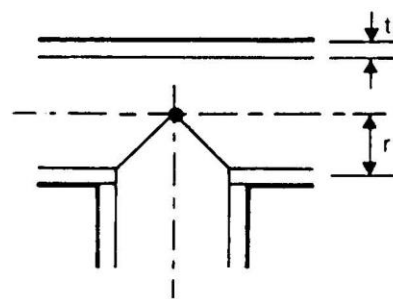
Sketch C



Sketch D



Sketch E



Sketch F

Allowable Pressure

The allowable pressure is calculated from 5.4.2.1.

$$P = 2StFLJT/D$$

where

- P = allowable pressure
- S = specified minimum yield strength
- t = minimum wall thickness
= nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance
- F = design factor = 0.8 for steel pipe (from 5.2.3)
- L = location factor (from Table 5.1)
- J = joint factor (from Table 5.2), input as material property
- T = temperature derating factor for steel pipe (from Table 5.3)
- D = outside diameter

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) and wind loads, is calculated from (5.19.3.5)

$$S_L = \frac{PD}{4t} + i \frac{M}{Z} \leq SFLJT$$

where

- P = maximum pressure
- D = outside diameter
- t = minimum wall thickness
- i = stress intensification factor
- M = resultant bending moment due to sustained loads
- Z = corroded section modulus
- S = specified minimum yield strength
- F = design factor
- L = location factor
- J = joint factor
- T = temperature derating factor

Occasional Stress

The stress (S_{LO}) is calculated as the sum of stress due to sustained and wind loads (S_L) and stress due to occasional loads (S_O), such as earthquake. The allowable stress for occasional stress is not given in the code, therefore it is conservatively taken the same as the sustained stress allowable.

$$S_{LO} = S_L + i \frac{M}{Z} \leq SFLJT$$

where

- M = resultant bending moment due to occasional loads

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from (5.6.3.3).

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where

S_b = resultant bending stress = iM_b/Z

S_t = torsional stress = $M_t/2Z$

M_b = resultant bending moment due to expansion loads

M_t = torsional moment due to expansion loads

Z = un-corroded section modulus

Table 5.8
Flexibility and Stress Intensification Factors

Description	Flex- ibility Factor k	Stress Intens. Factor i	Description	Flex- ibility Factor k^*	Stress Intens. Factor i^*	Flexibility Character- istic h	See sketch
Buttwelded joint, reducer, or welding neck flange	1	1.0	Welding elbow, or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{1R}{r^2}$	A
Double-welded slip-on or socket welding flange	1	1.2	Mitre bend with close spacing†† $s < r(1 + \tan \alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cot \alpha}{2} \cdot \frac{ts}{r^2}$	B
Fillet welded joint, or single-welded socket welding flange	1	1.3	Mitre bend with wide spacing †‡ $s \geq r(1 + \tan \alpha)$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1 + \cot \alpha}{2} \cdot \frac{t}{r}$	C
Lap joint flange (with ANSI B16.9 lap joint stub)	1	1.6	Welding tee per CSA Standard CAN/CSA-Z245.11	1	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{t}{r}$	D
Screwed pipe joint, or screwed flange	1	2.3	Reinforced fabricated tee, with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t + 1/2 T)^{5/2}}{t^{3/2} r}$	E
Corrugated pipe, straight or curved, or creased bend**	5	2.5	Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	F

*The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system, and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for curved and mitre elbows, and to the intersection point for tees.

† Where flanges are attached to one or both ends, the values of k and i in the Table shall be multiplied by the following factors:

One end flanged: $(h)^{1/6}$

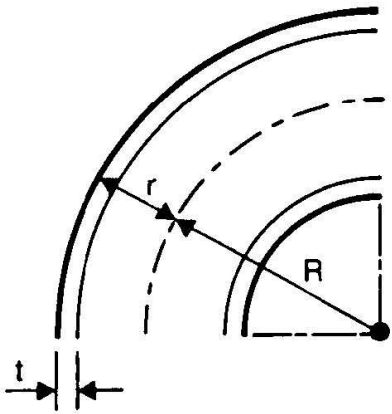
Both ends flanged: $(h)^{1/3}$

‡ Subject to the limitations of Clause 7.2.3(e).

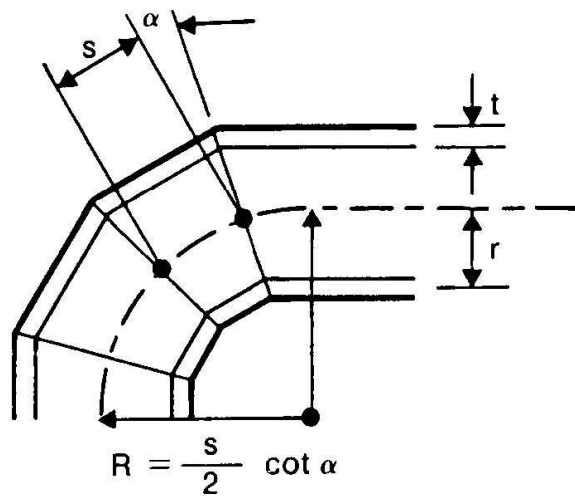
§ Also includes single-mitre joint.

** Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

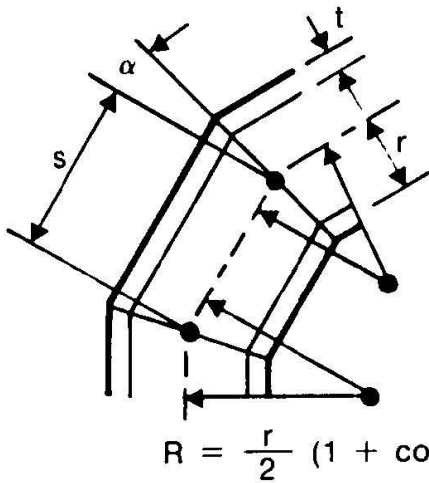
Note: Designers are cautioned that specific cases may require more comprehensive analysis than that specified in Clause 5.19.



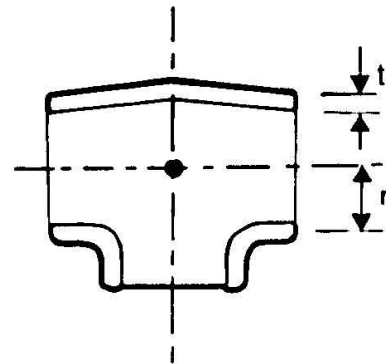
Sketch A



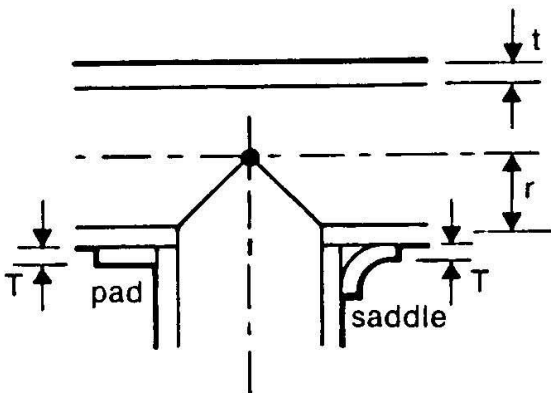
Sketch B



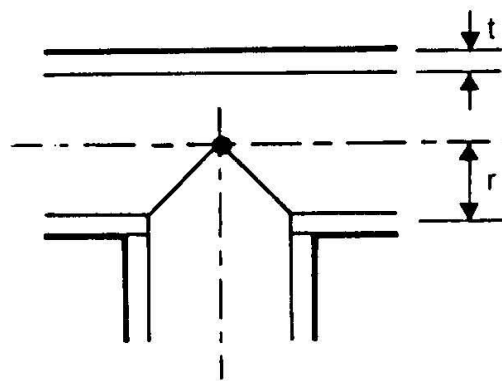
Sketch C



Sketch D



Sketch E



Sketch F

Allowable Pressure

For straight pipe, the allowable pressure for a given wall thickness shall be determined by the following formula from Clause 4.3.5.1.

$$P = FLJT \left(\frac{2St}{D} \right)$$

where

P = allowable pressure

S = specified minimum yield strength, input as material property in CAEPIPE

t = minimum wall thickness = nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance (see Note below)

F = design factor = 0.8 as per Clause 4.3.6.

L = location factor (from Table 4.2), input into CAEPIPE analysis option

J = joint factor (from Table 4.3), input as material property in CAEPIPE

T = temperature factor for steel pipe (from Table 4.4), determined based on Design Temperature input into CAEPIPE

D = outside diameter

Note:

Corrosion allowance input into CAEPIPE should include corrosion/erosion allowance and allowance for grooving and threading.

Sustained + Occasional Stress (Unrestrained Piping = Un-buried Piping)

The sum of longitudinal pressure stress and the total bending stress due to sustained force (pressure, weight and other sustained mechanical loads) and occasional loads (such as wind, seismic, etc.) shall be limited in accordance with the following formula from Clause 4.8.5.

$$0.5S_h + s_B \leq SFLT$$

where

S_h = hoop stress due to pressure P , as computed using formula given in Clause 4.6.5 = $\frac{PD}{2t}$

s_B = absolute value of beam bending stresses resulting from sustained and occasional loads
= $\frac{iM_B}{Z_C}$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter of pipe

t = minimum wall thickness = nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance (see Note above for corrosion allowance)

i = stress intensification factor (from Table 4.8)

M_B = resultant bending moment due to sustained and occasional loads

Z_C = corroded section modulus computed using corroded wall thickness = Nominal wall thickness - corrosion allowance, in which mill tolerance is not deducted.

S = specified minimum yield strength

F = design factor = 0.8 as per Clause 4.3.6

L = location factor (from Table 4.2)

T = temperature factor for steel pipe (from Table 4.4) determined based on Maximum Temperature input into CAEPIPE (T1 through T10)

Expansion Stress (Unrestrained Piping = Un-buried Piping)

The thermal expansion stress range (S_E) for those portions of pipeline systems shall be limited in accordance with the formulae given in Clauses 4.8.3 and 4.8.4.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where

S_b = resultant bending stress = iM_b/Z

S_t = torsional stress = $M_t/(2Z)$

M_b = resultant bending moment due to expansion loads

M_t = torsional moment due to expansion loads

Z = un-corroded section modulus

i = stress intensification factor (from Table 4.8)

S = specified minimum yield strength

T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot}

T_{hot} = maximum(T_{opr} , T_{ref}) (see Note 3 below)

Combined Stress (Restrained Piping = Buried Piping)

For those portions of restrained pipelines, the combined stress shall be limited in accordance with the formula given in Clause 4.7.2.1.

$$S_h - S_L + S_B \leq ST$$

where

S_h = hoop stress due to pressure P , as determined using formula given in Clause 4.6.5 = $\frac{PD}{2t}$

S_L = longitudinal compressive stress as determined using the formula given in Clause 4.7.1
= $S_L = \vartheta S_h - E_c \alpha (T_{opr} - T_{ref})$ (see Notes below)

S_B = absolute value of beam bending stresses resulting from sustained and occasional loads
= $\frac{iM_B}{Z_C}$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter of pipe

t = minimum wall thickness

= nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance (see Note above)

i = stress intensification factor (from Table 4.8)

M_B = resultant bending moment due to sustained and occasional loads

Z_C = corroded section modulus computed using corroded wall thickness = Nominal wall thickness - corrosion allowance, in which mill tolerance is not deducted.

Oil and gas pipeline systems
CSA Z662 (2019)

ν = Poisson's ratio, input as material property in CAEPIPE

T_{opr} = operating temperature under consideration. See Note 2 below.

T_{ref} = ambient temperature at the time of restraint = Reference temperature in CAEPIPE

E_c = modulus of elasticity of steel at T_{ref}

α = coefficient of thermal expansion at T_{opr} defined above

S = specified minimum yield strength

T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot} .

T_{hot} = maximum(T_{opr}, T_{ref}) (see Note 3 below)

Note:

1. Evaluation as per Clause 4.7.2.1 (listed above) for Restrained Piping shall be performed in CAEPIPE only when the value of S_L computed as listed above is negative (compressive).

2. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE calculates longitudinal stress (S_L) due to

Thermal expansion range from T_{ref} to T1 as

$$E_c \alpha (T_{opr} - T_{ref}) = E_c \alpha_{T1} (T_1 - T_{ref})$$

Thermal expansion range from T_{ref} to T2 as

$$E_c \alpha (T_{opr} - T_{ref}) = E_c \alpha_{T2} (T_2 - T_{ref})$$

Thermal expansion range from T1 to T2 as

$$E_c \alpha (T_n - T_m) = E_c \alpha_n (T_n - T_{ref}) - E_c \alpha_m (T_m - T_{ref}), \text{ where } n = 1 \text{ and } m = 2$$

3. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE determines Temperature factor (T) as given below.

Thermal expansion range from T_{ref} to T_1 as maximum(T_1, T_{ref})

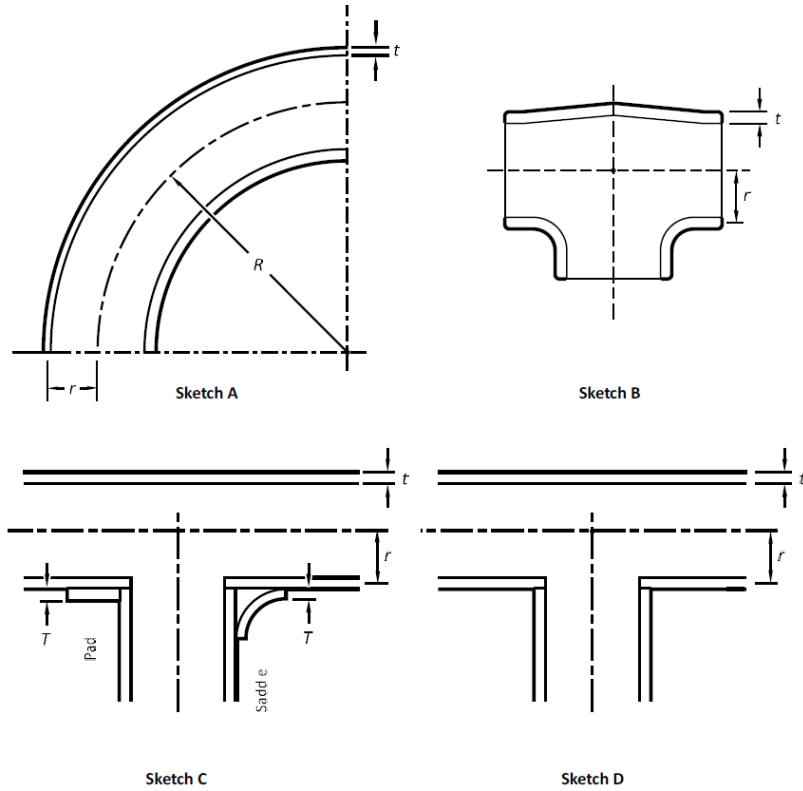
Thermal expansion range from T_{ref} to T_2 as maximum(T_2, T_{ref})

Thermal expansion range from T_1 to T_2 as maximum(T_1, T_2)

Oil and gas pipeline systems
CSA Z662 (2019)

Table 4.8
Flexibility and stress intensification factors
(See Clauses 4.8.7 and 11.14.2.)

Ⓢ There is a commentary available for this Table.



(Continued)

Oil and gas pipeline systems
CSA Z662 (2019)

Table 4.8 (Concluded)

Description	Flexibility factor, κ^*	Stress intensification factor, i^*	Description	Flexibility factor, κ^*	Stress intensification factor, i^*	Flexibility characteristic, h	See sketch
Buttwelded joint, reducer, or welding neck flange	1	1.0	Welding elbow or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{tR}{r^2}$	A
Double-welded slip-on or socket welding flange	1	1.2	Welding tee per CSA Z245.11	1	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{t}{r}$	B
Fillet-welded joint or single-welded socket welding flange	1	1.3	Reinforced fabricated tee with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t+1/27)^{5/2}}{t^{3/2}r}$	C
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6	Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	D
Screwed pipe joint or screwed flange	1	2.3					
Corrugated pipe, straight or curved, or creased bend‡	5	2.5					

* The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for elbows, and to the intersection point for tees.

† Where flanges are attached to one or both ends, the values of κ and i in this Table shall be multiplied by the following factors:

- a) one end flanged: $(h)^{1/6}$
- b) both ends flanged: $(h)^{1/3}$

‡ Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Note: Designers are cautioned that more comprehensive analysis than that specified in Clauses 4.6 to 4.10 can be necessary for specific cases.

Allowable Pressure

For straight pipe, the allowable pressure for a given wall thickness shall be determined by the following formula from Clause 4.3.5.1.

$$P = FLJT \left(\frac{2St}{D} \right)$$

where

P = allowable pressure

S = specified minimum yield strength, input as material property in CAEPIPE

t = minimum wall thickness = nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance (see Note below)

F = design factor = 0.8 as per Clause 4.3.6.

L = location factor (from Table 4.2), input into CAEPIPE analysis option

J = joint factor (from Table 4.3), input as material property in CAEPIPE

T = temperature factor for steel pipe (from Table 4.4), determined based on Design Temperature input into CAEPIPE

D = outside diameter

Note:

Corrosion allowance input into CAEPIPE should include corrosion/erosion allowance and allowance for grooving and threading.

Sustained + Occasional Stress (Unrestrained Piping = Un-buried Piping)

The sum of longitudinal pressure stress and the total bending stress due to sustained force (pressure, weight and other sustained mechanical loads) and occasional loads (such as wind, seismic, etc.) shall be limited in accordance with the following formula from Clause 4.8.5.

$$0.5S_h + s_B \leq SFLT$$

where

S_h = hoop stress due to pressure P , as computed using formula given in Clause 4.6.5 = $\frac{PD}{2t}$

s_B = absolute value of beam bending stresses resulting from sustained and occasional loads
 $= \frac{iM_B}{Z_C}$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter of pipe

t = minimum wall thickness = nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance (see Note above for corrosion allowance)

i = stress intensification factor (from Table 4.8)

M_B = resultant bending moment due to sustained and occasional loads

Z_C = corroded section modulus computed using corroded wall thickness = Nominal wall thickness - corrosion allowance, in which mill tolerance is not deducted.

S = specified minimum yield strength

F = design factor = 0.8 as per Clause 4.3.6

L = location factor (from Table 4.2)

T = temperature factor for steel pipe (from Table 4.4) determined based on Maximum Temperature input into CAEPIPE (T1 through T10)

Expansion Stress (Unrestrained Piping = Un-buried Piping)

The thermal expansion stress range (S_E) for those portions of pipeline systems shall be limited in accordance with the formulae given in Clauses 4.8.3 and 4.8.4.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72ST$$

where

S_b = resultant bending stress = iM_b/Z

S_t = torsional stress = $M_t/(2Z)$

M_b = resultant bending moment due to expansion loads

M_t = torsional moment due to expansion loads

Z = un-corroded section modulus

i = stress intensification factor (from Table 4.8)

S = specified minimum yield strength

T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot} .

T_{hot} = maximum(T_{opr} , T_{ref}) (see Note 3 below)

Combined Stress (Restrained Piping = Buried Piping)

For those portions of restrained pipelines, the combined stress shall be limited in accordance with the formula given in Clause 4.7.2.1.

$$S_h - S_L + s_B \leq ST$$

where

S_h = hoop stress due to pressure P , as determined using formula given in Clause 4.6.5 = $\frac{PD}{2t}$

S_L = longitudinal compressive stress as determined using the formula given in Clause 4.7.1
 = $S_L = \vartheta S_h - E_c \alpha (T_{opr} - T_{ref})$ (see Notes below)

S_B = absolute value of beam bending stresses resulting from sustained and occasional loads
 = $\frac{iM_B}{Z_C}$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter of pipe

t = minimum wall thickness

= nominal wall thickness \times (1 - mill tolerance/100) - corrosion allowance (see Note above)

i = stress intensification factor (from Table 4.8)

M_B = resultant bending moment due to sustained and occasional loads

Oil and gas pipeline systems
 CSA Z662 (2015)
 [superseded by CSA Z662 (2019)]

Z_c = corroded section modulus computed using corroded wall thickness = Nominal wall thickness – corrosion allowance, in which mill tolerance is not deducted.

ν = Poisson’s ratio, input as material property in CAEPIPE

T_{opr} = operating temperature under consideration. See Note 2 below.

T_{ref} = ambient temperature at the time of restraint = Reference temperature in CAEPIPE

E_c = modulus of elasticity of steel at T_{ref}

α = coefficient of thermal expansion at T_{opr} defined above

S = specified minimum yield strength

T = temperature factor for steel pipe (from Table 4.4), determined at T_{hot} .

T_{hot} = maximum(T_{opr}, T_{ref}) (see Note 3 below)

Note:

1. Evaluation as per Clause 4.7.2.1 (listed above) for Restrained Piping shall be performed in CAEPIPE only when the value of S_L computed as listed above is negative (compressive).

2. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE calculates longitudinal stress (S_L) due to

Thermal expansion range from T_{ref} to T1 as

$$E_c \alpha (T_{opr} - T_{ref}) = E_c \alpha_{T1} (T_1 - T_{ref})$$

Thermal expansion range from T_{ref} to T2 as

$$E_c \alpha (T_{opr} - T_{ref}) = E_c \alpha_{T2} (T_2 - T_{ref})$$

Thermal expansion range from T1 to T2 as

$$E_c \alpha (T_n - T_m) = E_c \alpha_n (T_n - T_{ref}) - E_c \alpha_m (T_m - T_{ref}), \text{ where } n = 1 \text{ and } m = 2$$

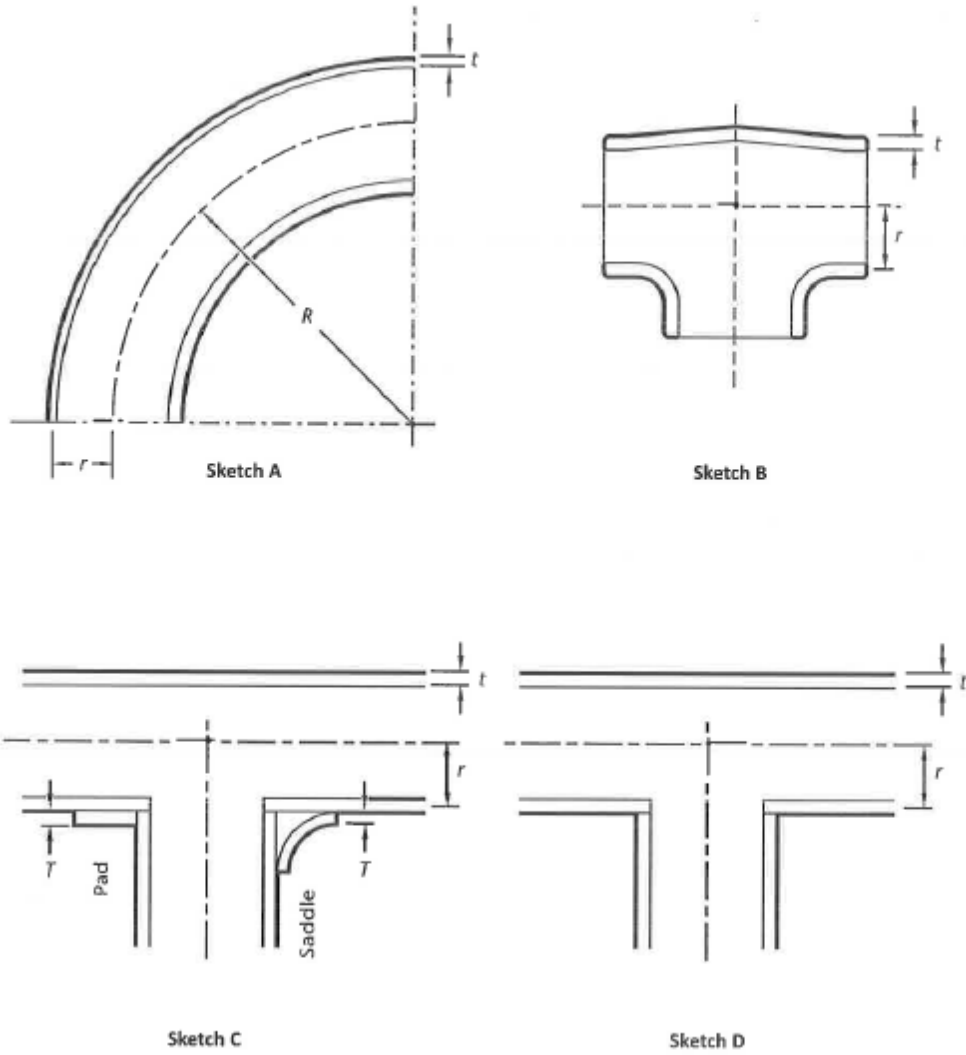
3. If there are more than one thermal load defined in CAEPIPE, for example T1 and T2, then CAEPIPE determines Temperature factor (T) as given below.

Thermal expansion range from T_{ref} to T_1 as maximum(T_1, T_{ref})

Thermal expansion range from T_{ref} to T_2 as maximum(T_2, T_{ref})

Thermal expansion range from T_1 to T_2 as maximum(T_1, T_2)

Table 4.8
Flexibility and stress intensification factors
(See Clauses 4.8.7, 11.14.2, and C.5.1.4.)



(Continued)

Oil and gas pipeline systems
 CSA Z662 (2015)
 [superseded by CSA Z662 (2019)]

Table 4.8 (Concluded)

Description	Flexibility factor, κ^*	Stress intensification factor, i^*	Description	Flexibility factor, κ^*	Stress intensification factor, i^*	Flexibility characteristic, h	See sketch
Buttwelded joint, reducer, or welding neck flange	1	1.0	Welding elbow or pipe bend†	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	$\frac{rR}{r^2}$	A
Double-welded slip-on or socket welding flange	1	1.2	Welding tee per CSA Z245.11	1	$\frac{0.9}{h^{2/3}}$	$4.4 \frac{t}{r}$	B
Fillet-welded joint or single-welded socket welding flange	1	1.3	Reinforced fabricated tee with pad or saddle	1	$\frac{0.9}{h^{2/3}}$	$\frac{(t+1/2T)^{5/2}}{t^{3/2}r}$	C
Lap joint flange (with ASME B16.9 lap joint stub)	1	1.6	Unreinforced fabricated tee	1	$\frac{0.9}{h^{2/3}}$	$\frac{t}{r}$	D
Screwed pipe joint or screwed flange	1	2.3					
Corrugated pipe, straight or curved, or creased bend‡	5	2.5					

* The flexibility factors and stress intensification factors apply to fittings of the same nominal wall thickness as the pipe used in the pipeline system and shall in no case be taken as less than unity. They apply over the effective arc length (shown by dash-dot lines in the sketches) for elbows, and to the intersection point for tees.

† Where flanges are attached to one or both ends, the values of κ and i in this Table shall be multiplied by the following factors:

a) one end flanged: $(h)^{1/6}$

b) both ends flanged: $(h)^{1/3}$

‡ Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Note: Designers are cautioned that more comprehensive analysis than that specified in Clauses 4.6 to 4.10 can be necessary for specific cases.

FRP Stress

Fiber Reinforced Plastic Pipe Stress

$$\text{Hoop stress: } S_H = \frac{PD}{2t_m}$$

$$\text{Axial stress: } S_A = \frac{PD}{4t_m} + \frac{F}{A}$$

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

$$\text{Torsional stress: } S_T = \frac{M_t}{2Z}$$

$$\text{Longitudinal maximum} = \text{Axial} + \text{Bending} = S_A + S_B$$

$$\text{Longitudinal Minimum} = \text{Axial} - \text{Bending} = S_A - S_B$$

where

P = pressure

D = outside diameter

t_m = minimum thickness

= nominal thickness x (1 – mill tolerance/100) – corrosion allowance

i_i = in-plane stress intensification factor

i_o = out of plane stress intensification factor

M_i = in plane bending moment

M_o = out of plane bending moment

M_t = torque

Z = section modulus

F = axial force

A = cross-section area

Von Mises Stress and Maximum & Minimum Principal Stresses

$$\text{Hoop stress: } S_H = \frac{PD}{2t_m}$$

$$\text{Axial stress: } S_A = \frac{PD}{4t} + \frac{F}{A}$$

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

$$\text{Torsional stress: } S_T = \frac{M_t}{2Z}$$

(a) At one Extreme Surface of Pipe

$$T1 = \frac{S_H - S_A - S_B}{2}$$

$$U1 = \sqrt{T1^2 + (S_T)^2}$$

$$\text{Sigma 1} = \sigma_1 = \frac{S_H + S_A + S_B}{2} + U1$$

$$\text{Sigma 2} = \sigma_2 = \frac{S_H + S_A + S_B}{2} - U1$$

$$\text{VonMises}_t = \sqrt{(\sigma_1)^2 - \sigma_1 \sigma_2 + (\sigma_2)^2}$$

$$\text{Max}_t = \sigma_1$$

$$\text{Min}_t = \sigma_2$$

(b) At the other Extreme Surface of Pipe

$$T2 = \frac{S_H - S_A + S_B}{2}$$

$$U2 = \sqrt{T2^2 + (S_T)^2}$$

$$\text{Sigma 1} = \sigma_1 = \frac{S_H + S_A - S_B}{2} + U2$$

$$\text{Sigma 2} = \sigma_2 = \frac{S_H + S_A - S_B}{2} - U2$$

$$\text{VonMises}_b = \sqrt{(\sigma_1)^2 - \sigma_1 \sigma_2 + (\sigma_2)^2}$$

$$\text{Max}_b = \sigma_1$$

$$\text{Min}_b = \sigma_2$$

(c) For the entire Pipe Cross-section at a Node

$$\text{VonMises Stress} = \text{Max}(\text{VonMises}_t, \text{VonMises}_b)$$

$$\text{Maximum Principal Stress} = \text{Max}(\text{Max}_t, \text{Max}_b)$$

$$\text{Minimum Principal Stress} = \text{Min}(\text{Min}_t, \text{Min}_b)$$

Piping Code=NONE

where

P = pressure

D = outside diameter

t = nominal thickness

t_m = minimum thickness = $t \times (1 - \text{mill tolerance}/100) - \text{corrosion allowance}$

i_i = in-plane stress intensification factor

i_o = out-of-plane stress intensification factor

M_i = in-plane bending moment

M_o = out-of-plane bending moment

M_t = torque

Z = section modulus

F = axial force

A = cross-section area

Stress Intensification Factors (SIFs)

CAEPIPE computes Stress Intensification Factors (SIFs) for “None” code as per SIF equations provided in ASME B31.3 as given below.

For “Piping code = None” and a non-FRP material, the in-plane and out-of-plane Stress Intensification Factors (SIF) for a 90° bend/elbow are taken to be the same as those computed using Appendix D of ASME B31.3 (appended below for reference).

For a bend with bend angle less than 90°, the in-plane and out-of-plane SIFs are computed using the procedure given in ASME/BPVC Section III, Division 1, Case N-319-2 “Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping.”

For better clarity, when piping code = None, the SIF for a bend of other than 90 deg is as follows:

The SIF for curved pipe of arc lengths between 0 and 180 deg can be estimated by multiplying the SIF for 90 deg bend as given by ASME B31.3 code by a scalar multiplier. This scalar multiplier is arrived at by taking the ratio of the involved Bending stress index $C(2z)$ values as given below.

Scalar multiplier = $[C(2z) \text{ value for the required angle bend} / C(2z) \text{ value for 90 deg bend}]$, where the $C(2z)$ values are taken from ASME/BPVC Section III, Division 1, Code Case N-319-2 document titled "Alternate Procedure for Evaluation of Stresses in Butt Welding Elbows in Class 1 Piping", which are listed below.

$C(2z) = 1.95/h^{(2/3)}$ for bend angles of 90 deg or greater

$C(2z) = 1.75/h^{(0.56)}$ for a bend angle of 45 deg

$C(2z) = 1.0$ for a bend angle of 0 deg (straight pipe)

Piping Code=NONE

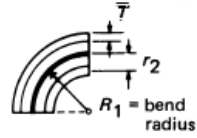
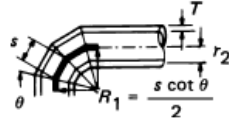
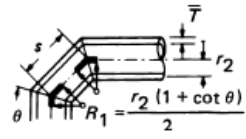
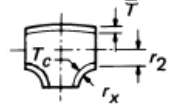
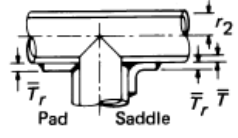
For other bend angles, the $C(2z)$ values can be interpolated between the above $C(2z)$ values.

As an example, a 45 deg bend SIF could be reasonably estimated to be {SIF for B31 90 deg bend} x [$C(2z)$ for a 45 deg bend / $C(2z)$ for a 90 deg bend]. You may note that the Scalar multiplier is 1.0 for bend angles greater than 90 deg.

APPENDIX D FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

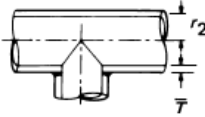
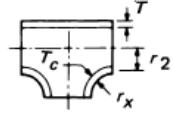
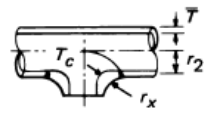
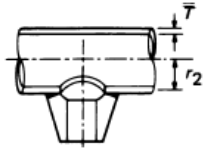
See Table D300.

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

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

Piping Code=NONE

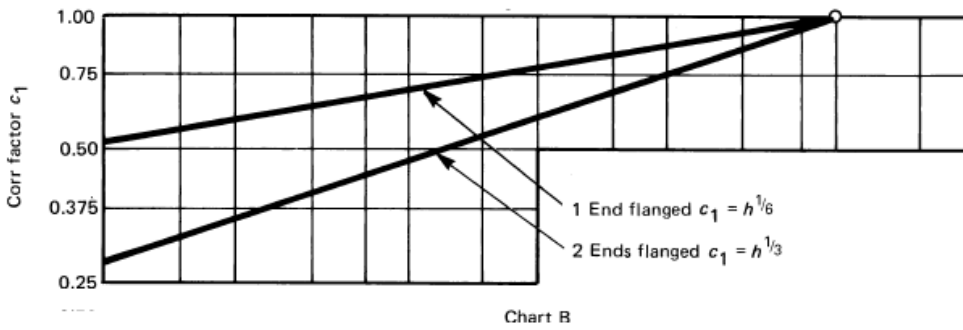
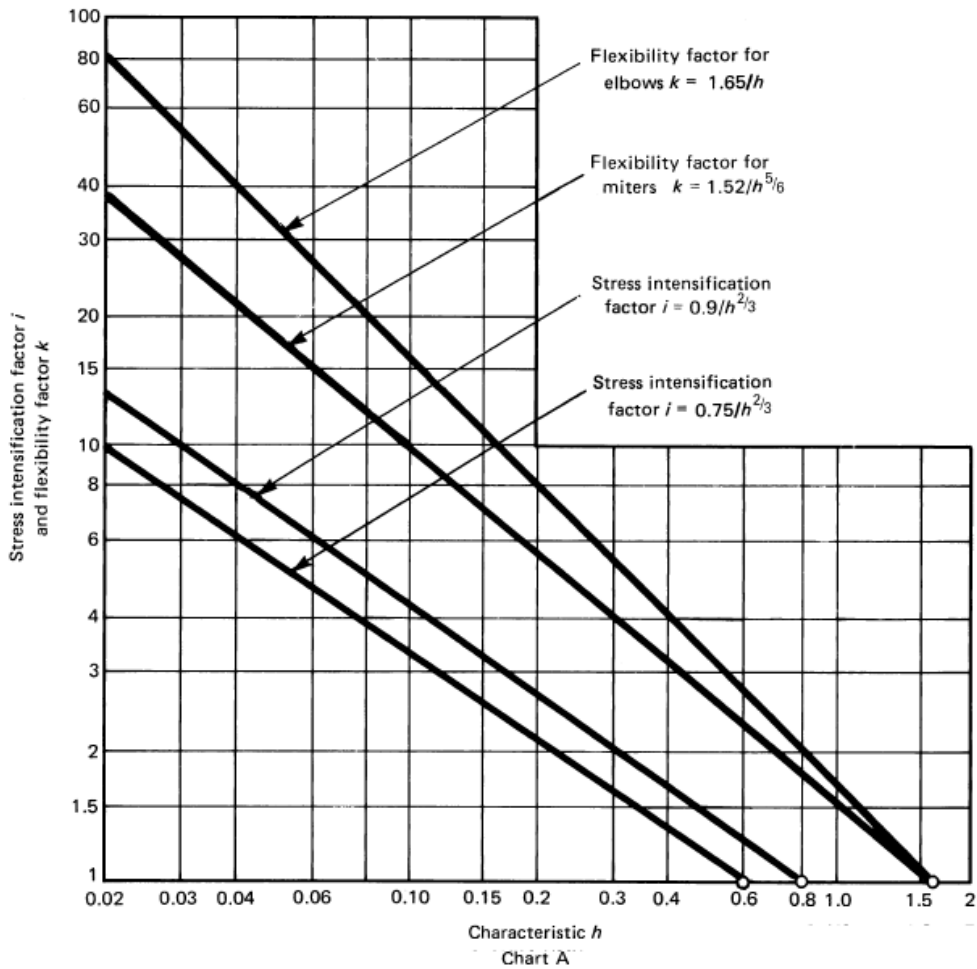
Table D300 Flexibility Factor, k , and Stress Intensification Factor, i (Cont'd)

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

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

Piping Code=NONE

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



Piping Code = NONE

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

(14)

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

NOTES:

- (1) The flexibility factor, k , in the Table applies to bending in any plane; also see para. 319.3.6. The flexibility factors, k , and stress intensification factors, i , shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.
- (2) A single intensification factor equal to $0.9/h^{2/3}$ may be used for both i_1 and i_2 if desired.
- (3) The values of k and i can be read directly from Chart A by entering with the characteristic h computed from the formulas given above. Nomenclature is as follows:
 - D_b = outside diameter of branch
 - R_1 = bend radius of welding elbow or pipe bend
 - r_x = see definition in para. 304.3.4(c)
 - r_2 = mean radius of matching pipe
 - s = miter spacing at centerline
 - \bar{T} = for elbows and miter bends, the nominal wall thickness of the fitting
 - = for tees, the nominal wall thickness of the matching pipe
 - \bar{T}_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations
 - \bar{T}_r = pad or saddle thickness
 - θ = one-half angle between adjacent miter axes
- (4) Where flanges are attached to one or both ends, the values of k and i in the Table shall be corrected by the factors C_1 , which can be read directly from Chart B, entering with the computed h .
- (5) The designer is cautioned that cast butt-welded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.
- (6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of k and i . To correct values from the Table, divide k by

$$1 + 6 \left(\frac{P_j}{E_j} \right) \left(\frac{r_2}{\bar{T}} \right)^{2/3} \left(\frac{R_1}{r_2} \right)^{1/3}$$

divide i by

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

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 $\bar{T}_c \geq 1.5 \bar{T}$, a flexibility characteristic of $4.4 \bar{T}/r_2$ may be used.
- (8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.
- (9) When \bar{T}_r is $> 1\frac{1}{2} \bar{T}$, use $h = 4 \bar{T}/r_2$.
- (10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be nonconservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.
- (11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.
- (12) For welds to socket welded fittings, the stress intensification factor is based on the assumption that the pipe and fitting are matched in accordance with ASME B16.11 and a fillet weld is made between the pipe and fitting as shown in Fig. 328.5.2C. For welds to socket welded flanges, the stress intensification factor is based on the weld geometry shown in Fig. 328.5.2B, illustration (3) and has been shown to envelope the results of the pipe to socket welded fitting tests. Blending the toe of the fillet weld smoothly into the pipe wall, as shown in the concave fillet welds in Fig. 328.5.2A, has been shown to improve the fatigue performance of the weld.
- (13) Factors shown apply to bending. Flexibility factor for torsion equals 0.9.

Operating Stress for NDE / Impact Test

This function is available to users who wish to inspect or examine high stress areas (Non-Destructive Evaluation, NDE) where piping has high “operating stresses” or examine stress areas that are higher than 35% of the allowable stress for Impact Testing as per para. 523.2.2 (f)(4) of ASME B31.5 (2017) code

*While piping codes do not consider the operating condition (W+P+T) as a required load case for code compliance, you may, however, evaluate this load case the same way as you would do for other code compliance cases such as Sustained (W+P) and Expansion (I). CAEPIPE will show columns displaying Operating Stress (S_{opt}) and Allowable stress (S_{all}) alongside the code required stresses even though the *Operating Stress is not a code requirement.**

To display these columns, you will have to turn them on first:(mouse right click) > Show Operating Stress for NDE for all codes excepting ASME B31.5. For ASME B31.5 Code, this option will change as “Show Operating Stress for Impact Test”.

The screenshot shows the CAEPIPE software window titled "Caepipe : B31.3 (2010) Code compliance [Sorted stresses] - [Sample.re...". The window contains a menu bar (File, Results, View, Options, Window, Help) and a toolbar with various icons. Below the toolbar is a table with columns for Sustained and Expansion stress data. A context menu is open over the table, with the option "Show Operating Stress for NDE" highlighted by the mouse cursor.

#	Sustained				Expansion			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA
1	80	2538	17900	0.14	30	52765	29475	1.79
2	60	2205	17900	0.12	50	50365	29475	1.
3	70	2133	17900	0.12	20A	47368	29475	1.
4	30	2033	17900	0.11	20B	33541	29475	1.
5	10	1448	17900	0.08	10	32123	29475	1.
6	40B	1053	17900	0.06	80	27166	29475	0.
7	20B	980	17900	0.05	40A	18838	29475	0.
8	20A	937	17900	0.05	60	17572	29475	0.
9	50	924	17900	0.05	70	12275	29475	0.
10	40A	902	17900	0.05	40B	10284	29475	0.35

Operating Stress for NDE / Impact Test

Caepipe : B31.5 (2016) Code compliance (Sorted stresses) - [Low-Temp Piping Model 2018.res (C:\Do...]

File Results View Options Window Help

#	Sustained				Expansion				Occasional			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA	Node	SL+S0 (psi)	1.33SH (psi)	SL+S0/1.33SH
1	2285	8850	17100	0.52	2030B	11852	21900	0.54	3040	10341	19418	0.53
2	2760	8843	17100	0.52	2030A	11409	21900	0.52	2760	10669	22743	0.47
3	2810	6161	17100	0.36	762	9438	21900	0.43	20A	8900	19418	0.45
4	2450	6159	17100	0.36	932	9276	21900	0.42	2285	10341	19418	0.53
5	20A	5189	14600	0.36	2020A	9080	21900	0.41	20B	8900	19418	0.45
6	30A	4691	14600	0.32	20B	8874	21900	0.41	3020B	8900	19418	0.45
7	3040	4531	14600	0.31	2020B	8686	21900	0.40	30A	8900	19418	0.45
8	2515	5162	17100	0.30	3040	8627	21900	0.39	630B	8900	19418	0.45
9	2635	5153	17100	0.30	260	7962	21900	0.36	60B	8900	19418	0.45
10	20B	4380	14600	0.30	3020B	7675	21900	0.35	60A	8900	19418	0.45
11	530	4350	14600	0.30	750A	7654	21900	0.35	30B	8900	19418	0.45
12	50	4151	14600	0.28	920A	7283	21900	0.33	3030A	5997	19418	0.31
13	40	4148	14600	0.28	20A	6529	21900	0.30	520B	5909	19418	0.30
14	2680	4790	17100	0.28	1140	6417	21900	0.29	310B	5872	19418	0.30
15	2560	4788	17100	0.28	1110	6129	21900	0.28	480B	5868	19418	0.30
16	220	3997	14600	0.27	60B	6120	21900	0.28	620A	5779	19418	0.30

Caepipe : B31.3 (2010) Code compliance (Sorted stresses) - [Sample.re...]

File Results View Options Window Help

#	Sustained				Expansion				Operating Stress for NDE			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA	Node	Sopr (psi)	Sall (psi)	Sopr/Sall
1	80	2538	17900	0.14	30	52765	29475	1.79	30	51580	47375	1.09
2	60	2205	17900	0.12	50	50365	29475	1.71	50	50571	47375	1.07
3	70	2133	17900	0.12	20A	47368	29475	1.61	20A	43725	47375	0.92
4	30	2033	17900	0.11	20B	33541	29475	1.14	20B	32188	47375	0.68
5	10	1448	17900	0.08	10	32123	29475	1.09	10	28281	47375	0.60
6	40B	1053	17900	0.06	80	27166	29475	0.92	40A	17801	47375	0.38
7	20B	980	17900	0.05	40A	18838	29475	0.64	80	10496	47375	0.22
8	20A	937	17900	0.05	60	17572	29475	0.60	40B	10383	47375	0.22
9	50	924	17900	0.05	70	12275	29475	0.42	70	3072	47375	0.06
10	40A	902	17900	0.05	40B	10284	29475	0.35	60	1509	47375	0.03

This allowable stress is NOT specified nor recommended by piping codes but, as mentioned above, may aid you in identifying regions of high combined stress in your piping system, which may warrant a closer examination in your engineering judgment.

Operating Stress for NDE / Impact Test

#	Sustained				Expansion				Occasional				Oper. Stress for Impact Test			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA	Node	SL+SO (psi)	1.33SH (psi)	SL+SO/1.33SH	Node	Soppr (psi)	Sall (psi)	Soppr/Sall
1	2285	8850	17100	0.52	2030B	11852	21900	0.54	3040	10341	19418	0.53	2030B	13389	5110	2.62
2	2760	8843	17100	0.52	2030A	11409	21900	0.52	2760	10669	22743	0.47	2030A	12913	5110	2.53
3	2810	6161	17100	0.36	762	9438	21900	0.43	20A	8800	19418	0.45	20B	12489	5110	2.44
4	2450	6159	17100	0.36	932	9276	21900	0.42	2285	10086	22743	0.44	762	10916	5110	2.14
5	20A	5189	14600	0.36	2020A	9080	21900	0.41	20B	7164	19418	0.37	932	10753	5110	2.10
6	30A	4691	14600	0.32	20B	8874	21900	0.41	3020B	7131	19418	0.37	2020A	10249	5110	2.01
7	3040	4531	14600	0.31	2020B	8686	21900	0.40	30A	6984	19418	0.36	3020B	10204	5110	2.00
8	2515	5162	17100	0.30	3040	8627	21900	0.39	630B	6491	19418	0.33	260	10135	5110	1.98
9	2635	5153	17100	0.30	260	7962	21900	0.36	60B	6379	19418	0.33	60B	9927	5110	1.94
10	20B	4380	14600	0.30	3020B	7675	21900	0.35	60A	6283	19418	0.32	750A	9717	5110	1.90
11	530	4350	14600	0.30	750A	7654	21900	0.35	30B	6075	19418	0.31	20A	9659	5110	1.89
12	50	4151	14600	0.28	920A	7283	21900	0.33	3030A	5997	19418	0.31	2020B	9583	5110	1.88
13	40	4148	14600	0.28	20A	6529	21900	0.30	520B	5909	19418	0.30	1140	9458	5110	1.85
14	2680	4790	17100	0.28	1140	6417	21900	0.29	310B	5872	19418	0.30	920A	9338	5110	1.83
15	2560	4788	17100	0.28	1110	6129	21900	0.28	480B	5868	19418	0.30	30B	8620	5110	1.69
16	320	3907	14600	0.27	60B	6120	21900	0.28	630A	6770	19418	0.30	30A	9501	5110	1.86

Allowable stress for Impact Test is specified for the materials given in Table 502.3.1 of ASME B31.5 (2016) Code. Accordingly, “Sall” is computed and shown above.

The equation used to calculate the operating stresses is modeled along the lines of a piping code specified stress equation. The three components of the equation are:

1. Axial stress combined with the longitudinal pressure stress,
2. Bending stress from in-plane and out-of-plane bending moments, and
3. A torsional stress from the torsion term.

The allowable stress for this case is simply a combination of the sustained and the thermal allowable stresses.

Note that the Operating Stress is calculated and shown only for the first Operating case (W+P1+T1). Details follow.

Operating Stress for NDE / Impact Test

The stress (S_{opr}) due to operating loads (pressure, weight and thermal load T_1) is calculated as

$$S_{opr} = S_a + \sqrt{(S_a)^2 + (2S_t)^2} \leq S_{all}$$

where

$$S_a = \left[\frac{PD}{4t} + \frac{F}{A} \right]_{Operating1}$$

$$S_b = \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z} \right]_{Operating1}$$

$$S_t = \left[\frac{M_t}{2Z} \right]_{Operating1}$$

P = maximum of CAEPIPE input pressures P1 through P10

D = outside diameter

t = nominal wall thickness

A = un-corroded cross-sectional area of the pipe

F = longitudinal force

i_i = in-plane stress intensification factor according to analysis code selected in CAEPIPE

i_o = out-of-plane stress intensification factor according to analysis code selected in CAEPIPE

Note: If the analysis code selected provides only the stress intensification i , then $i_i = i_o = i$.

M_i = in-plane bending moment

M_o = factor for loose type flanges (from Fig. 2-7.5)

M_t = factor for loose type flanges (from Fig. 2-7.4)

Z = un-corroded section modulus; for reduced outlets / branch connections, effective section modulus

$S_{all} = f(1.25S_{cold} + 0.25S_{hot}) + S_{hot}$ for all codes excepting ASME B31.5. For ASME B31.5, it is calculated as $0.35 S_{hot}$.

f = stress range reduction factor = $6/N^{0.2}$

N = Number of equivalent full-range thermal cycles

S_{cold} = basic allowable stress at T_{ref}

S_{hot} = basic allowable stress at CAEPIPE input temperature T_1

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

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

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

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
Section Modulus used	-	-	Corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Corroded Section Modulus; For Branch, effective section modulus
ASME B31.8					
Pipe Thickness used	Nominal Thk.	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus
ASME B31.9					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus
ASME B31.12					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus	Un-corroded Section Modulus; For Branch, effective section modulus

Note:

1. Corrosion allowance includes thickness required for threading, grooving, erosion, corrosion etc.
2. Un-corroded section modulus = section modulus calculated using the nominal thickness.
3. Corroded section modulus = section modulus calculated using the “corroded thickness”

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

corroded thickness = nominal thickness – corrosion allowance

4. Effective section modulus = section modulus calculated using effective branch thickness, which is lesser of $i_t t_b$ or t_h

where, t_b = branch nominal thickness, t_h = header nominal thickness, i_i = in-plane SIF at branch

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Rotating Equipment Qualification

API 610 (11th Edition, 2010) / ISO 13709:2009

API 610 (11th Edition, 2010) / ISO 13709:2009 for Pumps

The allowable nozzle forces and moments for pumps are taken from Table 4 of the eleventh edition of API Standard 610 / ISO 13709.

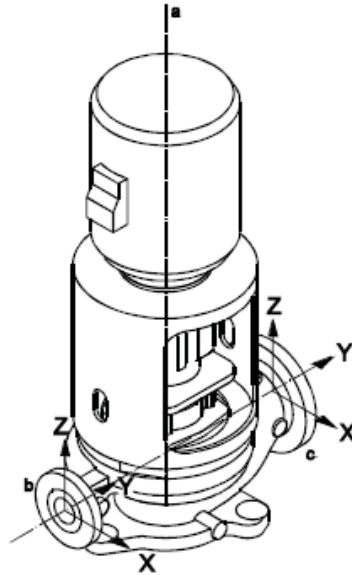
Table 4 — Nozzle loadings

	SI units								
	Nominal size of flange (DN)								
	≤ 50	80	100	150	200	250	300	350	400
	Forces (N)								
Each top nozzle									
F_X	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Y	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_Z	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Each side nozzle									
F_X	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Y	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_Z	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
Each end nozzle									
F_X	890	1 330	1 780	3 110	4 890	6 670	8 000	8 900	10 230
F_Y	710	1 070	1 420	2 490	3 780	5 340	6 670	7 120	8 450
F_Z	580	890	1 160	2 050	3 110	4 450	5 340	5 780	6 670
F_R	1 280	1 930	2 560	4 480	6 920	9 630	11 700	12 780	14 850
	Moments (N·m)								
Each nozzle									
M_X	460	950	1 330	2 300	3 530	5 020	6 100	6 370	7 320
M_Y	230	470	680	1 180	1 760	2 440	2 980	3 120	3 660
M_Z	350	720	1 000	1 760	2 580	3 800	4 610	4 750	5 420
M_R	620	1 280	1 800	3 130	4 710	6 750	8 210	8 540	9 820

Table 4 — Nozzle loadings (continued)

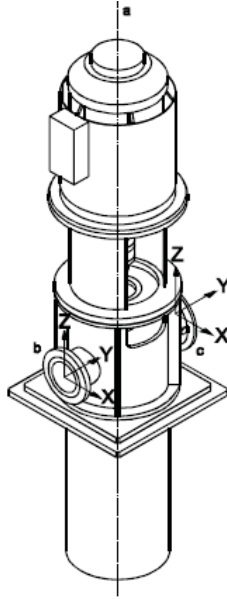
	US Customary units								
	Nominal size of flange (NPS)								
	≤ 2	3	4	6	8	10	12	14	16
Forces (lbf)									
Each top nozzle									
F_X	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Y	130	200	260	460	700	1 000	1 200	1 300	1 500
F_Z	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Each side nozzle									
F_X	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Y	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_Z	130	200	260	460	700	1 000	1 200	1 300	1 500
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Each end nozzle									
F_X	200	300	400	700	1 100	1 500	1 800	2 000	2 300
F_Y	160	240	320	560	850	1 200	1 500	1 600	1 900
F_Z	130	200	260	460	700	1 000	1 200	1 300	1 500
F_R	290	430	570	1 010	1 560	2 200	2 600	2 900	3 300
Moments (ft-lbf)									
Each nozzle									
M_X	340	700	980	1 700	2 600	3 700	4 500	4 700	5 400
M_Y	170	350	500	870	1 300	1 800	2 200	2 300	2 700
M_Z	260	530	740	1 300	1 900	2 800	3 400	3 500	4 000
M_R	460	950	1 330	2 310	3 500	5 000	6 100	6 300	7 200
NOTE 1 See Figures 20 through 24 for orientation of nozzle loads (X, Y and Z).									
NOTE 2 Each value shown above indicates range from minus that value to plus that value; for example 160 indicates a range from -160 to +160.									

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



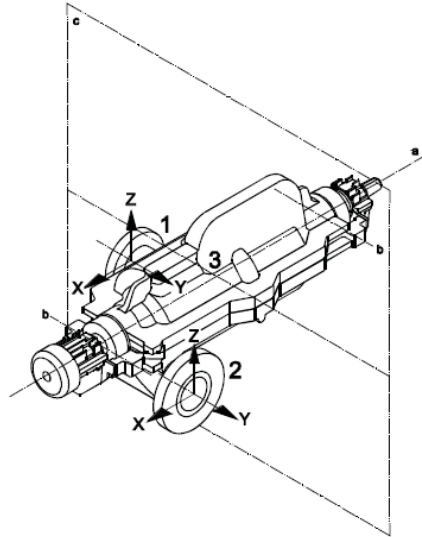
- a Shaft centreline.
- b Discharge.
- c Suction.

**Figure 21 — Coordinate system for the forces and moments in
Table 5 — Vertical in-line pumps**



- a Shaft centreline.
- b Discharge.
- c Suction.

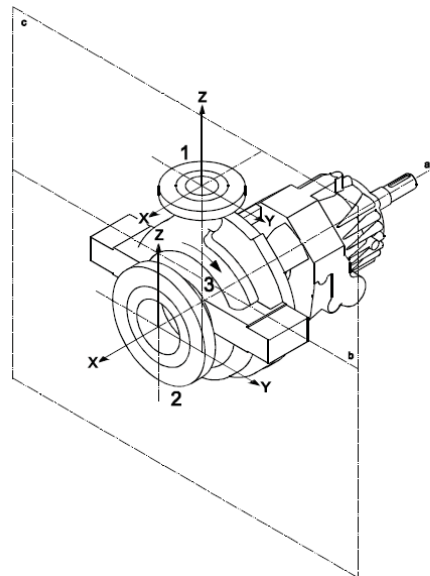
**Figure 22 — Coordinate system for the forces and moments in
Table 5 — Vertically suspended, double-casing pumps**



Key

- 1 discharge nozzle
- 2 suction nozzle
- 3 centre of pump
- a Shaft centreline.
- b Pedestal centreline.
- c Vertical plane.

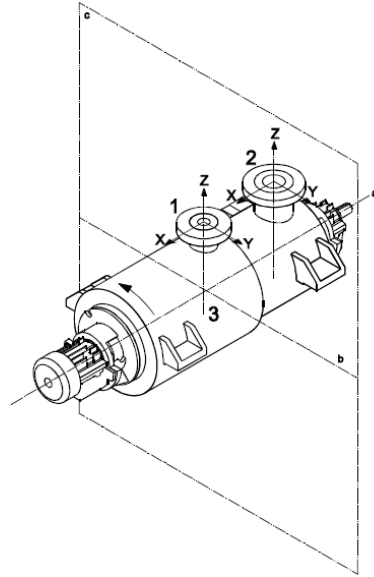
Figure 23 — Coordinate system for the forces and moments in Table 5 — Horizontal pumps with side suction and side discharge nozzles



Key

- 1 discharge nozzle
- 2 suction nozzle
- 3 centre of pump
- a Shaft centreline.
- b Pedestal centreline.
- c Vertical plane.

Figure 24 — Coordinate system for the forces and moments in Table 5 — Horizontal pumps with end suction and top discharge nozzles



- Key**
- 1 discharge nozzle
 - 2 suction nozzle
 - 3 centre of pump
 - a Shaft centreline.
 - b Pedestal centreline.
 - c Vertical plane.

Figure 25 — Coordinate system for the forces and moments in
Table 5 — Horizontal pumps with top nozzles

Criteria for Piping Design

The criteria for piping design are taken from Appendix F of the API 610.

F.1 Horizontal pumps

F.1.1 Acceptable piping configurations should not cause excessive misalignment between the pump and driver. Piping configurations that produce component nozzle loads lying within the ranges specified in Table 5 limit casing distortion to one-half the pump vendor's design criterion (see 6.3.3) and ensure pump shaft displacement of less than 250 µm (0,010 in).

F.1.2 Piping configurations that produce loads outside the ranges specified in Table 5 are also acceptable without consultation with the pump vendor if the conditions specified in F.1.2 a) through F.1.2 c) as follows are satisfied. Satisfying these conditions ensures that any pump casing distortion is within the vendor's design criteria (see 6.3.3) and that the displacement of the pump shaft is less than 380 µm (0,015 in).

- a) The individual component forces and moments acting on each pump nozzle flange shall not exceed the range specified in Table 5 (T4) by a factor of more than 2.
- b) The resultant applied force (F_{RSA} , F_{RDA}) and the resultant applied moment (M_{RSA} , M_{RDA}) acting on each pump-nozzle flange shall satisfy the appropriate interaction equations as given in Equations (F.1) and (F.2):

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

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

- c) The applied component forces and moments acting on each pump nozzle flange shall be translated to the centre of the pump. The magnitude of the resultant applied force, F_{RCA} , the resultant applied moment, M_{RCA} , and the applied moment shall be limited by Equations (F.3) to (F.5). (The sign convention shown in Figures 21 through 25 and the right-hand rule should be used in evaluating these equations.)

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

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

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

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

$$M_{XCA} = M_{XSA} + M_{XDA} - [(F_{YSA})(zD) + (F_{YDA})(zD) - (F_{ZSA})(yS) - (F_{ZDA})(yD)]/1\ 000$$

$$M_{YCA} = M_{YSA} + M_{YDA} + [(F_{XSA})(zD) + (F_{XDA})(zD) - (F_{ZSA})(xS) - (F_{ZDA})(xD)]/1\ 000$$

$$M_{ZCA} = M_{ZSA} + M_{ZDA} - [(F_{XSA})(yS) + (F_{XDA})(yD) - (F_{YSA})(xS) - (F_{YDA})(xD)]/1\ 000$$

In USC units, the constant 1 000 shall be changed to 12. This constant is the conversion factor to change millimetres to metres or inches to feet.

F.1.3 Piping configurations that produce loads greater than those allowed in F.1.2 shall be approved by the purchaser and the vendor.

NOTE In order to evaluate the actual machine distortion (at ambient conditions), the piping alignment checks required in API RP 686, Chapter 6, should be performed. API RP 686 allows only a small fraction of the permitted distortion resulting from use of the values from this annex.

F.2 Vertical in-line pumps

Vertical in-line pumps that are supported only by the attached piping may be subjected to component piping loads that are more than double the values shown in Table 4 if these loads do not cause a principal stress greater than 41 N/mm² (5 950 psi) in either nozzle. For calculation purposes, the section properties of the pump nozzles shall be based on Schedule 40 pipe whose nominal size is equal to that of the appropriate pump nozzle. Equation (F.6), Equation (F.7), and Equation (F.8) can be used to evaluate principal stress, longitudinal stress and shear stress, respectively, in the nozzles.

For SI units, the following equations apply:

$$\sigma_p = (\sigma/2) + (\sigma^2/4 + \tau^2)^{0.5} < 41 \quad (\text{F.6})$$

$$\sigma_l = [1,27 \times F_Y / (D_o^2 - D_i^2)] + [10\,200 \times D_o (M_X^2 + M_Z^2)^{0.5}] / (D_o^4 - D_i^4) \quad (\text{F.7})$$

$$\tau = [1,27 \times (F_X^2 + F_Z^2)^{0.5}] / (D_o^2 - D_i^2) + [5\,100 \times D_o (|M_Y|)] / (D_o^4 - D_i^4) \quad (\text{F.8})$$

For USC units, the following equations apply:

$$\sigma_p = (\sigma/2) + (\sigma^2/4 + \tau^2)^{0.5} < 5\,950 \quad (\text{F.9})$$

$$\sigma_l = [1,27 \times F_Y / (D_o^2 - D_i^2)] + [122 \times D_o (M_X^2 + M_Z^2)^{0.5}] / (D_o^4 - D_i^4) \quad (\text{F.10})$$

$$\tau = [1,27 \times (F_X^2 + F_Z^2)^{0.5}] / (D_o^2 - D_i^2) + [61 \times D_o (|M_Y|)] / (D_o^4 - D_i^4) \quad (\text{F.11})$$

where

σ_p is the principal stress, expressed in MPa (lbf/in²);

σ_l is the longitudinal stress, expressed in MPa (lbf/in²);

τ is the shear stress, expressed in MPa (lbf/in²);

F_X is the applied force on the X axis;

F_Y is the applied force on the Y axis;

F_Z is the applied force on the Z axis;

M_X is the applied moment on the X axis;

M_Y is the applied moment on the Y axis;

M_Z is the applied moment on the Z axis;

D_i, D_o are the inner and outer diameters of the nozzles, expressed in millimetres (inches).

$F_X, F_Y, F_Z, M_X, M_Y,$ and M_Z represent the applied loads acting on the suction or discharge nozzles; thus, subscripts S_A and D_A have been omitted to simplify the equations. The sign of F_Y is positive if the load puts the nozzle in tension; the sign is negative if the load puts the nozzle in compression. One should refer to Figure 20 and the applied nozzle loads to determine whether the nozzle is in tension or compression. The absolute value of M_Y should be used in Equations (F.8) to (F.11).

F.3 Nomenclature

The following definitions apply to the sample problems in F.4

where

- C** is the centre of the pump. For pump types OH2 and BB2 with two support pedestals, the centre is defined by the intersection of the pump shaft centreline and a vertical plane passing through the centre of the two pedestals (see Figure 23 and Figure 24). For pump types BB1, BB3, BB4 and BB5 with four support pedestals, the centre is defined by the intersection of the pump shaft centreline and a vertical plane passing midway between the four pedestals (see Figure 22);
- D** is the discharge nozzle;
- D_i is the inside diameter of Schedule 40 pipe whose nominal size is equal to that of the pump nozzle in question, expressed in millimetres (inches);
- D_o is the outside diameter of Schedule 40 pipe whose nominal size is equal to that of the pump nozzle in question, expressed in millimetres (inches);
- F** is the force, expressed in newtons (pounds force);
- F_R is the resultant force. (F_{RSA} and F_{RDA} are calculated by the square root of the sum of the squares method using the applied component forces acting on the nozzle flange. F_{RST4} and F_{RDT4} are extracted from Table 4, using the appropriate nozzle size);
- M** is the moment, expressed in newton metres (foot-pounds force);
- M_R is the resultant moment. (M_{RSA} and M_{RDA} are calculated by the square root of the squares method using the applied component moments acting on the nozzle flange. M_{RST4} and M_{RDT4} are extracted from Table 4 using the appropriate nozzle size);
- σ_p is the principal stress, expressed in megapascals (pounds force per square inch);
- σ_l is the longitudinal stress, expressed in newtons per square millimetre (pounds per square inch);
- τ is the shear stress, expressed in newtons per square millimetre (pounds per square inch);
- S** is the suction nozzle;
- x, y, z are the location coordinates of the nozzle flanges with respect to the centre of the pump, expressed in millimetres (inches);
- X, Y, Z** are the directions of the load (see Figures 20 to 24);
- Subscript A is an applied load;
- Subscript T4 is a load extracted from Table 4.

Verification of API 610 Pump Compliance

Implementation of API 610 Pump Compliance in CAEPIPE is verified using the sample provided in API Standard 610, 11th Edition and presented in this section.

F.4.3 Example 1B — USC units

F.4.3.1 Problem

For an overhung end-suction process pump (OH2), the nozzle sizes and location coordinates are as given in Table F.4. The applied nozzle loadings are as given in Table F.5. The problem is to determine whether the conditions specified in F.1.2 a), F.1.2 b), and F.1.2 c) are satisfied.

Table F.4 — Nozzle sizes and location coordinates for Example 1B

Dimensions in inches

Nozzle	Size	x	y	z
Suction	10	+10,50	0	0
Discharge	8	0	-12,25	+15

Table F.5 — Applied nozzle loadings for Example 1B

Force	Value lbf	Moment	Value ft-lbf
—	—	Suction	—
F_{XSA}	+2 900	M_{XSA}	-1 000
F_{YSA}	0	M_{YSA}	-3 700 ^a
F_{ZSA}	-1 990	M_{ZSA}	-5 500
—	—	Discharge	—
F_{XDA}	+1 600	M_{XDA}	+500
F_{YDA}	-100	M_{YDA}	-2 500
F_{ZDA}	+1 950	M_{ZDA}	-3 600

^a See F.4.1.2.1.

CAEPIPE model corresponding to the above API Publication sample

The screenshot shows the CAEPIPE software interface with a window titled "Caepipe: Layout (8) - [API610_Example_1B.mod (D:\KPDevelopm...". The menu bar includes File, Edit, View, Options, Loads, Misc, Window, and Help. The toolbar contains icons for file operations and viewing. Below the toolbar is a table representing the model layout:

#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matt	Sect	Load	Data
1	Title = Verification of Horizontal Pump								
2	Example 1B of API 610, 11th Edition Publication								
3	10	From	0'10-1/2"						Anchor
4	10	Location							Force
5	20		1'0"			1	10	1	
6	50	From		-1'0-1/4"	1'3"				Anchor
7	50	Location							Force
8	60				1'0"	1	8	1	
9									

Caepipe : Pipe Sections (2) - [API610_Example_1B.mod (D:\KPDevelopment\Ve...]

File Edit View Options Misc Window Help

#	Name	Nom Dia	Sch	OD (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Thk (inch)	Lin.Dens (lb/ft3)	Lin.Thk (inch)	Soil
1	10	10"	STD	10.75	0.365							
2	8	8"	STD	8.625	0.322							
3												

Caepipe : Materials (1) - [API610_Example_1B.mod (D:\KPDevelopment\Verifi...]

File Edit View Options Misc Window Help

#	Name	Description	Type	Density (lb/in3)	Nu	Joint factor	#	Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
1	1	A53 Grade B	CS	0.0	0.3	1.00	1	-100	30.2E+6	5.65E-6	15000
2							2	70	29.5E+6	6.07E-6	15000
							3	200	28.8E+6	6.38E-6	15000
							4	300	28.3E+6	6.60E-6	15000
							5	400	27.7E+6	6.82E-6	15000
							6	500	27.3E+6	7.02E-6	15000
							7	600	26.7E+6	7.23E-6	15000
							8	650	26.1E+6	7.34E-6	15000
							9	700	25.5E+6	7.44E-6	14400
							10	750	24.9E+6	7.55E-6	13000
							11	800	24.2E+6	7.65E-6	10800

Force at node 10

FX: 2900 (lb) FY: FZ: -1990 (lb)

MX: -1000 (ft-lb) MY: -3700 (ft-lb) MZ: -5500 (ft-lb)

Add to W+P Add to T1

OK Cancel

Force at node 50

FX: 1600 (lb) FY: -100 (lb) FZ: 1950 (lb)

MX: 500 (ft-lb) MY: -2500 (ft-lb) MZ: -3600 (ft-lb)

Add to W+P Add to T1

OK Cancel

Pump #1

Description: Example 1B Horizontal Vertical inline ANSI/HI 9.6.2

Pump type: Pump size: Material group: Mounting type: Temperature: (F)

Suction Node: 10 Location: Top Side End

Discharge Node: 50 Location: Top Side End

Shaft axis direction: X comp: 1.000 Y comp: Z comp: Location of the center of pump: X: Y: 0.001 Z: (ft-in)

OK Cancel

Results from API 610, 11th Edition

F.4.3.2 Solution

F.4.3.2.1 A check of condition of F.1.2 a) is as follows:

For the 10 in end suction nozzle:

$$|F_{XSA}/F_{XST4}| = |2\,900/1\,500| = 1,93 < 2,00$$

$$|F_{YSA}/F_{YST4}| = |0/1\,200| = 0 < 2,00$$

$$|F_{ZSA}/F_{ZST4}| = |-1\,990/1\,000| = 1,99 < 2,00$$

$$|M_{XSA}/M_{XST4}| = |-1\,000/3\,700| = 0,27 < 2,00$$

$$|M_{YSA}/M_{YST4}| = |-3\,700/1\,800| = 2,06 > 2,00$$

$$|M_{ZSA}/M_{ZST4}| = |-5\,500/2\,800| = 1,96 < 2,00$$

For the 8 in top discharge nozzle:

$$|F_{XDA}/F_{XDT}| = |1\,600/850| = 1,88 < 2,00$$

$$|F_{YDA}/F_{YDT}| = |-100/700| = 0,14 < 2,00$$

$$|F_{ZDA}/F_{ZDT}| = |1\,950/1\,100| = 1,77 < 2,00$$

$$|M_{XDA}/M_{XDT}| = |500/2\,600| = 0,19 < 2,00$$

$$|M_{YDA}/M_{YDT}| = |-2\,500/1\,300| = 1,93 < 2,00$$

$$|M_{ZDA}/M_{ZDT}| = |-3\,600/1\,900| = 1,89 < 2,00$$

F.4.3.2.2 A check of condition F.1.2 b) is as follows:

For the suction nozzle, F_{RSA} and M_{RSA} are determined using the square root of the sum of the squares method:

$$F_{RSA} = [(F_{XSA})^2 + (F_{YSA})^2 + (F_{ZSA})^2]^{0,5} = [(2\,900)^2 + (0)^2 + (-1\,990)^2]^{0,5} = 3\,517$$

$$M_{RSA} = [(M_{XSA})^2 + (M_{YSA})^2 + (M_{ZSA})^2]^{0,5} = [(-1\,000)^2 + (-3\,599)^2 + (-5\,500)^2]^{0,5} = 6\,649$$

Referring to Equation (F.1),

$$F_{RSA}/(1,5 \times F_{RST4}) + M_{RSA}/(1,5 \times M_{RST4}) < 2$$

$$3\,517/(1,5 \times 2\,200) + 6\,649/(1,5 \times 5\,000) < 2$$

$$1,95 < 2$$

For the discharge nozzle, F_{RDA} and M_{RDA} are determined by the same method used to find F_{RSA} and M_{RSA} :

$$F_{RDA} = [(F_{XDA})^2 + (F_{YDA})^2 + (F_{ZDA})^2]^{0,5} = [(+1\ 600)^2 + (-100)^2 + (+1\ 950)^2]^{0,5} = 2\ 524$$

$$M_{RDA} = [(M_{XDA})^2 + (M_{YDA})^2 + (M_{ZDA})^2]^{0,5} = [(+500)^2 + (-2\ 500)^2 + (-3\ 600)^2]^{0,5} = 4\ 411$$

Referring to Equation (F.2),

$$F_{RDA}/(1,5 \times F_{RDT4}) + M_{RDA}/(1,5 \times M_{RDT4}) < 2$$

$$2\ 524/(1,5 \times 1\ 560) + 4\ 411/(1,5 \times 3\ 500) < 2$$

$$1,92 < 2$$

The loads acting on each nozzle satisfy the appropriate interaction equation, so the condition specified in F.1.2 b) is satisfied.

Results from CAEPIPE Rotating Equipment Report

API 610 (11th ed.), Sep 2010 / ISO 13709 report for pump - Example 1B

Load case: Operating (W+P1+T1)

Shaft axis: Xcomp = 1.000, Ycomp = 0.000, Zcomp = 0.000

Center location: X = 0, Y = 0.001, Z = 0 (ft/in)

Suction node: 10, Location: (End), Size: 10.000 (inch)

Offsets from center: dx = 0'10-1/2", dy = -0.001, dz = 0 (ft/in)

Check of condition F.1.1 for suction node 10:

	Calculated	Allowed	Ratio	Status
FX (lb)	2900	1500	1.933	—
FY (lb)	0	1200	0.000	OK
FZ (lb)	-1990	1000	1.990	—
FR (lb)	3517	2200	1.599	—
MX (ft-lb)	-1000	3700	0.270	OK
MY (ft-lb)	-3700	1800	2.056	Failed
MZ (ft-lb)	-5500	2800	1.964	—
MR (ft-lb)	6704	5000	1.341	—

Condition F.1.2.a for suction node 10 failed ***

Discharge node: 50, Location: (Top), Size: 8.000 (inch)

Offsets from center: dx = 0, dy = -1.0218, dz = 1'3" (ft/in)

Check of condition F.1.1 for discharge node 50:

	Calculated	Allowed	Ratio	Status
FX (lb)	1600	850	1.882	—
FY (lb)	-100	700	0.143	OK
FZ (lb)	1950	1100	1.773	—
FR (lb)	2524	1560	1.618	—
MX (ft-lb)	500	2600	0.192	OK
MY (ft-lb)	-2500	1300	1.923	—
MZ (ft-lb)	-3600	1900	1.895	—
MR (ft-lb)	4411	3500	1.260	—
(FR/1.5FRT4) + (MR/1.5MRT4) =			1.919	OK

Coordinate System for ASME B73.1, B73.3 and B73.5M horizontal end suction pumps

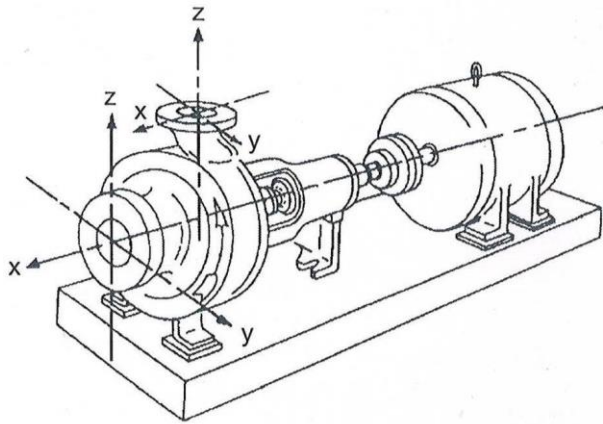


Figure 1 – Coordinate system for ASME B73.1, B73.3 and B73.5M horizontal end suction pumps

A1.0 Definitions (refer to Figure above)

F_{xs} = applied force on X-axis on suction nozzle, to be assessed using equation sets 1-5

F_{ys} = applied force on Y-axis on suction nozzle, to be assessed using equation sets 1-5

F_{zs} = applied force on Z-axis on suction nozzle, to be assessed using equation sets 1-5

M_{xs} = applied moment about X-axis on suction nozzle, to be assessed using equation sets 1-5

M_{ys} = applied moment about Y-axis on suction nozzle, to be assessed using equation sets 1-5

M_{zs} = applied moment about Z-axis on suction nozzle, to be assessed using equation sets 1-5

F_{xd} = applied force on X-axis on discharge nozzle, to be assessed using equation sets 1-5

F_{yd} = applied force on Y-axis on discharge nozzle, to be assessed using equation sets 1-5

F_{zd} = applied force on Z-axis on discharge nozzle, to be assessed using equation sets 1-5

M_{xd} = applied moment about X-axis on discharge nozzle, to be assessed using equation sets 1-5

M_{yd} = applied moment about Y-axis on discharge nozzle, to be assessed using equation sets 1-5

M_{zd} = applied moment about Z-axis on discharge nozzle, to be assessed using equation sets 1-5

$F_{xs\ max}$ = maximum value of force on X-axis on suction nozzle, to be used with equation sets 1-5

$F_{ys\ max}$ = maximum value of force on Y-axis on suction nozzle, to be used with equation sets 1-5

$F_{zs\ max}$ = maximum value of force on Z-axis on suction nozzle, to be used with equation sets 1-5

$M_{xs \max}$ = maximum value of moment about X-axis on suction nozzle, to be used with equation sets 1-5

$M_{ys \max}$ = maximum value of moment about Y-axis on suction nozzle, to be used with equation sets 1-5

$M_{zs \max}$ = maximum value of moment about Z-axis on suction nozzle, to be used with equation sets 1-5

$F_{xd \max}$ = maximum value of force on X-axis on discharge nozzle, to be used with equation sets 1-5

$F_{yd \max}$ = maximum value of force on Y-axis on discharge nozzle, to be used with equation sets 1-5

$F_{zd \max}$ = maximum value of force on Z-axis on discharge nozzle, to be used with equation sets 1-5

$M_{xd \max}$ = maximum value of moment about X-axis on discharge nozzle, to be used with equation sets 1-5

$M_{yd \max}$ = maximum value of moment about Y-axis on discharge nozzle, to be used with equation sets 1-5

$M_{zd \max}$ = maximum value of moment about Z-axis on discharge nozzle, to be used with equation sets 1-5

Group 1 is defined as ASME B73.1, B73.3 and B73.5M sizes AA and AB. Two/four-pole, 60 cycle speed and up to 20/10 hp, respectively.

Group 2 is defined as ASME B73.1, B73.3 and B73.5M sizes A05, A10, A20, A30, A40, A50, A60, A70 and A80. Two/four-pole, 60-cycle speed and up to 130/65 hp, respectively.

Group 3 is defined as ASME B73.1, B73.3 and B73.5M sizes A90, A100, A110 and A120. Four/six-pole, 60-cycle speed and up to 220/146 hp, respectively.

A1.1 ASME B73.1 pump assessment of applied nozzle loads

Loads given in Tables B through E are applicable for ASME B73.1 pumps constructed of ASTM A351/A351M – Grade CF8M (Type 316SS) operated between 20 and 1000 F and mounted on a grouted metal baseplate with anchor bolts.

For an individual force or moment, pumps must be capable of satisfactory operation when subjected to loads shown in Table B while meeting the criteria of equation set 1 provided in Table A below.

For a combination of more than one force and/or moment, pumps must be capable of satisfactory operation when subjected to the loads in Tables C through E while meeting the criteria of equation sets 2 – 5 of Table A given below. When combining loads, the absolute value of any individual load must not exceed the value given in Table B.

Rotodynamic Pumps - ANSI/HI 9.6.2 - 2011

Adjustment of the tabulated maximum forces and moments are performed if any of the following occur.

- a. Temperature is above 100⁰ F.
- b. The pump material construction is not ASTM A351/A351M – Grade CF8M.
- c. The base is not a fully grouted metal baseplate with anchor bolts.

Table A – Equation sets 1 through 5 (using the maximum forces and moments of the referenced tables, applied loads shall satisfy the criteria defined by these equations)

Set	Equation	Reference	Remarks
1	$\left| \frac{F_{Xs}}{F_{Xsmax}} \right| \leq 1.0, \left| \frac{F_{Ys}}{F_{Ysmax}} \right| \leq 1.0, \left| \frac{F_{Zs}}{F_{Zsmax}} \right| \leq 1.0, \left| \frac{M_{Xs}}{M_{Xsmax}} \right| \leq 1.0, \left| \frac{M_{Ys}}{M_{Ysmax}} \right| \leq 1.0, \left| \frac{M_{Zs}}{M_{Zsmax}} \right| \leq 1.0$ $\left| \frac{F_{Xd}}{F_{Xdmax}} \right| \leq 1.0, \left| \frac{F_{Yd}}{F_{Ydmax}} \right| \leq 1.0, \left| \frac{F_{Zd}}{F_{Zdmax}} \right| \leq 1.0, \left| \frac{M_{Xd}}{M_{Xdmax}} \right| \leq 1.0, \left| \frac{M_{Yd}}{M_{Ydmax}} \right| \leq 1.0, \left| \frac{M_{Zd}}{M_{Zdmax}} \right| \leq 1.0$	Table B	Individual loading
2	$\frac{1}{2} \times \left[ \left| \frac{F_{Xs}}{F_{Xsmax}} \right| + \left| \frac{F_{Ys}}{F_{Ysmax}} \right| + \left| \frac{F_{Zs}}{F_{Zsmax}} \right| + \left| \frac{M_{Xs}}{M_{Xsmax}} \right| + \left| \frac{M_{Ys}}{M_{Ysmax}} \right| + \left| \frac{M_{Zs}}{M_{Zsmax}} \right| + \left| \frac{F_{Xd}}{F_{Xdmax}} \right| + \left| \frac{F_{Yd}}{F_{Ydmax}} \right| + \left| \frac{F_{Zd}}{F_{Zdmax}} \right| + \left| \frac{M_{Xd}}{M_{Xdmax}} \right| + \left| \frac{M_{Yd}}{M_{Ydmax}} \right| + \left| \frac{M_{Zd}}{M_{Zdmax}} \right| \right] \leq 1.0$	Table C	Nozzle stress, hold-down bolt stress, pumps slippage
3	$-1.0 \leq a = \frac{F_{Ys}}{F_{Ysmax}} + \frac{M_{Xs}}{M_{Xsmax}} + \frac{M_{Ys}}{M_{Ysmax}} + \frac{M_{Zs}}{M_{Zsmax}} + \frac{F_{Yd}}{F_{Ydmax}} + \frac{M_{Xd}}{M_{Xdmax}} + \frac{M_{Yd}}{M_{Ydmax}} + \frac{M_{Zd}}{M_{Zdmax}} \leq 1.0$	Table D	y-axis movement
4	$-1.0 \leq b = \frac{F_{Xs}}{F_{Xsmax}} + \frac{F_{Zs}}{F_{Zsmax}} + \frac{M_{Xs}}{M_{Xsmax}} + \frac{M_{Ys}}{M_{Ysmax}} + \frac{M_{Zs}}{M_{Zsmax}} + \frac{F_{Xd}}{F_{Xdmax}} + \frac{F_{Yd}}{F_{Ydmax}} + \frac{F_{Zd}}{F_{Zdmax}} + \frac{M_{Xd}}{M_{Xdmax}} + \frac{M_{Yd}}{M_{Ydmax}} + \frac{M_{Zd}}{M_{Zdmax}} \leq 1.0$	Table E	z-axis movement
5	$\sqrt{a^2 + b^2} \leq 1.0$	Equation sets 3 and 4	Combined axis movement

Table B – Maximum forces and moments for use with equation set 1 to assess applied loads

ASME B73 Designation	Pump Size	Suction						Discharge					
		Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
		$F_{xs\ max}$	$F_{ys\ max}$	$F_{zs\ max}$	$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$	$F_{xd\ max}$	$F_{yd\ max}$	$F_{zd\ max}$	$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
AA	1.5 × 1 × 6	1050	750	750	720	170	170	800	1350	3000	410	410	410
AB	3 × 1.5 × 6	1050	1240	1250	900	490	490	800	1350	3000	500	550	510
A10	3 × 2 × 6	1050	1050	1050	900	220	220	800	1350	3000	500	1000	510
AA	1.5 × 1 × 8	1050	1210	1210	720	190	190	800	1350	3000	360	360	360
---	3 × 1.5 × 8 ^a	1050	1240	1250	900	490	490	800	1350	3000	440	440	440
A50	3 × 1.5 × 8	2700	1350	1500	1300	370	370	1400	1350	3250	460	460	460
A60	3 × 2 × 8	2700	1350	1500	1300	600	600	1400	1350	3250	660	660	660
A70	4 × 3 × 8	2700	1350	1500	1300	350	350	1400	1350	3250	1200	1460	690
A05	2 × 1 × 10	2340	960	960	1270	220	220	1400	1350	3250	660	660	660
A50	3 × 1.5 × 10	2700	1350	1500	1300	420	420	1400	1350	3250	370	370	370
A60	3 × 2 × 10	2700	1350	1480	1300	310	310	1400	1350	3250	560	560	560
A70	4 × 3 × 10	2300	1350	1500	1300	310	310	1400	1350	3250	1200	1460	690
A80	6 × 4 × 10	2700	1350	1500	1300	1100	1100	1400	1350	3250	1200	1500	690
A20	3 × 1.5 × 13	2700	1350	1500	1300	670	670	1400	1350	3250	530	530	530
A30	3 × 2 × 13	1920	1230	1230	1300	350	350	1400	1350	3250	1200	1270	690
A40	4 × 3 × 13	2700	1350	1500	1300	400	400	1400	1350	3250	1200	1500	690
A80	6 × 4 × 13	2700	1350	1500	1300	1300	1100	1400	1350	3250	1200	1500	690
A90	8 × 6 × 13	3500	3180	2000	1500	1170	1170	1500	3000	3500	1250	2840	2840
A100	10 × 8 × 13	3500	3180	2000	1500	2000	2150	1500	3000	3500	1250	2840	2840
A110	8 × 6 × 15	3500	3180	2000	1500	1480	1480	1500	3000	3500	1250	2840	2840
A120	10 × 8 × 15	3500	3180	2000	1500	1130	1130	1500	3000	3500	1250	2840	2840

Table C- Maximum forces and moments for use with equation set 2 to assess applied loads

ASME B73 Designation	Pump Size	Suction						Discharge					
		Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
		$F_{xs\ max}$	$F_{ys\ max}$	$F_{zs\ max}$	$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$	$F_{xd\ max}$	$F_{yd\ max}$	$F_{zd\ max}$	$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
AA	1.5 × 1 × 6	2020	750	750	1830	170	170	2020	1350	6240	410	410	410
AB	3 × 1.5 × 6	2020	1240	2110	2290	490	490	2020	1350	6240	550	550	510
A10	3 × 2 × 6	2020	1050	1050	2290	220	220	2020	1350	6240	1030	1030	510
AA	1.5 × 1 × 8	2020	1210	1210	1830	190	190	2020	1350	6240	360	360	360
—	3 × 1.5 × 8 ^a	2020	1240	1640	2290	490	490	2020	1350	6240	440	440	440
A50	3 × 1.5 × 8	2700	1350	1820	3730	370	370	2020	1350	6240	460	460	460
A60	3 × 2 × 8	2700	1350	2490	3730	600	600	1970	1350	6240	660	660	660
A70	4 × 3 × 8	2700	1350	1840	3730	350	350	2020	1350	6240	1460	1460	690
A05	2 × 1 × 10	2340	960	960	3640	220	220	2020	1350	6240	660	660	660
A50	3 × 1.5 × 10	2700	1350	1910	3730	420	420	1940	1350	6240	370	370	370
A60	3 × 2 × 10	2700	1350	1480	3730	310	310	2020	1350	6240	560	560	560
A70	4 × 3 × 10	2300	1350	1640	3730	310	310	2020	1350	6240	1460	1460	690
A80	6 × 4 × 10	2700	1350	6240	3730	1100	1100	2020	1350	6240	3100	3100	690
A20	3 × 1.5 × 13	2700	1350	3060	3730	670	670	2020	1350	6240	530	530	530
A30	3 × 2 × 13	1920	1230	1230	3730	350	350	2020	1350	6240	1460	1460	690
A40	4 × 3 × 13	2700	1350	2390	3730	400	400	2020	1350	6240	1730	1730	690
A80	6 × 4 × 13	2700	1350	6240	3730	4980	1100	2020	1350	6240	2150	2150	690
A90	8 × 6 × 13	6360	3180	5080	8970	1170	1170	6360	3180	13,460	6780	3850	2840
A100	10 × 8 × 13	6360	3180	13,460	8970	2450	2150	6360	3180	13,460	8970	7220	2840
A110	8 × 6 × 15	6360	3180	6680	8970	1480	1480	6360	3180	13,460	6560	3720	2840
A120	10 × 8 × 15	6360	3180	5130	8970	1130	1130	6360	3180	13,460	8970	9060	2840

Table D – Maximum forces and moments for use with equation set 3 to assess applied loads

Pump Group	Suction						Discharge					
	Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
		$F_{ys\ max}$		$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$		$F_{yd\ max}$		$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
Group 1		-2000		900	1200	1250		1500		-500	1500	1250
Group 2		-3500		1300	1300	3000		2500		-1200	1500	3000
Group 3		-5000		1500	2000	4000		3000		-1250	5000	4000

Table E – Maximum forces and moments for use with equation set 4 to assess applied loads

Pump Group	Suction						Discharge					
	Forces (lb)			Moments (lb•ft)			Forces (lb)			Moments (lb•ft)		
	$F_{xs\ max}$		$F_{zs\ max}$	$M_{xs\ max}$	$M_{ys\ max}$	$M_{zs\ max}$	$F_{xd\ max}$	$F_{yd\ max}$	$F_{zd\ max}$	$M_{xd\ max}$	$M_{yd\ max}$	$M_{zd\ max}$
Group 1	1050		-1250	1500	1200	-2500	800	2000	-3000	-1500	1000	-2500
Group 2	3500		-1500	1500	1300	-3500	1400	2500	-3250	-1500	2150	-3500
Group 3	3500		-2000	1500	4100	-4000	1500	4000	-3500	-1500	5000	-4000

A1.2 Nozzle loads and adjustment factors

The loads in the tables are multiplied by adjustment factors when applicable. The lowest correction factor is applied when more than one adjustment factor is involved. For instance, if the pump is an ASME B73.5 pump (90% reduction factor) mounted on a fully grouted nonmetallic baseplate (80% reduction factor), then the reduction factor for Tables B through E is 80%

A1.2.1 Alternate pump mounting

For alternate mounting conditions, the pump must be mounted on a base that can, as a minimum, withstand the applied nozzle loads combined with normal operating loads.

A1.2.1.1 Still-mounted metal baseplate

100% of the values in Table C and 90% of values in Table D and Table E are used. If after adjusting the value for a particular load in Tables D and E, the absolute value of any adjusted value is lower than the corresponding load in Table B, then the lower value is substituted into Table B.

A1.2.1.2 UngROUTED metal baseplate that is anchored down

100% of the values in Table C and 80% of the values in Tables D and E are used. If after adjusting the value for a particular load in Tables D and E, the absolute value of any adjusted value is lower than the corresponding load in Table B, then the lower value is substituted into Table B.

A1.2.1.3 Grouted nonmetal baseplate with anchor bolts

80% of the values in Tables B through E are used.

A1.2.1.4 UngROUTED nonmetal baseplate that is anchored down

70% of the values in Tables B through E are used.

A1.2.2 Temperature and material adjustment factors for ASME B73.1 and ASME B73.3 pumps

A1.2.2.1 Adjustment factors

For temperatures above 100⁰ F and/or the use of a material other than ASTM A351/351M – Grade CF8M, the loads in Table C are reduced by multiplying the proper adjustment factor from Table A1.2.2b.

If after adjusting the value for a particular load in Table C, any adjusted value is lower than the corresponding load in Table B, then the lower value is substituted in Table B.

Rotodynamic Pumps - ANSI/HI 9.6.2 - 2011

Material group numbers used in Table A1.2.2b are defined in Table A1.2.2.a

Table A1.2.2a – List of material specifications as used in Table B

Material Groups		Castings	
Material Group No.	Nominal Designation	Spec. No.	Grade(s)
1.0	Ductile Iron	A395	---
1.1	Carbon Steel	A216	WCB
2.1	Type 304	A744	CF-8
2.2	Type 316	A744	CF-8M
2.3	Type 304L Type 316L	A744	CF-3 CF-3M
2.4	Type 321	---	---
2.8	CD-4MCu CD-4MCu	A744 A890	CD-4MCu CD-4MCu Grade 1A, 1B
3.1	Alloy 20	A744	CN-7M
3.2	Nickel	A494	CZ-100
3.4	Monel	A744	M-35-1 M-30C M-35-2
3.5	Inconel 600 Inconel 625 Inconel 825	A744 A744 A744	CY-40 CW-6MC Cu-5MCuC
3.7	Hastelloy B	A494	N-12MV N-7M
3.8	Hastelloy C	A494	CW-6M CW-2M CW-12MW CX-2MW

Table A1.2.2b – ASME B73.1 metallic pump temperature and material adjustment values used on Table C values

Temp, °F	Material Group No.:												
	1.0	1.1	2.1	2.2	2.3	2.4	2.8	3.1	3.2	3.4	3.5	3.7	3.8
	Ductile Iron	Carbon Steel	Austenitic Steels				Nickel and Nickel Alloys						
		Type 304	Type 316	Type 304L Type 316L	Type 321	CD-4M Cu	Alloy 20	Nickel	Monel	Inconel	Hast. B	Hast. C	
-20 to 100	0.89	1.00	1.00	1.00	0.83	1.00	1.00	0.83	0.50	0.83	1.00	1.00	1.00
200	0.83	0.94	0.83	0.86	0.70	0.98	1.00	0.77	0.50	0.74	0.93	1.00	1.00
300	0.78	0.91	0.74	0.78	0.63	0.83	1.00	0.73	0.50	0.69	0.89	1.00	1.00
400	0.73	0.88	0.65	0.72	0.58	0.69	0.98	0.67	0.50	0.67	0.85	0.98	0.98
500	0.69	0.83	0.60	0.67	0.53	0.64	0.92	0.65	0.50	0.66	0.83	0.92	0.92
600	0.65	0.76	0.58	0.63	0.50	0.60	0.84	0.63	0.50	0.66	0.80	0.84	0.84
650	0.63	0.74	0.57	0.62	0.49	0.60	0.82	0.63	---	0.66	0.78	0.82	0.82
700	---	0.74	0.56	0.60	0.48	0.58	0.79	0.62	---	0.66	0.77	0.79	0.79

Coordinate System for ASME B73.2 vertical in-line pumps

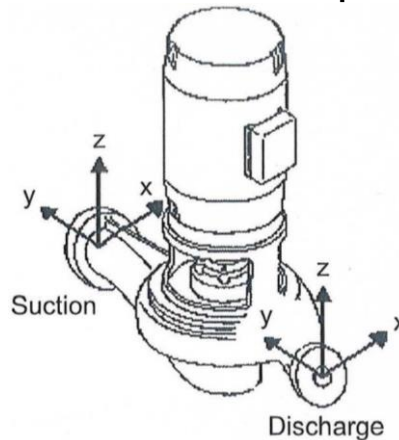


Figure 2 – Coordinate system for ASME B73.2 vertical in-line pumps

A2.0 Definitions (refer to Figure above)

- F_{xs} = applied force on X-axis on suction nozzle, to be assessed using equation set 6
- F_{ys} = applied force on Y-axis on suction nozzle, to be assessed using equation set 6
- F_{zs} = applied force on Z-axis on suction nozzle, to be assessed using equation set 6
- M_{xs} = applied moment about X-axis on suction nozzle, to be assessed using equation set 6
- M_{ys} = applied moment about Y-axis on suction nozzle, to be assessed using equation set 6
- M_{zs} = applied moment about Z-axis on suction nozzle, to be assessed using equation set 6
- F_{xd} = applied force on X-axis on discharge nozzle, to be assessed using equation set 6
- F_{yd} = applied force on Y-axis on discharge nozzle, to be assessed using equation set 6
- F_{zd} = applied force on Z-axis on discharge nozzle, to be assessed using equation set 6
- M_{xd} = applied moment about X-axis on discharge nozzle, to be assessed using equation set 6
- M_{yd} = applied moment about Y-axis on discharge nozzle, to be assessed using equation set 6
- M_{zd} = applied moment about Z-axis on discharge nozzle, to be assessed using equation set 6
- $F_{x\max}$ = maximum value of force on X-axis on suction or discharge nozzles, to be used with equation set 6
- $F_{y\max}$ = maximum value of force on Y-axis on suction or discharge nozzles, to be used with equation set 6
- $F_{z\max}$ = maximum value of force on Z-axis on suction or discharge nozzles, to be used with equation set 6
- $M_{x\max}$ = maximum value of moment about X-axis on either nozzle, to be used with equation set 6
- $M_{y\max}$ = maximum value of moment about Y-axis on either nozzle, to be used with equation set 6
- $M_{z\max}$ = maximum value of moment about Z-axis on either nozzle, to be used with equation set 6

A2.1 ANSI/ASME B73.2 pump assessment of applied nozzle loads

Loads given in Table B above are applicable for ASME B73.2 pumps constructed of ASTM A351/A351M – Grade CF8M (Type 316SS) operated between -20 and 100⁰ F.

For an individual force or moment or for a combination of more than one force and/or moment, pumps should be capable of satisfactory operation when subjected to loads shown in Table A2.1b (adjusted if applicable) while meeting the criteria of equation set 6 in Table A2.1a.

Table A2.1a – Equation set 6

Set	Equation	Reference	Remarks
6	$\left| \frac{F_{XS}}{F_{Xmax}} \right| \leq 1.0, \left| \frac{F_{YS}}{F_{Ymax}} \right| \leq 1.0, \left| \frac{F_{ZS}}{F_{Zmax}} \right| \leq 1.0, \left| \frac{M_{XS}}{M_{Xmax}} \right| \leq 1.0, \left| \frac{M_{YS}}{M_{Ymax}} \right| \leq 1.0, \left| \frac{M_{ZS}}{M_{Zmax}} \right| \leq 1.0$ $\left| \frac{F_{Xd}}{F_{Xmax}} \right| \leq 1.0, \left| \frac{F_{Yd}}{F_{Ymax}} \right| \leq 1.0, \left| \frac{F_{Zd}}{F_{Zmax}} \right| \leq 1.0, \left| \frac{M_{Xd}}{M_{Xmax}} \right| \leq 1.0, \left| \frac{M_{Yd}}{M_{Ymax}} \right| \leq 1.0, \left| \frac{M_{Zd}}{M_{Zmax}} \right| \leq 1.0$	-	Individual loading

Table A2.1b – Maximum forces and moments for use with equation set 6 to assess applied loads

Discharge Nozzle Size (in)	Nominal Impeller Diameter (in)	Nominal overall length, flange face to flange face (in)	Forces (lb)			Moments (lb•ft)		
			$F_{x max}$	$F_{y max}$	$F_{z max}$	$M_{x max}$	$M_{y max}$	$M_{z max}$
1.5	6	15	410	3976	410	510	720	510
1.5	8	17	360	3976	360	510	720	510
1.5	10	19	320	3976	320	510	720	510
1.5	13	24	255	3976	255	510	720	510
2	6	17	635	6328	635	900	1270	900
2	8 & 10	20	540	6328	540	900	1270	900
2	13	24	450	6328	450	900	1270	900
3	8	22	725	6328	725	1330	1880	1330
3	10	25	638	6328	638	1330	1880	1330
3	13	28	570	6328	570	1330	1880	1330
4	10	28	700	18,704	700	1630	2300	1630
4	13	30	650	18,704	650	1630	2300	1630

A2.1.1 Temperature and material adjustment factors

Adjustments of allowable load values are performed when any of the following occurs:

- a. Temperature is above 100⁰ F
- b. The pump material construction is not ASTM A351/A351M – Grade CF8M

A2.1.2 Adjustment factors

For temperatures above 100⁰ F and/or the use of a material other than ASTM A351/A351M – Grade CF8M, the loads in Table A2.1b are reduced by multiplying them by the proper adjustment factor from Table A2.1d. Material group numbers used in Table A2.1d are defined in Table A2.1c.

Rotodynamic Pumps - ANSI/HI 9.6.2 - 2011

Table A2.1c – List of materials specifications as used in Table A2.1d

Material Groups (See NOTE 1)		Castings		
Material Group No.	Nominal Designation	Spec. No.	Grade(s)	NOTES
1.0	Ductile Iron	A395	---	(2)
1.1	Carbon Steel	A216	WCB	
2.1	Type 304	A744	CF-8	
2.2	Type 316	A744	CF-8M	
2.3	Type 304L Type 316L	A744	CF-3 CF-3M	
2.4	Type 321	---	---	
2.8	CD-4MCu CD-4MCu	A744 A890	CD-4MCu CD-4MCu Grade 1A, 1B	
3.1	Alloy 20	A744	CN-7M	
3.2	Nickel	A494	CZ-100	(3)
3.4	Monel	A744	M-35-1 M-30C M-35-2	
3.5	Inconel 600 Inconel 625 Inconel 825	A744 A744 A744	CY-40 CW-6MC Cu-5MCuC	
3.7	Hastelloy B	A494	N-12MV N-7M	
3.8	Hastelloy C	A494	CW-6M CW-2M CW-12MW CX-2MW	

NOTES:
 (1) Material groups are similar to material classes taken from ANSI B16.5 except for Class 1.0 - ductile iron, which is not listed in ANSI B16.5. Note that the material grades are not the same as listed in ANSI B16.5. However, they are comparable grades as far as strength is concerned.
 (2) Operating temperature range is 20 °F to 650 °F for ductile iron.
 (3) Operating temperature range is -20 °F to 600 °F for nickel.

Table A2.1d – ASME B73.2 metallic pump temperature and material adjustment values used

Temp, °F	Material Group No.:												
	1.0	1.1	2.1	2.2	2.3	2.4	2.8	3.1	3.2	3.4	3.5	3.7	3.8
	Ductile Iron	Carbon Steel	Austenitic Steels					Nickel and Nickel Alloys					
Type 304			Type 316	Type 304L Type 316L	Type 321	CD-4M Cu	Alloy 20	Nickel	Monel	Inconel	Hast. B	Hast. C	
-20 to 100	0.89	1.00	1.00	1.00	0.83	1.00	1.00	0.83	0.50	0.83	1.00	1.00	1.00
200	0.83	0.94	0.83	0.86	0.70	0.98	1.00	0.77	0.50	0.74	0.93	1.00	1.00
300	0.78	0.91	0.74	0.78	0.63	0.83	1.00	0.73	0.50	0.69	0.89	1.00	1.00
400	0.73	0.88	0.65	0.72	0.58	0.69	0.98	0.67	0.50	0.67	0.85	0.98	0.98
500	0.69	0.83	0.60	0.67	0.53	0.64	0.92	0.65	0.50	0.66	0.83	0.92	0.92

Coordinate System for Axial split case pumps (single-stage double suction and two-stage single suction)

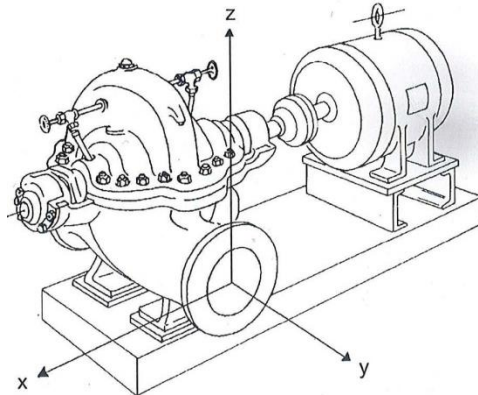


Figure 3 – Coordinate system for axial split case pumps

A3.0 Definitions (refer to Figure above)

- F_{xs} = applied force on X-axis on suction nozzle, to be assessed using equation 1
- F_{ys} = applied force on Y-axis on suction nozzle, to be assessed using equation 1
- F_{zs} = applied force on Z-axis on suction nozzle, to be assessed using equation 1
- M_{xs} = applied moment about X-axis on suction nozzle, to be assessed using equation 1
- M_{ys} = applied moment about Y-axis on suction nozzle, to be assessed using equation 1
- M_{zs} = applied moment about Z-axis on suction nozzle, to be assessed using equation 1
- F_{xd} = applied force on X-axis on discharge nozzle, to be assessed using equation 1
- F_{yd} = applied force on Y-axis on discharge nozzle, to be assessed using equation 1
- F_{zd} = applied force on Z-axis on discharge nozzle, to be assessed using equation 1
- M_{xd} = applied moment about X-axis on discharge nozzle, to be assessed using equation 1
- M_{yd} = applied moment about Y-axis on discharge nozzle, to be assessed using equation 1
- M_{zd} = applied moment about Z-axis on discharge nozzle, to be assessed using equation 1
- $F_{x\ max}$ = maximum value of force on X-axis on either nozzle, to be used with equation 1
- $F_{y\ max}$ = maximum value of force on Y-axis on either nozzle, to be used with equation 1
- $F_{z\ max}$ = maximum value of force on Z-axis on either nozzle, to be used with equation 1
- $M_{x\ max}$ = maximum value of moment about X-axis on either nozzle, to be used with equation 1
- $M_{y\ max}$ = maximum value of moment about Y-axis on either nozzle, to be used with equation 1
- $M_{z\ max}$ = maximum value of moment about Z-axis on either nozzle, to be used with equation 1

A3.1 Axial split case pumps assessment of applied loads

The lowest values of maximum forces and moments from Tables A3.1a and A3.1b are used. The combined applied loads should satisfy the criteria defined by equation 1 below.

$$\left\{ \left(\frac{F_{xs}}{F_{x \max}} \right)^2 + \left(\frac{F_{ys}}{F_{y \max}} \right)^2 + \left(\frac{F_{zs}}{F_{z \max}} \right)^2 + \left(\frac{M_{xs}}{M_{x \max}} \right)^2 + \left(\frac{M_{ys}}{M_{y \max}} \right)^2 + \left(\frac{M_{zs}}{M_{z \max}} \right)^2 + \left(\frac{F_{xd}}{F_{x \max}} \right)^2 + \left(\frac{F_{yd}}{F_{y \max}} \right)^2 + \left(\frac{F_{zd}}{F_{z \max}} \right)^2 + \left(\frac{M_{xd}}{M_{x \max}} \right)^2 + \left(\frac{M_{yd}}{M_{y \max}} \right)^2 + \left(\frac{M_{zd}}{M_{z \max}} \right)^2 \right\}^{0.5} \leq 1 \quad (\text{Eq. 1})$$

Table A3.1a – Maximum forces and moments for use with equation 1 to assess applied loads based on the hold-down bolts

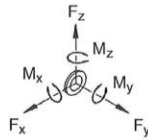
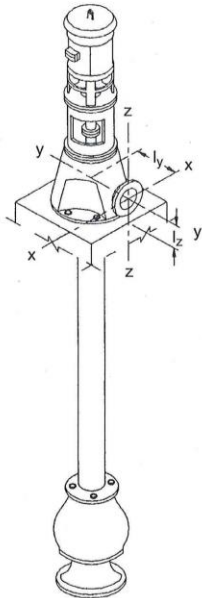
Nominal Bolt Diameter (in)	Forces (lb)		Moments (lb•ft)	
	$F_{x \max}$ and $F_{y \max}$	$F_{z \max}$	$M_{x \max}$ and $M_{y \max}$	$M_{z \max}$
0.625	600	4000	6000	450
0.75	800	6000	12,000	800
0.875	1200	8000	17,000	1500
1.00	5000	11,000	22,000	2400

Table A3.1b – Maximum forces and moments for use with equation 1 to assess applied loads based on the nozzle stress

Nozzle size (in)	Force (lb)			Moment (lb•ft)		
	$F_{x \max}$	$F_{y \max}$	$F_{z \max}$	$M_{x \max}$	$M_{y \max}$	$M_{z \max}$
2	1800	1400	1800	600	720	600
3	2400	2700	2400	734	900	734
4	3300	2700	3300	1200	1300	1200
6	4400	2700	4400	2400	1300	2400
8	6500	3500	6500	3800	1500	3800
10	8200	3500	8200	5400	1500	5400

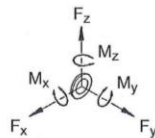
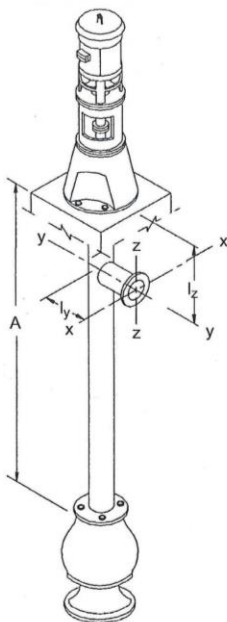
Coordinate System for Vertical turbine short set pumps

Category	Configuration	Flange Position	Application Limits		
			Max. Pressure (psi)	Max. Temp. (°F)	Max. Nozzle Size (in)
Shaft-driven, suspended pump, for water	Submerged suction	Discharge above base	300	100	36



Nozzle Size	Nozzle Material: Steel					
	Forces (lb)			Moments (lb-ft)		
	F_x	F_y	F_z	M_x	M_y	M_z
2	202	182	225	302	409	260
3	323	291	360	474	619	407
4	404	364	450	588	753	506
6	606	546	674	892	1099	770
8	808	728	899	1244	1499	1076
10	1010	910	1124	1667	1994	1445
12	1212	1092	1349	2178	2613	1890
14	1414	1274	1574	2790	3372	2422
16	1616	1456	1798	3507	4272	3043
18	1818	1638	2023	4329	5306	3753
20	2020	1820	2248	5251	6450	4545
22	2222	2002	2473	6260	7669	5406
24	2424	2184	2698	7338	8916	6319
30	3079	2774	3426	10,980	12,343	9327
36	3694	3329	4111	13,691	15,528	11,367

Category	Configuration	Flange Position	Application Limits		
			Max. Pressure (psi)	Max. Temp. (°F)	Max. Nozzle Size (in)
Shaft-driven, suspended pump, for water	Submerged suction	Discharge below base	300	100	36



Nozzle Size	Nozzle Material: Steel					
	Forces (lb)			Moments (lb-ft)		
	F_x	F_y	F_z	M_x	M_y	M_z
2	67	60	75	122	150	106
3	108	97	119	183	223	159
4	134	121	149	220	269	191
6	202	181	224	314	383	272
8	269	242	299	420	513	363
10	336	302	373	551	672	476
12	403	363	448	715	873	619
14	470	423	523	918	1121	796
16	538	484	567	1161	1419	1008
18	605	544	672	1442	1762	1252
20	672	605	747	1755	2142	1524
22	739	665	822	2091	2548	1815
24	806	726	896	2435	2962	2112
30	1024	922	1138	3378	4061	2908
36	1229	1106	1366	4029	4920	3523

A4.0 Definitions

f_x , f_y and f_z are the actual applied nozzle forces in their respective coordinate direction

m_x , m_y and m_z are actual applied nozzle moments in their respective coordinate direction

F_x , F_y and F_z are tabulated maximum permissible nozzle forces in their respective coordinate direction

M_x , M_y and M_z are tabulated maximum permissible nozzle moments in their respective coordinate direction

A4.1 Vertical turbine short set pumps assessment of applied loads

The tables above show maximum permissible forces and moments for each coordinate direction of each flange. Each value in the tables represents the maximum allowable load in a particular direction acting alone. For cases in which more than one load is applied simultaneously, the following formula should be satisfied.

$$\frac{f_x}{F_x} + \frac{f_y}{F_y} + \frac{f_z}{F_z} + \frac{m_x}{M_x} + \frac{m_y}{M_y} + \frac{m_z}{M_z} \leq 1$$

NEMA SM-23 (1991) for Turbines

NEMA SM-23 (1991) for Turbines

There are two types of allowables.

1. Allowables for each nozzle and
2. Combined allowables for each turbine.

1. Allowables for each Nozzle

The resultant force and the resultant moment at any connection must not exceed

$$3F_R + M_R \leq 500D_e$$

where

F_R = resultant force at the nozzle (lb)

M_R = resultant moment at the nozzle (ft.-lb)

D_e = nominal pipe size (inches) of the connection up to 8" in diameter
= $(16 + D_{nom})/3$ If the size is greater than 8"

2. Combined Allowables for the Turbine

The combined resultants of the forces and moments at the inlet, exhaust and extraction nozzles resolved at the centerline of the exhaust nozzle must not exceed the following two conditions:

- (a) These resultant should not exceed:

$$2F_C + M_C \leq 250D_C$$

where

F_C = combined resultant of inlet, exhaust and extraction forces (lb)

M_C = combined resultant of inlet, exhaust and extraction moments (ft.-lb.)

D_C = diameter (in inches) of a circular opening equal to the total areas of the inlet, exhaust and extraction nozzles up to a value of 9" in diameter
= $(18 + \text{Equivalent diameter}) / 3$ (in.) For values > 9"

- (b) The components of these resultants shall not exceed:

$$\begin{aligned} F_X &= 50D_C M_X = 250D_C \\ F_Y &= 125D_C M_Y = 125D_C \\ F_Z &= 100D_C M_Z = 125D_C \end{aligned}$$

where

F_X = horizontal component of F_R parallel to the turbine shaft

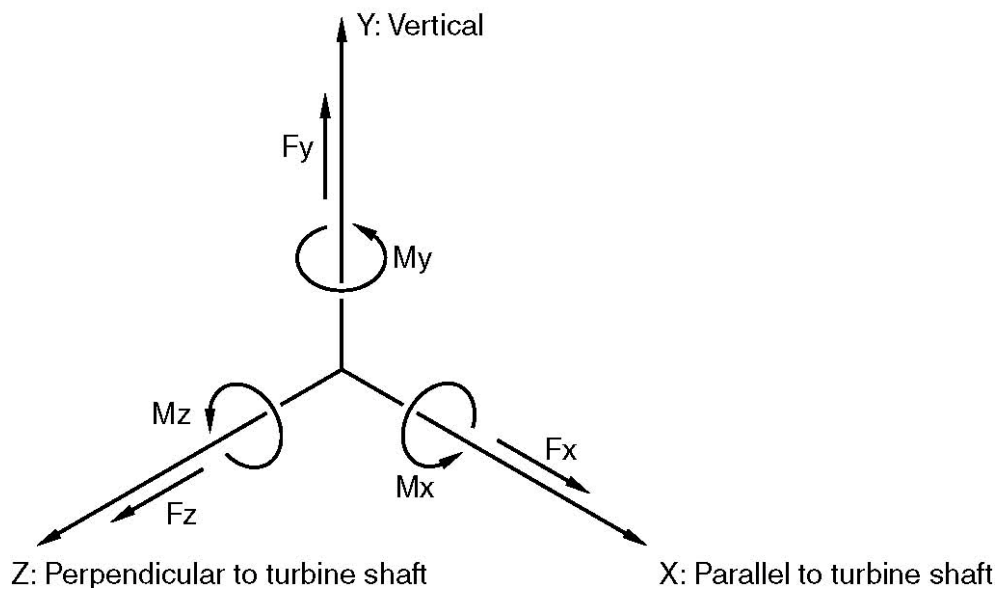
F_Y = vertical component of F_R

F_Z = horizontal component of F_R at right angles to the turbine shaft

M_X = horizontal component of M_R parallel to the turbine shaft

M_Y = vertical component of M_R

M_Z = horizontal component of M_R at right angles to the turbine shaft



API 617 (Seventh edition, June 2003) for Compressors

1. Allowables for each Nozzle

The total resultant force and resultant moment imposed on the compressor at any connection should not exceed

$$3F_r + M_r \leq 927D_e$$

Where

F_r = resultant force at the Nozzle (lb)

M_r = resultant moment at the Nozzle (ft.-lb)

D_e = nominal pipe size (inches) of the connection up to 8" in diameter

= $(16 + D_{nom})/3$ If the size is greater than 8"

2. Combined Allowables for Compressors

The combined resultants of the forces and moments of the inlet, sidestream, and discharge connections resolved at the centerlines of the largest connection should not exceed the following two conditions:

(a) The resultant should not exceed:

$$2F_c + M_c \leq 462D_c$$

Where

F_c = combined resultant of inlet, sidestream, and discharge forces (lb)

M_c = combined resultant of inlet, sidestream, and discharge moments, and moments resulting from forces (ft.-lb)

D_c = diameter of one circular opening equal to the total areas of the inlet, sidestream, and discharge openings. If the equivalent nozzle diameter is greater than 9", use a value of D_c equal to $(18 + \text{Equivalent Diameter}) / 3$

(b) The components of these resultants shall not exceed:

$$F_x = 92D_c \quad M_x = 462D_c$$

$$F_y = 231D_c \quad M_y = 231D_c$$

$$F_z = 185D_c \quad M_z = 231D_c$$

Where

F_x = horizontal component of F_c parallel to the compressor shaft (lb)

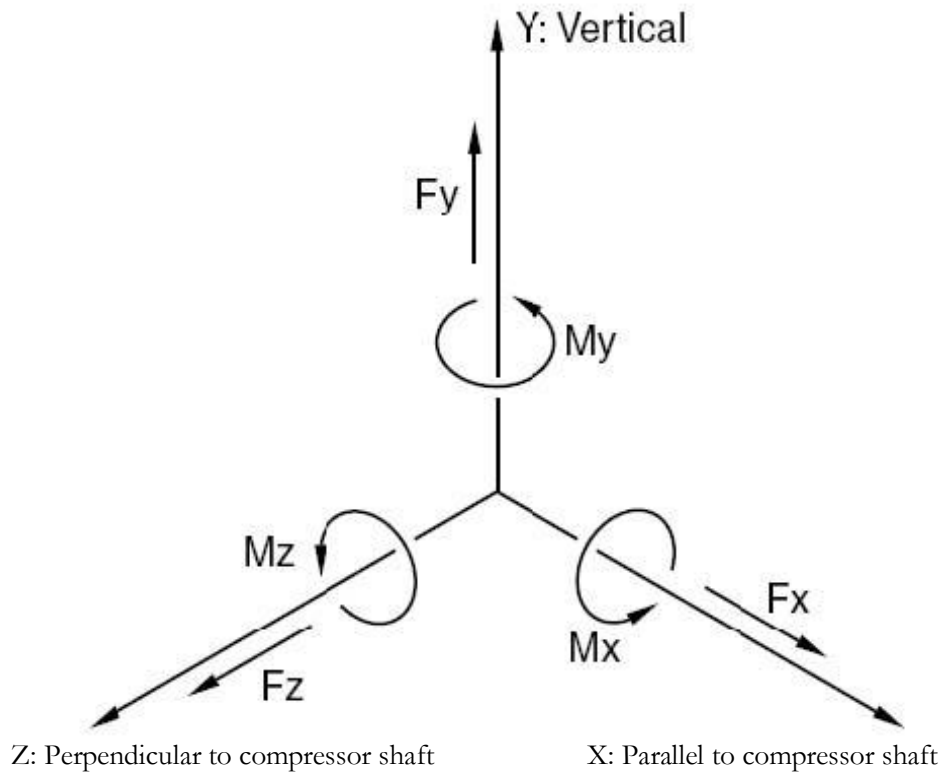
F_y = vertical component of F_c (lb)

F_z = horizontal component of F_c at right angles to be compressor shaft (lb)

M_x = component of M_c around the horizontal axis (ft.-lb)

M_y = component of M_c around the vertical axis (ft.-lb)

M_z = component of M_c around the horizontal axis at right angles to the compressor (ft.-lb)



Flange Qualification

Flange Qualification

Notation based on ASME Section VIII, Division 1, Appendix 2 (2013)

The symbols described below are used in the formulas for the design of flanges

A = outside diameter of flange

A_b = cross-sectional area of the bolts using the root diameter of the thread

A_m = total required cross-sectional area of bolts taken as greater of A_{m1} and A_{m2}

A_{m1} = total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions

$$= \frac{W_{m1}}{S_b}$$

A_{m2} = total cross-sectional area of bolts at root of thread or section of least diameter under stress

$$= \frac{W_{m2}}{S_a}$$

B = inside diameter of flange

B' = inside diameter of reverse flange

b = effective gasket or joint-contact-surface seating width

b_0 = basic gasket seating width (from Table 2-5.2)

C = bolt-circle diameter

c = basic dimension used for the minimum sizing of welds

e = factor = $\frac{F}{h_o}$

d = factor = $\frac{U}{V} h_o g_0^2$ for integral type flanges

d = factor = $\frac{U}{V_L} h_o g_0^2$ for loose type flanges

e = factor = $\frac{F}{h_o}$ for integral type flanges

c = factor = $\frac{F_L}{h_o}$ for loose type flanges

F = factor for integral type flanges (from Fig. 2-7.2)

F_L = factor for loose type flanges (from Fig. 2-7.4)

f = hub stress correction for integral flanges from Fig. 2-7.6 (when greater than one, this is the ratio of the stress in the small end of hub to the stress in the large end), (for values below limit of figure, use $f = 1$.)

G = diameter at location of gasket load reaction

g_0 = thickness of hub at small end

g_1 = thickness of hub at back of flange

H = total hydrostatic end force = $0.785G^2P$

H_D = hydrostatic end force on area inside of flange = $0.785B^2P$

H_G = gasket load (difference between flange design bolt load and total hydrostatic end force) = $W - H$

H_P = total joint-contact surface compression load = $2b \times 3.14 G_m P$

H_T = difference between total hydrostatic end force and the hydrostatic end force on area inside of flange = $H - H_D$

h = hub length

Flange Qualification

- h_D = radial distance from the bolt circle, to the circle on which H_D acts, as prescribed in Table 2-6
 h_G = radial distance from gasket load reaction to the bolt circle = $\frac{C-G}{2}$
 h_O = factor = $\sqrt{B_{g0}}$
 h_T = distance from the bolt circle, to the circle on which H_T acts, as prescribed in Table 2-6
 K = ratio of outside diameter of flange to inside diameter of flange = A / B
 L = factor = $\frac{(t_e+1)}{T} + \frac{t^3}{d}$
 M_D = component of moment due to $H_D = H_D h_D$
 M_G = component of moment due to $H_G = H_G h_G$
 M_T = component of moment due to $H_T = H_T h_T$
 M_O = total moment acting upon the flange for the operating conditions or gasket seating as may apply
 $M_O = W \frac{(C-G)}{2}$ for gasket seating condition
 $M_O = H_D h_D + H_G h_G + H_T h_T$ for operating condition
 N = width used to determine the basic gasket seating with b_0 , based upon the possible contact width of the gasket (see Table 2-5.2)
 P = internal design pressure
 R = radial distance from bolt circle to point of intersection of hub and back of flange. For integral and hub flanges, $R = (C-B / 2) - g_1$
 S_a = allowable bolt stress at reference temperature
 S_b = allowable bolt stress at design temperature
 S_f = allowable stress for material of flange at design temperature (operating condition)
 S_H = calculated longitudinal stress in hub
 S_R = calculated radial stress in flange
 S_T = calculated tangential stress in flange
 T = factor involving K (from Fig. 2-7.1)
 t = flange thickness
 U = factor involving K (from Fig. 2-7.1)
 V = factor for integral type flanges (from Fig. 2-7.3)
 V_L = factor for loose type flanges (from Fig. 2-7.5)
 W = flange design bolt load, for the operating condition or gasket seating
 = W_{m1} for operating condition
 = $\frac{(A_m+A_b)S_a}{2}$ for gasket seating condition
 W_{m1} = minimum required bolt load for the operating conditions
 W_{m1} = minimum required bolt load for gasket seating
 w = nubbin width used to determine the basic gasket seating width b_0 , based on contact width between the flange and the gasket (see Table 2-5.2)
 Y = factor involving K (from Fig. 2-7.1)
 y = gasket or joint-contact-surface unit seating load
 Z = factor involving K (from Fig. 2-7.1)

Calculation of Flange Stresses

The stresses in the flange shall be determined for both the operating conditions and gasket seating condition, in accordance with the following formulas:

(1) Integral type flanges

$$\text{Longitudinal hub stress } S_H = \frac{fM_O}{Lg_1^2B} < 1.5S_f$$

$$\text{Radial flange stress } S_R = \frac{(1.33te+1)M_O}{Lt^2B} < S_f$$

$$\text{Tangential flange stress } S_T = \frac{YM_O}{t^2B} - ZS_R < S_f$$

Combined stress

$$\frac{S_H+S_R}{2} < S_f \text{ and}$$

$$\frac{S_H + S_T}{2} < S_f$$

(2) Loose type flanges with hubs

$$\text{Longitudinal hub stress } S_H = \frac{fM_O}{Lg_1^2B} < 1.5S_f$$

$$\text{Radial flange stress } S_R = \frac{(1.33te+1)M_O}{Lt^2B} < S_f$$

$$\text{Tangential flange stress } S_T = \frac{YM_O}{t^2B} - ZS_R < S_f$$

Combined stress

$$\frac{S_H+S_R}{2} < S_f \text{ and}$$

$$\frac{S_H + S_T}{2} < S_f$$

where,

$$L = \text{factor} = \frac{(te+1)}{T} + \frac{t^3}{d}$$

$$d = \text{factor} = \frac{U}{V_L} h_o g_0^2 \text{ for integral type flanges}$$

$$e = \text{factor} = \frac{F_L}{h_o}$$

V_L = factor for loose type flanges (from Fig. 2-7.5)

F_L = factor for loose type flanges (from Fig. 2-7.4)

(3) Loose type flanges without hubs

Longitudinal hub stress $S_H = 0$

Radial flange stress $S_R = 0$

Tangential flange stress $S_T = \frac{YM_O}{t^2B} < S_f$

Combined stress

$$\frac{S_H + S_R}{2} < S_f \text{ and}$$

$$\frac{S_H + S_T}{2} < S_f$$

where,

$$L = \text{factor} = \frac{(te+1)}{T} + \frac{t^3}{d}$$

$$d = \text{factor} = \frac{U}{V_L} h_0 g_0^2$$

$$e = \text{factor} = \frac{F_L}{h_0}$$

V_L = factor for loose type flanges (from Fig. 2-7.5)

F_L = factor for loose type flanges (from Fig. 2-7.4)

(4) Optional type flanges (calculated as loose flanges without hubs)

Longitudinal hub stress $S_H = 0$

Radial flange stress $S_R = 0$

Tangential flange stress $S_T = \frac{YM_O}{t^2 B} < S_f$

Combined stress

$$\frac{S_H + S_R}{2} < S_f \text{ and}$$

$$\frac{S_H + S_T}{2} < S_f$$

where,

$$L = \text{factor} = \frac{(te+1)}{T} + \frac{t^3}{d}$$

$$d = \text{factor} = \frac{U}{V_L} h_0 g_0^2$$

$$e = \text{factor} = \frac{F_L}{h_0}$$

V_L = factor for loose type flanges (from Fig. 2-7.5)

F_L = factor for loose type flanges (from Fig. 2-7.4)

(5) Reverse type flanges

$$\text{Longitudinal hub stress } S_H = \frac{fM_O}{L_r g_1^2 B'} < 1.5S_f$$

$$\text{Radial flange stress } S_R = \frac{(1.33te_r+1)M_O}{L_r t^2 B'} < S_f$$

$$\text{Tangential flange stress } S_r = \frac{YM_O}{t^2 B} - ZS_R \frac{0.67te_r+1}{1.33te_r+1} < S_f$$

Combined stress

$$\frac{S_H+S_R}{2} < S_f \text{ and}$$

$$\frac{S_H + S_T}{2} < S_f$$

where,

$$L_r = \text{factor} = \frac{(te_r+1)}{T} + \frac{t^3}{d_r}$$

$$d_r = \text{factor} = \frac{U_r}{V} h_o g_0^2$$

$$e_r = \text{factor} = \frac{F}{h_o}$$

$$h_o = \text{factor} = \sqrt{Ag_0}$$

$$\alpha_r = \frac{1+0.668\frac{(K+1)}{Y}}{K^2}$$


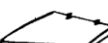
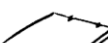
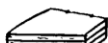






$$T_r = \frac{Z+0.3}{Z-0.3} \alpha_r T$$

$$U_r = \alpha_Y U$$

$$Y_r = \alpha_Y Y$$


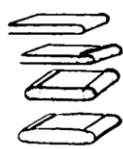



Flange Qualification

TABLE 2-5.1
GASKET MATERIALS AND CONTACT FACINGS¹
 Gasket Factors m for Operating Conditions and Minimum Design Seating Stress y

Gasket Material	Gasket Factor m	Min. Design Seating Stress y , psi (MPa)	Sketches	Facing Sketch and Column in Table 2-5.2
Self-energizing types (O rings, metallic, elastomer, other gasket types considered as self-sealing)	0	0 (0)	...	...
Elastomers without fabric or high percent of asbestos fiber:				
Below 75A Shore Durometer	0.50	0 (0)		(1a),(1b),(1c),(1d), (4),(5); Column II
75A or higher Shore Durometer	1.00	200 (1.4)		
Asbestos with suitable binder for operating conditions:				
$\frac{1}{8}$ in. (3.2 mm) thick	2.00	1,600 (11)		(1a),(1b),(1c),(1d), (4),(5); Column II
$\frac{1}{16}$ in. (1.6 mm) thick	2.75	3,700 (26)		
$\frac{1}{32}$ in. (0.8 mm) thick	3.50	6,500 (45)		
Elastomers with cotton fabric insertion	1.25	400 (2.8)		(1a),(1b),(1c),(1d), (4),(5); Column II
Elastomers with asbestos fabric insertion (with or without wire reinforcement):				
3-ply	2.25	2,200 (15)		(1a),(1b),(1c),(1d), (4),(5); Column II
2-ply	2.50	2,900 (20)		
1-ply	2.75	3,700 (26)		
Vegetable fiber	1.75	1,100 (7.6)		(1a),(1b),(1c),(1d), (4),(5); Column II
Spiral-wound metal, asbestos filled:				
Carbon	2.50	10,000 (69)		(1a),(1b); Column II
Stainless, Monel, and nickel-base alloys	3.00	10,000 (69)		
Corrugated metal, asbestos inserted, or corrugated metal, jacketed asbestos filled:				
Soft aluminum	2.50	2,900 (20)	 	(1a),(1b); Column II
Soft copper or brass	2.75	3,700 (26)		
Iron or soft steel	3.00	4,500 (31)		
Monel or 4%–6% chrome	3.25	5,500 (38)		
Stainless steels and nickel-base alloys	3.50	6,500 (45)		

Flange Qualification

TABLE 2-5.1
GASKET MATERIALS AND CONTACT FACINGS¹ (CONT'D)
 Gasket Factors m for Operating Conditions and Minimum Design Seating Stress y

Gasket Material	Gasket Factor m	Min. Design Seating Stress y , psi (MPa)	Sketches	Facing Sketch and Column in Table 2-5.2
Corrugated metal:				
Soft aluminum	2.75	3,700 (26)		(1a),(1b),(1c),(1d); Column II
Soft copper or brass	3.00	4,500 (31)		
Iron or soft steel	3.25	5,500 (38)		
Monel or 4%–6% chrome	3.50	6,500 (45)		
Stainless steels and nickel-base alloys	3.75	7,600 (52)		
Flat metal, jacketed asbestos filled:				
Soft aluminum	3.25	5,500 (38)		(1a),(1b),(1c), ² (1d) ² ;(2) ² ; Column II
Soft copper or brass	3.50	6,500 (45)		
Iron or soft steel	3.75	7,600 (52)		
Monel	3.50	8,000 (55)		
4%–6% chrome	3.75	9,000 (62)		
Stainless steels and nickel-base alloys	3.75	9,000 (62)		
Grooved metal:				
Soft aluminum	3.25	5,500 (38)		(1a),(1b),(1c),(1d), (2),(3); Column II
Soft copper or brass	3.50	6,500 (45)		
Iron or soft metal	3.75	7,600 (52)		
Monel or 4%–6% chrome	3.75	9,000 (62)		
Stainless steels and nickel-base alloys	4.25	10,100 (70)		
Solid flat metal:				
Soft aluminum	4.00	8,800 (61)		(1a),(1b),(1c),(1d), (2),(3),(4),(5); Column I
Soft copper or brass	4.75	13,000 (90)		
Iron or soft steel	5.50	18,000 (124)		
Monel or 4%–6% chrome	6.00	21,800 (150)		
Stainless steels and nickel-base alloys	6.50	26,000 (180)		
Ring joint:				
Iron or soft steel	5.50	18,000 (124)		(6); Column I
Monel or 4%–6% chrome	6.00	21,800 (150)		
Stainless steels and nickel-base alloys	6.50	26,000 (180)		

NOTES:

(1) This Table gives a list of many commonly used gasket materials and contact facings with suggested design values of m and y that have generally proved satisfactory in actual service when using effective gasket seating width b given in Table 2-5.2. The design values and other details given in this Table are suggested only and are not mandatory.

(2) The surface of a gasket having a lap should not be against the nubbin.

Flange Qualification

TABLE 2-5.2
EFFECTIVE GASKET WIDTH²

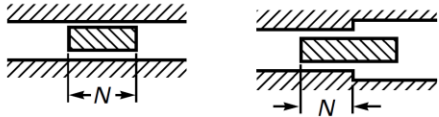
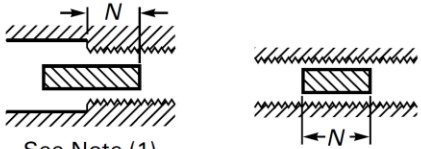
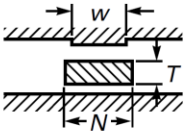
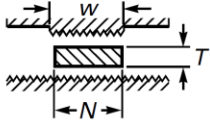
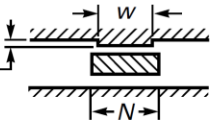
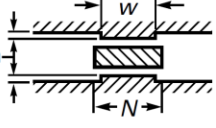
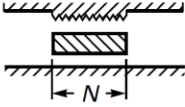
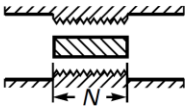
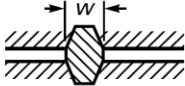
Facing Sketch (Exaggerated)		Basic Gasket Seating Width b_o	
		Column I	Column II
(1a)			
(1b)	 <p style="text-align: center;">See Note (1)</p>	$\frac{N}{2}$	$\frac{N}{2}$
(1c)	 <p style="text-align: center;">$w \leq N$</p>	$\frac{w + T}{2}; \left(\frac{w + N}{4} \max \right)$	$\frac{w + T}{2}; \left(\frac{w + N}{4} \max \right)$
(1d)	 <p style="text-align: center;">See Note (1)</p> <p style="text-align: center;">$w \leq N$</p>		
(2)	 <p style="text-align: center;">$\frac{1}{64}$ in. (0.4 mm) nubbin</p> <p style="text-align: center;">$w \leq N/2$</p>	$\frac{w + N}{4}$	$\frac{w + 3N}{8}$
(3)	 <p style="text-align: center;">$\frac{1}{64}$ in. (0.4 mm) nubbin</p> <p style="text-align: center;">$w \leq N/2$</p>	$\frac{N}{4}$	$\frac{3N}{8}$
(4)	 <p style="text-align: center;">See Note (1)</p>	$\frac{3N}{8}$	$\frac{7N}{16}$
(5)	 <p style="text-align: center;">See Note (1)</p>	$\frac{N}{4}$	$\frac{3N}{8}$
(6)		$\frac{w}{8}$	...

TABLE 2-6
MOMENT ARMS FOR FLANGE LOADS UNDER
OPERATING CONDITIONS

	h_D	h_T	h_G
Integral type flanges [see Fig. 2-4 sketches (5), (6), (6a), (6b), and (7)]; and optional type flanges calculated as integral type [see Fig. 2-4 sketches (8), (8a), (9), (9a), (10), (10a), and (11)]	$R + 0.5g_1$	$\frac{R + g_1 + h_G}{2}$	$\frac{C - G}{2}$
Loose type, except lap-joint flanges [see Fig. 2-4 sketches (2), (2a), (3), (3a), (4), and (4a)]; and optional type flanges calculated as loose type [see Fig. 2-4 sketches (8), (8a), (9), (9a), (10), (10a), and (11)]	$\frac{C - B}{2}$	$\frac{h_D + h_G}{2}$	$\frac{C - G}{2}$
Lap-type flanges [see Fig. 2-4 sketches (1) and (1a)]	$\frac{C - B}{2}$	$\frac{C - G}{2}$	$\frac{C - G}{2}$

Flange Qualification

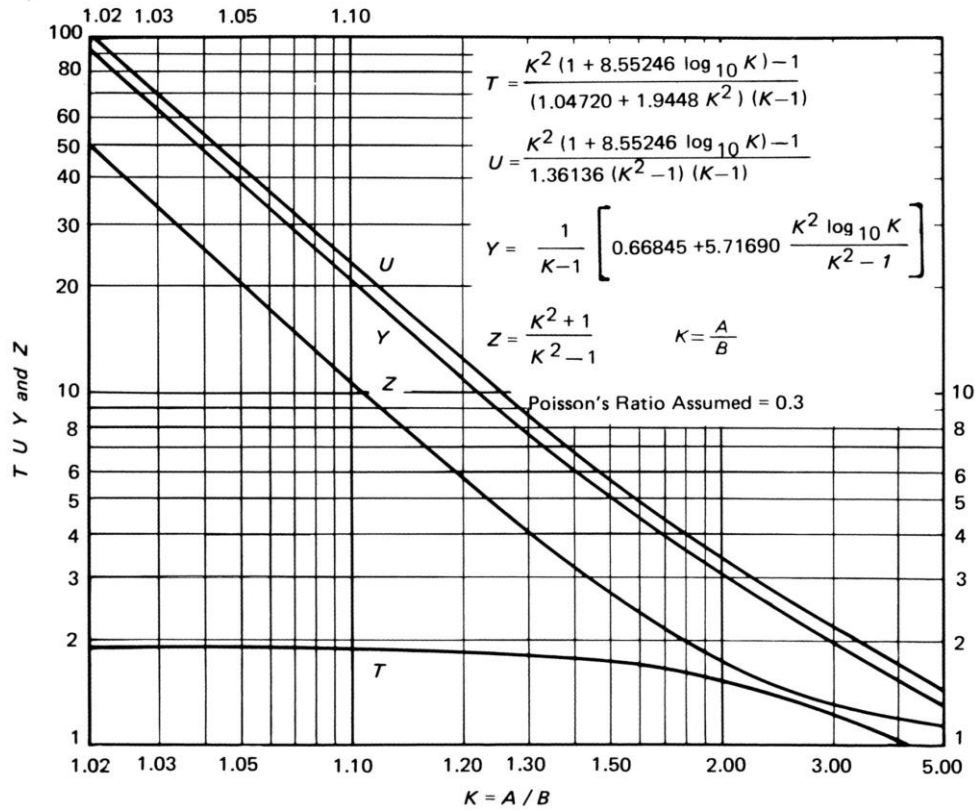


FIG. 2-7.1 VALUES OF T , U , Y , AND Z
(Terms Involving K)

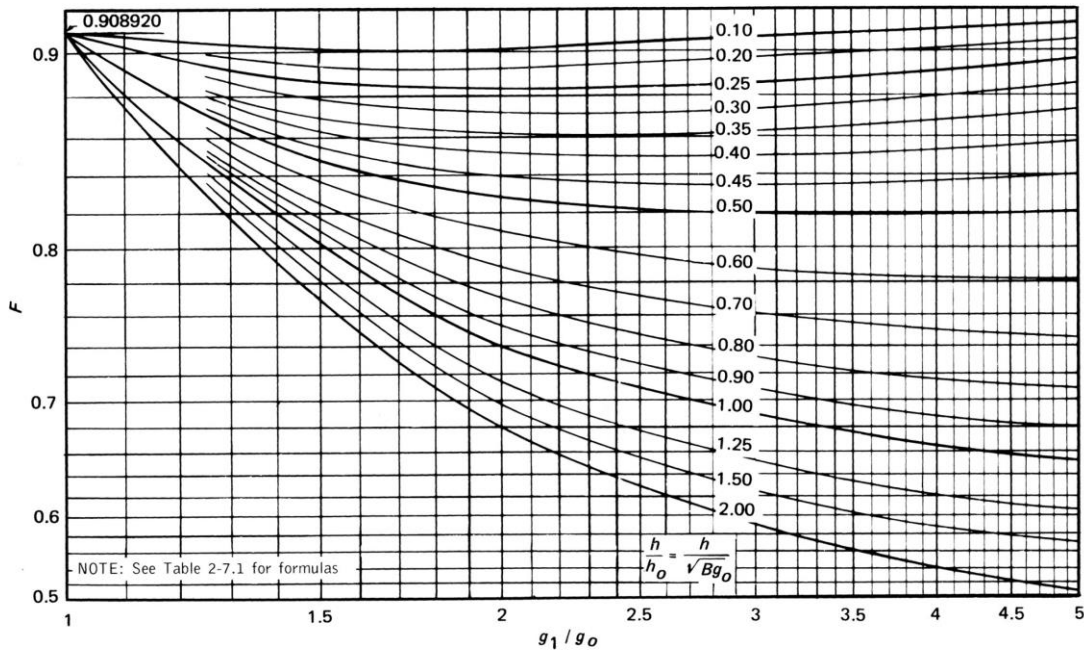


FIG. 2-7.2 VALUES OF F
(Integral Flange Factors)

Flange Qualification

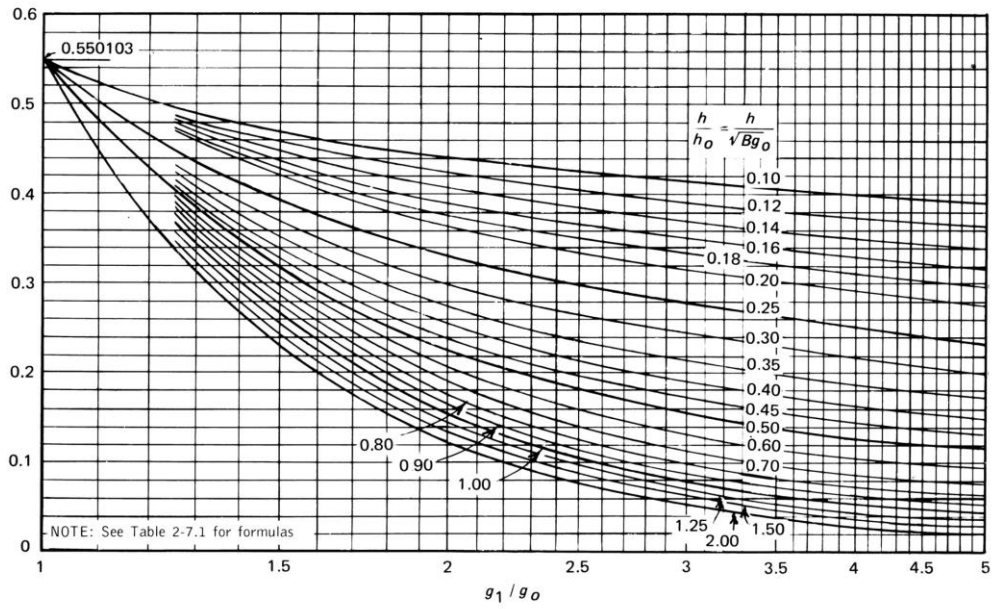


FIG. 2-7.3 VALUES OF V
(Integral Flange Factors)

Flange Qualification

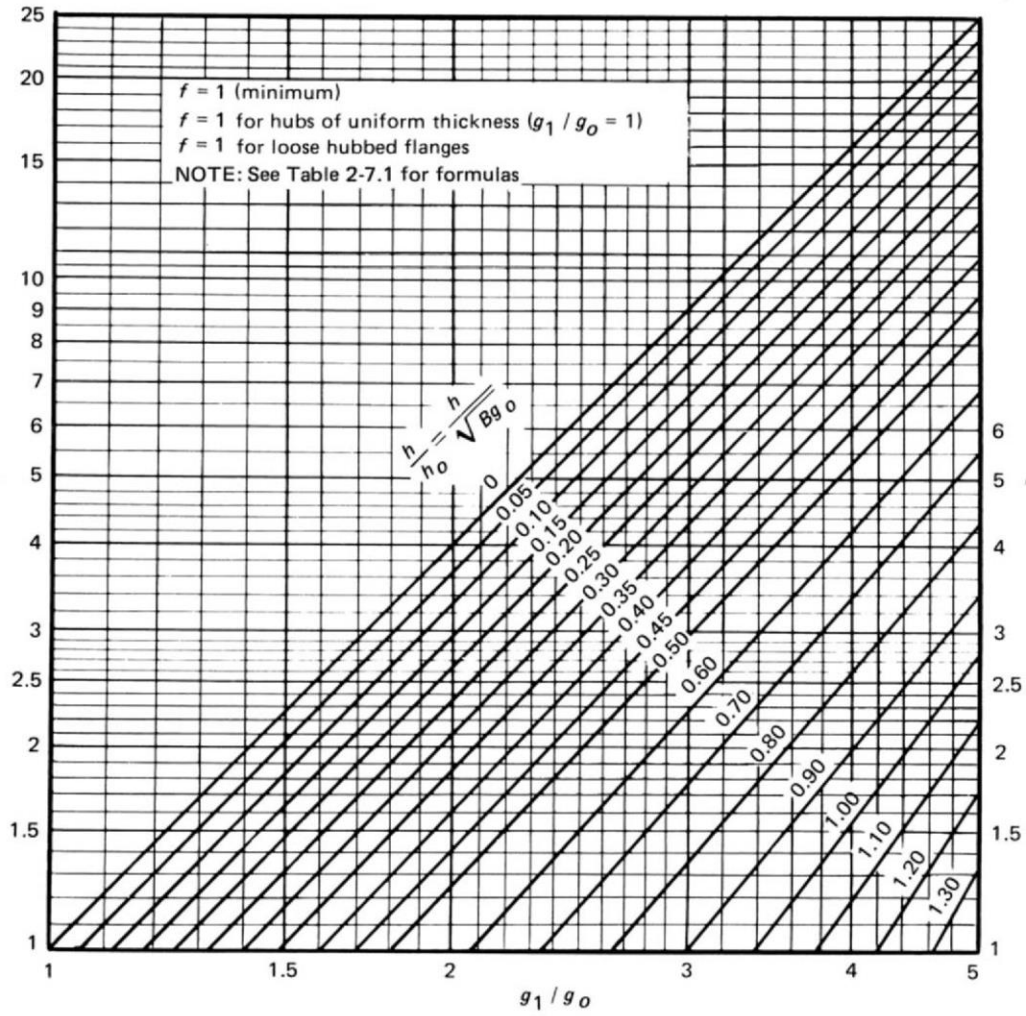


FIG. 2-7.6 VALUES OF f
(Hub Stress Correction Factor)

Flange Qualification

Problem 1:

(Example from “Taylor Forge & Pipe Works, 1961”)

Flange Details:

Flange Type : Loose Flanges with Hubs
Flange Outside Diameter [A] = 40.375 (inch)
Flange Inside Diameter [B] = 33.25 (inch)
Inside Diameter of Reverse Flange [B'] = 20 (inch)
Flange Thickness [t] = 2.125 (inch)
Small End Hub Thickness [g0] = 0.875 (inch)
Large End Hub Thickness [g1] = 1.125 (inch)
Hub Length [h] = 2.5 (inch)
All. Stress @ Design Temp [sf] = 17500 (psi)
All. Stress @ Ref. Temp [sfa] = 17500 (psi)
Modulus @ Design Temp [E] = 2.7E+7 (psi)
Modulus @ Ref. Temp [Ea] = 2.92E+7 (psi)

Bolting Information:

Bolt Circle Diameter = 38.25 (inch)
Number of Bolts = 44
Bolt Diameter = 1 (inch)
All. Stress @ Ref. Temp [sa] = 20000 (psi)
All. Stress @ Design Temp [sb] = 20000 (psi)

Gasket Information:

Gasket Outside Diameter = 35.75 (inch)
Gasket Inner Diameter = 34.25 (inch)
Leak Pressure Ratio [m] = 2.75
Gasket Seating Stress [y] = 3700 (psi)
Facing Sketch = 1
Facing Column = 1

Load Data:

Design Pressure = 400 (psi)
Design Temperature = 500 (F)
Axial Force = 1000 (lb)
Bending Moment = 200 (ft-lb)
Allowable Pressure = 665 (psi)

Flange Qualification

Comparison of Results:

Flange Stresses	Text Book Results (psi)	CAEPIPE (psi)	CAESAR II (psi)
Operating condition			
Longitudinal Hub (SH)	20800	21153	21214
Radial Flange (SR)	11100	11110	11155
Tangential Flange (ST)	13800	13826	13797
0.5(SH + SR)	15950	16132	16185
0.5(SH + ST)	17300	17489	17506
Gasket Seating Condition			
Longitudinal Hub (SH)	14400	14623	15095
Radial Flange (SR)	7660	7681	7938
Tangential Flange (ST)	9500	9558	9818
0.5(SH + SR)	11030	11152	11517
0.5(SH + ST)	11950	12091	12457

Problem 2:

(Example 10.5 on page 209 Chapter 10 on “CASTI Guidebook to ASME Section VIII Div.1 – Pressure Vessels – Third Edition”)

Flange Details:

Flange Type : Reverse Flanges
 Flange Outside Diameter [A] = 49 (inch)
 Flange Inside Diameter [B] = 48.25 (inch)
 Inside Diameter of Reverse Flange [B'] = 20.25 (inch)
 Flange Thickness [t] = 5.25 (inch)
 Small End Hub Thickness [g0] = 0.375 (inch)
 Large End Hub Thickness [g1] = 1.375 (inch)
 Hub Length [h] = 6 (inch)
 All. Stress @ Design Temp [sf] = 12000 (psi)
 All. Stress @ Ref. Temp [sfa] = 20000 (psi)
 Modulus @ Design Temp [E] = 2.7E+7 (psi)
 Modulus @ Ref. Temp [Ea] = 2.92E+7 (psi)

Bolting Information:

Bolt Circle Diameter = 44 (inch)
 Number of Bolts = 32
 Bolt Diameter = 1.25 (inch)
 All. Stress @ Ref. Temp [sa] = 25000 (psi)
 All. Stress @ Design Temp [sb] = 21000 (psi)

Gasket Information:

Gasket Outside Diameter = 24 (inch)
 Gasket Inner Diameter = 22 (inch)
 Leak Pressure Ratio [m] = 2.50
 Gasket Seating Stress [y] = 10000 (psi)
 Facing Sketch = 1

Flange Qualification

Facing Column = 1

Load Data:

Design Pressure = 150 (psi)

Design Temperature = 800 (F)

Axial Force = 1000 (lb)

Bending Moment = 200 (ft-lb)

Allowable Pressure = 665 (psi)

Comparison of Results:

Flange Stresses	Text Book Results (psi)	CAEPIPE (psi)	CAESAR II (psi)
Operating condition			
Longitudinal Hub (SH)	2060	2257	2055
Radial Flange (SR)	280	307	280
Tangential Flange (ST)	1340	1314	1336
0.5(SH + SR)	1170	1282	1168
0.5(SH + ST)	1700	1785	1695
Gasket Seating Condition			
Longitudinal Hub (SH)	9220	10082	9220
Radial Flange (SR)	1260	1372	1257
Tangential Flange (ST)	6000	7004	5997
0.5(SH + SR)	5240	5727	5239
0.5(SH + ST)	7610	8543	8703

Problem 3:

(Example from KEDKEP CONSULTING, INC. dated May 27, 2008)

Flange Details:

Flange Type : Loose Flanges without Hubs / Optional Flanges

Flange Outside Diameter [A] = 38.4 (inch)

Flange Inside Diameter [B] = 32 (inch)

Inside Diameter of Reverse Flange [B'] = 32 (inch)

Flange Thickness [t] = 4 (inch)

Small End Hub Thickness [g0] = 0.001 (inch)

Large End Hub Thickness [g1] = 0.001 (inch)

Hub Length [h] = 0.001 (inch)

All. Stress @ Design Temp [sf] = 20000 (psi)

All. Stress @ Ref. Temp [sfa] = 20000 (psi)

Modulus @ Design Temp [E] = 2.7E+7 (psi)

Modulus @ Ref. Temp [Ea] = 2.92E+7 (psi)

Bolting Information:

Bolt Circle Diameter = 36 (inch)

Number of Bolts = 28

Bolt Diameter = 1 (inch)

Flange Qualification

All. Stress @ Ref. Temp [sa] = 25000 (psi)

All. Stress @ Design Temp [sb] = 25000 (psi)

Gasket Information:

Gasket Outside Diameter = 32.75 (inch)

Gasket Inner Diameter = 32 (inch)

Leak Pressure Ratio [m] = 0.50

Gasket Seating Stress [y] = 0 (psi)

Facing Sketch = 2

Facing Column = 2

Load Data:

Design Pressure = 300 (psi)

Design Temperature = 295 (F)

Axial Force = 1000 (lb)

Bending Moment = 200 (ft-lb)

Allowable Pressure = 665 (psi)

Comparison of Results:

Flange Stresses	Text Book Results (psi)	CAEPIPE (psi)	CAESAR II (psi)
Operating Condition			
Longitudinal Hub (SH)	0	0	3
Radial Flange (SR)	0	0	0
Tangential Flange (ST)	10577	10569	10618
0.5(SH + SR)	0	0	1.5
0.5(SH + ST)	0	0	5310.5
Bolt Stress	16378	16371	16445
Gasket Seating Condition			
Longitudinal Hub (SH)	0	0	3
Radial Flange (SR)	0	0	0
Tangential Flange (ST)	12147	11987	12166
0.5(SH + SR)	0	0	1.5
0.5(SH + ST)	0	0	6085
Bolt Stress	0	0	124

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**Pressure Design of Pipe & Pipe Fittings
as per EN 13480-3 (2017)**

Pressure Design of Pipe & Pipe fittings according to SS EN 13480-3 (2017)

Internal pressure according to SS EN 13480-3 (2017)

Straight Pipes

The minimum required wall thickness for a straight pipe without allowances and tolerances, e_p , is calculated from equation 6.1-1 and 6.1-3 depending on the ratio between inner and outer diameter as follows:

For $D_o/D_i \leq 1.7$

$$e_p = \frac{P_c D_o}{2fz + P_c}$$

For $D_o/D_i > 1.7$

$$e_p = \frac{D_o}{2} \left[1 - \sqrt{\frac{fz - p_c}{fz + p_c}} \right]$$

where,

D_o = outside diameter of pipe

D_i = inside diameter of pipe = $D_o - 2 \times e_n$

e_n = nominal wall thickness of pipe

f = Allowable stress for material at maximum temperature

z = weld efficiency factor = 1.0

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

e_p = minimum required wall thickness

Elbows

The minimum required wall thickness of the intrados and the extrados of the elbow without allowances and tolerances, e_{p1} / e_{p2} , is calculated from equation B.4.1-3

$e_{p1} = e_{p2} = e.B$

$$B = \frac{D_o}{2e} - \frac{R}{e} + \sqrt{\left[\frac{D_o}{2e} - \frac{R}{e} \right]^2 + 2 \frac{R}{e} - \frac{D_o}{2e}}$$

where

D_o = outside diameter of elbow

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the elbow

$e_{p1} = e_{p2}$ = minimum required wall thickness of the elbow

Bends (formed by cold bending of straight pipes)

Wall thickness of the intrados of the bend

The minimum required wall thickness of the intrados of the bend without allowances and tolerances, e_{p1} , is calculated from equation B.4.1-1

$e_{p1} = e \cdot B_{int}$

$$B_{int} = \frac{D_o}{2e} + \frac{r}{e} - \left[\frac{D_o}{2e} + \frac{r}{e} - 1 \right] \sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e} \left(\frac{D_o}{2e} - 1\right)}}$$

r/e is calculated from

$$\frac{r}{e} = \sqrt{\frac{1}{2} \left\{ \left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2 \right\} + \sqrt{\frac{1}{4} \left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2 \right)^2 - \frac{D_o}{2e} \left(\frac{D_o}{2e} - 1\right) \left(\frac{R}{e}\right)^2}}$$

where

D_o = outside diameter of bend

D_i = inside diameter of bend = $D_o - 2 \times e_n$

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the bend

e_{p1} = minimum required wall thickness of the intrados

Wall thickness of the extrados of the bend

The minimum required wall thickness of the extrados of the bend without allowances and tolerances, e_{p2} , is calculated from equation B.4.1-8

$e_{p2} = e \cdot B_{ext}$

$$B_{ext} = \frac{D_o}{2e} - \frac{r}{e} - \left[\frac{D_o}{2e} - \frac{r}{e} - 1 \right] \sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e} \left(\frac{D_o}{2e} - 1\right)}}$$

r/e is calculated from

$$\frac{r}{e} = \sqrt{\frac{1}{2} \left\{ \left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2 \right\} + \sqrt{\frac{1}{4} \left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2 \right)^2 - \frac{D_o}{2e} \left(\frac{D_o}{2e} - 1\right) \left(\frac{R}{e}\right)^2}}$$

where

D_o = outside diameter of bend

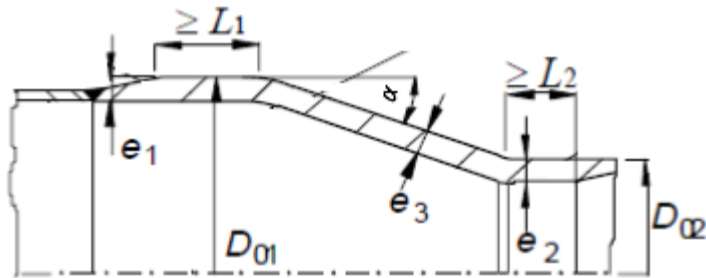
D_i = inside diameter of bend = $D_o - 2 \times e_n$

e = minimum required wall thickness of corresponding straight pipe computed as per Eq. 6.1-1 or 6.1-3

R = radius of the bend

e_{p2} = minimum required wall thickness of the extrados

Reducers



Junction between the large end of a cone and a cylinder without a knuckle

The minimum required wall thickness (e_1) of the larger cylinder adjacent to the junction is calculated from Subsection 6.4.6.2 as the greater of e_{cyl} and e_j where e_j is determined from

$$\beta = \frac{1}{3} \sqrt{\frac{D_c \tan \alpha}{e_j \left(1 + \frac{1}{\sqrt{\cos \alpha}}\right)}} - 0.15 \quad (\text{Eq. 6.4.6 - 2})$$

$$e_j = \frac{P_c \beta D_c}{2f} \quad (\text{Eq. 6.4.6 - 1})$$

The value of e_j is acceptable, if the value given by Eq. 6.4.6-1 is not less than that assumed in Eq. 6.4.6-2

$$e_{con} = \frac{p_c D_e}{2fZ + p_c} \frac{1}{\cos(\alpha)} \quad (\text{Eq. 6.4.4 - 2})$$

$$e_{cyl} = \frac{p_c D_{01}}{2fZ + p_c}$$

e_1 = thickness of larger cylinder = $\max(e_j, e_{cyl})$

e_3 = thickness of cone shell = $\max(e_j, e_{con})$

where

D_e = outside diameter of the cone

D_{01} = outside diameter of the larger cylinder

Pressure Design of Pipe & Pipe fittings according to SS EN 13480-3 (2017)

D_{02} = outside diameter of the small cylinder

D_c = mean diameter of the larger cylinder at the junction with the cone = $D_{01} - e_n$

e_n = nominal wall thickness of the larger cylinder at the junction with the cone

α = cone angle

e_1 = minimum required wall thickness for larger cylinder adjacent to the junction.

e_3 = minimum required wall thickness at cone.

f = Allowable stress for material at maximum temperature

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

Z = weld efficiency factor = 1.0

Junction between the small end of a cone and a cylinder without a knuckle

The minimum required wall thickness (e_2) of the small cylinder adjacent to the junction is calculated according to Subsection 6.4.8.2 as follows.

$$s = \frac{e_3}{e_{j2}}$$

With e_3 already determined in the earlier section, assume value of e_{j2} and calculate the values of s , τ and β_H

When $s < 1.0$, then

$$\tau = s \sqrt{\frac{s}{\cos \alpha}} + \sqrt{\frac{1 + s^2}{2}}$$

When $s \geq 1.0$, then

$$\tau = 1 + \sqrt{s \frac{1 + s^2}{2 \cos \alpha}}$$

$$\beta_H = 0.4 \sqrt{\frac{D_c \tan \alpha}{e_{j2} \tau}} + 0.5 \quad (\text{Eq. 6.4.8 - 4})$$

$$e_{j2} = \frac{p_c D_c \beta_H}{2fZ} \quad (\text{Eq. 6.4.8 - 5})$$

Pressure Design of Pipe & Pipe fittings according to SS EN 13480-3 (2017)

The value of e_{j2} is acceptable, if the value given by Eq. 6.4.8-5 is not less than that assumed for Eq. 6.4.8-4

$$e_{cyl} = \frac{p_c D_{02}}{2fZ + p_c}$$

$$e_2 = \max(e_{j2}, e_{cyl})$$

where

D_{02} = outside diameter of the small cylinder at the junction with the cone

D_c = mean diameter of the small cylinder at the junction with the cone = $D_{02} - e_n$

e_n = nominal wall thickness of the small cylinder at the junction with the cone

α = cone angle

e_2 = minimum required wall thickness of the small cylinder at the junction with the cone

f = Allowable stress for material at maximum temperature

p_c = maximum internal pressure = maximum of CAEPIPE input pressures P1 through P10

Z = weld efficiency factor = 1.0

External Pressure Design according to SS EN 13480-3 (2017)

Pipes, Elbows, Mitre Bends and Reducers

Interstiffener collapse

The thickness of the pipe within the unstiffened length L shall not be less than that determined by the following.

$$P_r \geq k \cdot P_c$$

$$P_y = \frac{S e_a}{R_m}$$

$$P_m = \frac{E_t e_a \varepsilon}{R_m}$$

$$\varepsilon = \frac{1}{n_{cyl}^2 - 1 + \frac{Z^2}{2}} \left\{ \frac{1}{\left(\frac{n_{cyl}^2}{Z^2} + 1\right)^2} + \frac{e_a^2}{12 R_m^2 (1 - \nu^2)} (n_{cyl}^2 - 1 + Z^2)^2 \right\}$$

$$Z = \frac{\pi R_m}{L}$$

using the calculated value of P_m/P_y , P_r/P_y is determined from Table 9.3.2.1 of Subsection 9.3.2

where

n_{cyl} = integer ≥ 2 to minimize the value of P_m .

CAEPIPE goes through an iterative routine by increasing the value of n_{cyl} from 2 and above until the minimum collapse pressure (p_m) is reached.

R_m = mean radius of the pipe

L = length between the stiffener, is calculated from CAEPIPE input as follows

for Pipe, L = length of pipe (= distance between the “From” and “To” node of CAEPIPE)

for Elbow and Miter bend, L = arc length measured on extrados of elbow and miter bend

for Reducer, L = Length of the reducer

E_t = Young’s modulus of material at design temperature (max of CAEPIPE Temperature T1 through T10)

e_a = analysis thickness of reducer at smaller end = e_n – corr.all – mill tolerance

e_n = nominal thickness of reducer at smaller end

k = factor = 1.5

P_c = external pressure = maximum negative CAEPIPE input pressures P1 through P10

Pressure Design of Pipe & Pipe fittings according to SS EN 13480-3 (2017)

S = elastic stress limits for pipe and stiffener for External Pressure Design

= “Rp0.2t” for non-austenitic steels

= “Rp0.2t/1.25” for austenitic steels

Note:

Generally, allowable stress is $(2/3) \times \text{Yield}$. So, for Piping code = EN 13480-3, the value of Rp0.2t is computed as “Rp0.2t = f x 1.5”

For all other Piping Codes, the value of Rp0.2t is computed as “Rp0.2t = allowable stress x 1.5”.

Additional check for Reducers

In addition to the above, as stated in Subsection 9.4.2 of EN 13480-3, the moment of inertia, I_x taken parallel to the axis of the cylinder, of the part of the cone and cylinder with a distance of $\sqrt{D_{eq}} \cdot e$ on either side of the junction is not less than:

$$I_x = 0.18 D_{eq} L D_s^2 \frac{p_c}{E_t} \leq I_{xa}$$

where

$$D_{eq} = \text{equivalent diameter} = \frac{D_1 + D_2}{2 \cos(\alpha)}$$

D_1 = outside diameter of larger end of reducer

D_2 = outside diameter of smaller end of reducer

α = cone angle of reducer input in CAEPIPE

I_{xa} = moment of inertia of reducer at smaller end

D_s = diameter of the centroid of the moment of inertia of the stiffening cross section calculated as shown below

$$I_{cone} = \left(\sqrt{D_{eq} e_1} \cdot e_1 \right) \left(\frac{D_{mcon}}{2} \right)^2 = (A_{cone}) \left(\frac{D_{mcon}}{2} \right)^2$$

$$I_{cyl} = \left(\sqrt{D_{eq} e_2} \cdot e_2 \right) \left(\frac{D_{mcyl}}{2} \right)^2 = (A_{cyl}) \left(\frac{D_{mcyl}}{2} \right)^2$$

$$I_{stiff} = (A_{cone} + A_{cyl}) \left(\frac{D_s}{2} \right)^2$$

From the above,

$$I_{cone} + I_{cyl} = I_{stiff}$$

and

Pressure Design of Pipe & Pipe fittings according to SS EN 13480-3 (2017)

$$D_s = 2 \sqrt{\frac{I_{stiff}}{(A_{cone} + A_{cyl})}}$$

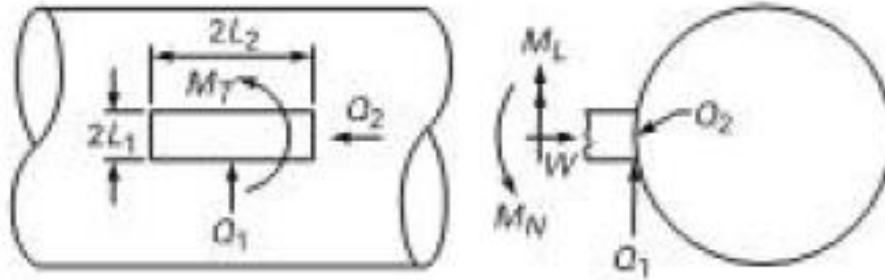
e_1 = analysis thickness of reducer at larger end = e_{n1} – corr.all – mill tolerance

e_2 = analysis thickness of reducer at smaller end = e_{n2} – corr.all – mill tolerance

e_{n1} & e_{n2} = nominal thickness of reducer at larger end and smaller end respectively

Lug Evaluation

Rectangular Cross-section Welded Attachments



The notations described below are used in the formulas for the design.

L_1 = half length of attachment in circumferential direction of the run pipe

L_2 = half length of attachment in longitudinal direction of the run pipe

R = mean pipe radius

D_o = outside diameter of run pipe

T = nominal run pipe wall thickness

L_a = lesser of L_2 and T

L_b = lesser of L_1 and T

L_c = lesser of L_1 and L_2

L_d = greater of L_1 and L_2

$A_T = 4 \cdot L_1 \cdot L_2$ = cross-sectional area of the rectangular attachment

$$Z_{tL} = \left(\frac{4}{3}\right) \cdot L_1 \cdot L_2^2$$

$$Z_{tN} = \left(\frac{4}{3}\right) \cdot L_1^2 \cdot L_2$$

$$\beta_1 = \frac{L_1}{R}$$

$$\beta_2 = \frac{L_2}{R}$$

$$\gamma = \frac{R}{T}$$

Limits of Applicability

$$\beta_1 \leq 0.5$$

$$\beta_2 \leq 0.5$$

$$\beta_1 \cdot \beta_2 \leq 0.75$$

M_L = bending moment applied to the attachment as shown in figure above

- M_N = bending moment applied to the attachment as shown in figure above
 M_T = torsional moment applied to the attachment as shown in figure above
 Q_1 = shear load applied to the attachment as shown in figure above.
 Q_2 = shear load applied to the attachment as shown in figure above
 W = thrust load applied to the attachment as shown in figure above

M_L , M_N , M_T , Q_1 , Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L^{**} , M_N^{**} , M_T^{**} , Q_1^{**} , Q_2^{**} and W^{**} are absolute values of maximum loads occurring simultaneously under all service loading conditions.

Calculate η , X_1 and Y_1 using the factors listed in Table below.

Load	Index	A_o	θ	X_o	Y_o
Thrust (W)	C_W	2.2	40^0	0	0.05
Longitudinal Moment (M_L)	C_L	2.0	50^0	-0.45	-0.55
Circumferential Moment (M_N)	C_N	1.8	40^0	-0.75	-0.60

$$X_1 = X_o + \log_{10}\beta_1$$

$$Y_1 = Y_o + \log_{10}\beta_2$$

$$\eta = -(X_1 \cos\theta + Y_1 \sin\theta) - \frac{1}{A_o} (X_1 \sin\theta - Y_1 \cos\theta)^2$$

$$C_W = 3.82(\gamma)^{1.64} \beta_1 \beta_2 \eta^{1.54} \text{ but not less than } 1.0$$

$$C_L = 0.26(\gamma)^{1.74} \beta_1 \beta_2^2 \eta^{4.74} \text{ but not less than } 1.0$$

$$C_N = 0.38(\gamma)^{1.90} \beta_1^2 \beta_2 \eta^{3.40} \text{ but not less than } 1.0$$

$$B_L = (2/3) C_L \text{ but not less than } 1.0$$

$$B_N = (2/3) C_N \text{ but not less than } 1.0$$

$$B_W = (2/3) C_W \text{ but not less than } 1.0$$

$$K_T = 2.0 \text{ for full penetration welds and fillet or partial penetration welds welded on 4 sides}$$

$$= 3.6 \text{ for fillet or partial penetration welds welded on 2 or 3 sides}$$

$$S_A = f(1.25S_c + 0.25S_h) \text{ as defined in NC/ND-3611.2 (lesser of pipe or attachment material allowable)}$$

$$S_c = \text{allowable stress at ambient temperature (lesser of pipe or attachment material allowable)}$$

$$S_h = \text{allowable stress at Max. Temperature (lesser of pipe or attachment material allowable)}$$

$$S_y = \text{yield stress (lesser of pipe or attachment material yield stress)}$$

(A) Calculate Pipe Stress S_{MTS} due to Sustained Loads on Attachment

$$M_{TTS} = \max \left(\frac{M_{TS}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}; \frac{M_{TS}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_{tN}} + \frac{B_L M_{LS}}{Z_{tL}} + \frac{Q_{1S}}{2L_1 L_a} + \frac{Q_{2S}}{2L_2 L_b} + M_{TTS}$$

where

W_S , Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS} , M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(B) Calculate PipeStress S_{MTO} due to Occasional Loads on Attachment

$$M_{TTO} = \max \left(\frac{M_{TO}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}, \frac{M_{TO}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_{tN}} + \frac{B_L M_{LO}}{Z_{tL}} + \frac{Q_{1O}}{2L_1 L_a} + \frac{Q_{2O}}{2L_2 L_b} + M_{TTO}$$

where

W_O , Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO} , M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate PipeStresses S_{NTE} and S_{PTE} due to Thermal Loads on Attachment

$$M_{TTE} = \max \left(\frac{M_{TE}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}, \frac{M_{TE}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_{tN}} + \frac{C_L M_{LE}}{Z_{tL}} + \frac{Q_{1E}}{2L_1 L_a} + \frac{Q_{2E}}{2L_2 L_b} + M_{TTE}$$

$$S_{PTE} = K_T \cdot S_{NTE}$$

where

W_E , Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE} , M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{NTD} and S_{PTD} due to Settlement Loads on Attachment

$$M_{TTD} = \max \left(\frac{M_{TD}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}; \frac{M_{TD}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{NTD} = \frac{C_W W_D}{A_T} + \frac{C_N M_{ND}}{Z_{tN}} + \frac{C_L M_{LD}}{Z_{tL}} + \frac{Q_{1D}}{2L_1 L_a} + \frac{Q_{2D}}{2L_2 L_b} + M_{TTD}$$

$$S_{PTD} = K_T \cdot S_{NTD}$$

where

W_D , Q_{1D} and Q_{2D} are the thrust load and shear forces applied at the attachment due to Settlement Loads

M_{TD} , M_{LD} and M_{ND} are the torsional moment and bending moments applied at the attachment due to Settlement Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTD} Stresses.

(E) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads

S_{MTR} = Stress S_{MIS} calculated in Subsection A above

S_{PTR} = Stress S_{PTE} calculated in Subsection C above

(F) Calculate Attachment Stresses: S_{NT}^{} due to Abs. Max. Loads**

$$M_{TT}^{**} = \max \left(\frac{M_T^{**}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}; \frac{M_T^{**}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{NT}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N^{**}}{Z_{tN}} + \frac{C_L M_L^{**}}{Z_{tL}} + \frac{Q_1^{**}}{2L_1 L_a} + \frac{Q_2^{**}}{2L_2 L_b} + M_{TT}^{**}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

$$\text{Sustained Stress } (S_{SL}) = S_L + S_{MIS} \leq 1.5S_h$$

$$\text{Occasional Stress } (S_{SO}) = S_{LO} + S_{MIS} + S_{MTO} \leq k.S_y$$

$$\text{Thermal Stress } (S_{SE}) = S_E + (S_{PTE} / 2.0) \leq S_A$$

$$\text{Settlement Stress } (S_{SD}) = S_D + (S_{PTD} / 2.0) \leq 3.0S_h$$

$$\text{Sustained + Thermal Stress } (S_{SR}) = S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$$

Additional Check

$$S_{NT}^{**} \leq 2.S_y$$

$$\left| \frac{Q_1^{**}}{2L_1 L_a} + \frac{Q_2^{**}}{2L_2 L_b} + M_{TT}^{**} \right| \leq S_y$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

$$\text{Sustained Stress } (S_{SL}) = S_L + S_{MTS} \leq 1.5S_h$$

$$\text{Occasional Stress } (S_{SO}) = S_{LO} + S_{MTS} + S_{MTO} \leq k.S_y$$

$$\text{Thermal Stress } (S_{SE}) = S_E + (S_{PTE} / 2.0) \leq S_A$$

$$\text{Settlement Stress } (S_{SD}) = S_D + (S_{PTD} / 2.0) \leq 3.0S_h$$

$$\text{Sustained + Thermal Stress } (S_{SR}) = S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$$

Additional Check

$$|S_{NT}^{**}| \leq 2.S_y$$

$$\left| \frac{Q_1^{**}}{2L_1L_a} + \frac{Q_2^{**}}{2L_2L_b} + M_{TT}^{**} \right| \leq S_y$$

Note: Additional compliance check as per Eq. 7 and Eq. 8 of Y-3420 (b) are not performed in CAEPIPE at this time

where,

k = 1.5 for Level A& B loadings, 1.8 for Level C loadings and 2.0 for Level D loadings

S_L = Sustained Stress on Run Pipe as per NC-3652 Eq. (8)

S_{LO} = Sustained + Occasional Stress on Run Pipe as per NC-3653.1 Eq. (9)

S_E = Thermal Stress on Run Pipe as per NC-3653.2 Eq. (10)

S_D = Settlement Stress on Run Pipe as per NC-3653.2 Eq. (10a)

S_{TE} = Sustained + Thermal Stress on Run Pipe as per NC-3653.2 Eq. (11)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

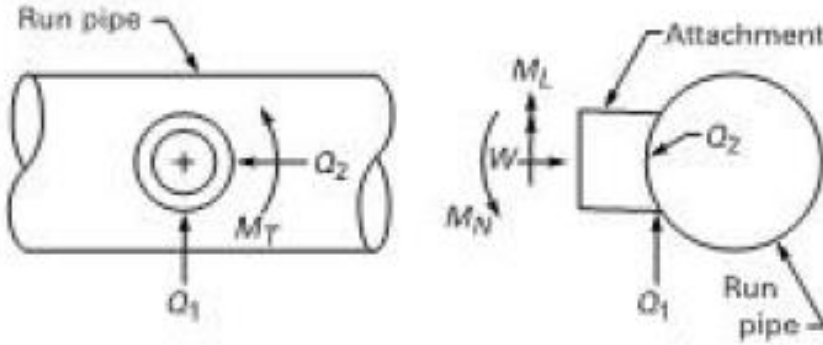
S_{PTD} = Pipe Stress S_{PTD} computed in Subsection D above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTR} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}^{**} = Pipe Stress S_{NT}^{**} computed in Subsection F above

Hollow Circular Cross-section Welded Attachments



The notations described below are used in the formulas for the design.

R = mean run pipe radius

R_o = run pipe outside radius

r_o = attachment outside radius

r_i = attachment inside radius

D_o = outside diameter of run pipe

d_o = outside diameter of attachment

T = nominal run pipe wall thickness

t = nominal attachment wall thickness

$A_T = \pi(r_o^2 - r_i^2)$ = cross-sectional area of the circular attachment

$$I_T = \frac{\pi}{4}(r_o^4 - r_i^4)$$

$$Z_T = \frac{I_T}{r_o}$$

$$J = \min(\pi r_o^2 T, Z_T)$$

$$\gamma = \frac{R_o}{T}$$

$$\beta = \frac{d_o}{D_o}$$

$$\tau = \frac{t}{T}$$

Limits of Applicability

$$4.0 \leq \gamma \leq 50$$

$$0.2 \leq \tau \leq 1.0$$

$$0.3 \leq \beta \leq 1.0$$

- M_L = bending moment applied to the attachment as shown in figure above
- M_N = bending moment applied to the attachment as shown in figure above
- M_T = torsional moment applied to the attachment as shown in figure above
- Q_1 = shear load applied to the attachment as shown in figure above.
- Q_2 = shear load applied to the attachment as shown in figure above
- W = thrust load applied to the attachment as shown in figure above

M_L , M_N , M_T , Q_1 , Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L^{**} , M_N^{**} , M_T^{**} , Q_1^{**} , Q_2^{**} and W^{**} are absolute values of maximum loads occurring simultaneously under all service loading conditions.

$$C = A_o(2\gamma)^{n1}\beta^{n2}\tau^{n3} \text{ but not less than 1.0}$$

Equation for C is used to determine C_W , C_L and C_N based on the following Table. Maximum values of C_W , C_L and C_N among the values calculated for the pipe and the attachment are used subsequently.

Load	Index	Part	β range	A_o	n1	n2	n3
Thrust (W)	C_W	Pipe	0.3 to 1.0	1.40	0.81	(a)	1.33
		Attachment	0.3 to 1.0	4.00	0.55	(b)	1.00
Longitudinal Moment (M_L)	C_L	Pipe	0.3 to 1.0	0.46	0.60	-0.04	0.86
		Attachment	0.3 to 1.0	1.10	0.23	-0.38	0.38
Circumferential Moment (M_N)	C_N	Pipe	0.3 to 0.55	0.51	1.01	0.79	0.89
		Attachment	0.3 to 0.55	0.84	0.85	0.80	0.54
Circumferential Moment (M_N)	C_N	Pipe	>0.55 to 1.0	0.23	1.01	-0.62	0.89
		Attachment	>0.55 to 1.0	0.44	0.85	-0.28	0.54
(a) - Replace β^{n2} with $e^{-1.2\beta^3}$							
(b) - Replace β^{n2} with $e^{-1.35\beta^3}$							

- $C_T = 1.0$ for $\beta \leq 0.55$
- $= C_N$ for $\beta = 1.0$, but not less than 1.0;
- C_T should be linearly interpolated for $0.55 \leq \beta < 1.0$, but not less than 1.0

- $B_W = 0.5 C_W$ but not less than 1.0
- $B_L = 0.5 C_L$ but not less than 1.0
- $B_N = 0.5 C_N$ but not less than 1.0
- $B_T = 0.5 C_T$ but not less than 1.0
- $K_T = 1.8$ for full penetration welds
- $= 2.0$ for fillet or partial penetration welds
- $S_A = f(1.25S_c + 0.25S_h)$ as defined in NC/ND-3611.2 (lesser of pipe or attachment material allowable)
- $S_c =$ allowable stress at ambient temperature (lesser of pipe or attachment material allowable)
- $S_h =$ allowable stress at maximum temperature (lesser of pipe or attachment material allowable)
- $S_y =$ yield stress (lesser of pipe or attachment material yield stress)

M_L , M_N , M_T , Q_1 , Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L^{**} , M_N^{**} , M_T^{**} , Q_1^{**} , Q_2^{**} and W^{**} are absolute values of maximum loads occurring simultaneously under all service loading conditions.

(A) Calculate PipeStress S_{MTS} due to Sustained Loads on Attachment

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_T} + \frac{B_L M_{LS}}{Z_T} + \frac{2Q_{1S}}{A_T} + \frac{2Q_{2S}}{A_T} + \frac{B_T M_{TS}}{J}$$

where

W_S , Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS} , M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate PipeStress S_{MTO} due to Occasional Loads on Attachment

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_T} + \frac{B_L M_{LO}}{Z_T} + \frac{2Q_{1O}}{A_T} + \frac{2Q_{2O}}{A_T} + \frac{B_T M_{TO}}{J}$$

where

W_O , Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO} , M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate PipeStresses S_{NTE} and S_{PTE} due to Thermal Loads on Attachment

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_T} + \frac{C_L M_{LE}}{Z_T} + \frac{2Q_{1E}}{A_T} + \frac{2Q_{2E}}{A_T} + \frac{C_T M_{TE}}{J}$$

$$S_{PTE} = K_T \cdot S_{NTE}$$

where

W_E , Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE} , M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{NTD} and S_{PTD} due to Settlement Loads on Attachment

$$S_{NTD} = \frac{C_W W_D}{A_T} + \frac{C_N M_{ND}}{Z_T} + \frac{C_L M_{LD}}{Z_T} + \frac{2Q_{1D}}{A_T} + \frac{2Q_{2D}}{A_T} + \frac{C_T M_{TD}}{J}$$

$$S_{PTD} = K_T \cdot S_{NTD}$$

where

W_D , Q_{1D} and Q_{2D} are the thrust load and shear forces applied at the attachment due to Settlement Loads

M_{TD} , M_{LD} and M_{ND} are the torsional moment and bending moments applied at the attachment due to SettlementLoads

Note: Absolute values of Forces and Moments are used while calculating S_{NTD} Stresses.

(E) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads on Attachment

S_{MTR} = Stress S_{MTS} calculated in Subsection A above

S_{PTR} = Stress S_{PTE} calculated in Subsection C above

(F) Calculate Attachment Stresses: S_{NT}^{} due to Abs. Max. Loads**

$$S_{NT}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N^{**}}{Z_T} + \frac{C_L M_L^{**}}{Z_T} + \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{C_T M_T^{**}}{J}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SL}) = $S_L + S_{MTS} \leq 1.5S_h$

Occasional Stress (S_{SO}) = $S_{LO} + S_{MTS} + S_{MTO} \leq k.S_y$

Thermal Stress (S_{SE}) = $S_E + (S_{PTE} / 2.0) \leq S_A$

Settlement Stress (S_{SD}) = $S_D + (S_{PTD} / 2.0) \leq 3.0S_h$

Sustained + Thermal Stress (S_{SR}) = $S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$

Additional Check

$$|S_{NT}^{**}| \leq 2.S_y$$

$$\left| \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{M_T^{**}}{J} \right| \leq S_y$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SL}) = $S_L + S_{MTS} \leq 1.5S_h$

Occasional Stress (S_{SO}) = $S_{LO} + S_{MTS} + S_{MTO} \leq k.S_y$

Thermal Stress (S_{SE}) = $S_E + (S_{PTE} / 2.0) \leq S_A$

Settlement Stress (S_{SD}) = $S_D + (S_{PTD} / 2.0) \leq 3.0S_h$

Sustained + Thermal Stress (S_{SR}) = $S_{TE} + S_{MTR} + (S_{PTR} / 2.0) \leq (S_h + S_A)$

Additional Check

$$|S_{NT}^{**}| \leq 2.S_y$$

$$\left| \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{M_T^{**}}{J} \right| \leq S_y$$

Note: Additional compliance checks as per Eq. 7 and Eq. 8 of Y-5420 (b) are not performed in CAEPIPE at this time

where,

$k = 1.5$ for Level A& B Loadings, 1.8 for Level C loadings and 2.0 for Level D loadings

S_L = Sustained Stress on Run Pipe as per NC-3652 Eq. (8)

S_{LO} = Sustained + Occasional Stress on Run Pipe as per NC-3653.1 Eq. (9)

S_E = Thermal Stress on Run Pipe as per NC-3653.2 Eq. (10)

S_D = Settlement Stress on Run Pipe as per NC-3653.2 Eq. (10a)

S_{TE} = Sustained + Thermal Stress on Run Pipe as per NC-3653.2 Eq. (11)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

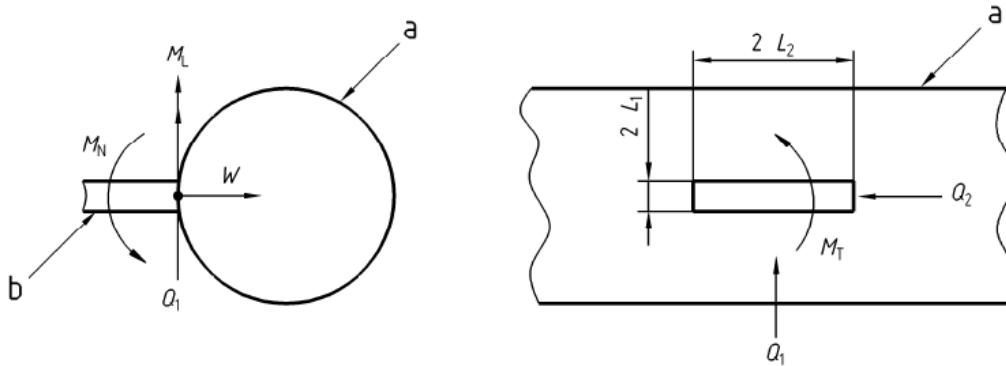
S_{PTD} = Pipe Stress S_{PTD} computed in Subsection D above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTR} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}^{**} = Pipe Stress S_{NT}^{**} computed in Subsection F above

Rectangular Cross-section Welded Attachments



The notations described below are used in the formulas for the design.

L_1 = half length of attachment in circumferential direction of the run pipe

L_2 = half length of attachment in longitudinal direction of the run pipe

R = mean pipe radius

D_o = outside diameter of run pipe

T = nominal run pipe wall thickness

L_a = lesser of L_2 and T

L_b = lesser of L_1 and T

L_c = lesser of L_1 and L_2

L_d = greater of L_1 and L_2

$A_T = 4 \cdot L_1 \cdot L_2$ = cross-sectional area of the rectangular attachment

$$Z_{tL} = \left(\frac{4}{3}\right) \cdot L_1 \cdot L_2^2$$

$$Z_{tN} = \left(\frac{4}{3}\right) \cdot L_1^2 \cdot L_2$$

$$\beta_1 = \frac{L_1}{R}$$

$$\beta_2 = \frac{L_2}{R}$$

$$\gamma = \frac{R}{T}$$

Limits of Applicability

$$\beta_1 \leq 0.5$$

$$\beta_2 \leq 0.5$$

$$\beta_1 \cdot \beta_2 \leq 0.75$$

M_L = bending moment applied to the attachment as shown in figure above

M_N = bending moment applied to the attachment as shown in figure above

M_T = torsional moment applied to the attachment as shown in figure above

Q_1 = shear load applied to the attachment as shown in figure above.

Q_2 = shear load applied to the attachment as shown in figure above

W = thrust load applied to the attachment as shown in figure above

M_L , M_N , M_T , Q_1 , Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L^{**} , M_N^{**} , M_T^{**} , Q_1^{**} , Q_2^{**} and W^{**} are absolute values of maximum loads occurring simultaneously under all service loading conditions.

Calculate η , X_1 and Y_1 using the factors listed in Table below.

Load	Index	A_o	θ	X_o	Y_o
Thrust (W)	C_W	2.2	40^0	0	0.05
Longitudinal Moment (M_L)	C_L	2.0	50^0	-0.45	-0.55
Circumferential Moment (M_N)	C_N	1.8	40^0	-0.75	-0.60

$$X_1 = X_o + \log_{10}\beta_1$$

$$Y_1 = Y_o + \log_{10}\beta_2$$

$$\eta = -(X_1 \cos\theta + Y_1 \sin\theta) - \frac{1}{A_o} (X_1 \sin\theta - Y_1 \cos\theta)^2$$

$$C_W = 3.82(\gamma)^{1.64} \beta_1 \beta_2 \eta^{1.54} \text{ but not less than } 1.0$$

$$C_L = 0.26(\gamma)^{1.74} \beta_1 \beta_2^2 \eta^{4.74} \text{ but not less than } 1.0$$

$$C_N = 0.38(\gamma)^{1.90} \beta_1^2 \beta_2 \eta^{3.40} \text{ but not less than } 1.0$$

$$B_L = (2/3) C_L \text{ but not less than } 1.0$$

$$B_N = (2/3) C_N \text{ but not less than } 1.0$$

$$B_W = (2/3) C_W \text{ but not less than } 1.0$$

$$K_T = 2.0 \text{ for full penetration welds and fillet or partial penetration welds welded on 4 sides}$$

$$= 3.6 \text{ for fillet or partial penetration welds welded on 2 or 3 sides}$$

$$f_a = \text{allowable stress range as defined in Clause 12.1.3 of EN 13480-3 (2017)}$$

$$S_c = \text{allowable stress at ambient temperature}$$

$$f_h = \text{allowable stress at max temperature as provided in Clause 12.1.3 of EN 13480-3 (2017)}$$

$$f_{cr} = \text{design stress in the creep range as defined in Clause 5.3 of EN 13480-3 (2017)}$$

$$R_{eHt} = \text{yield stress}$$

Pipe Stresses are calculated using the equations 11.5.3-1, 11.5.3-2, 11.5.3-3 and 11.5.3-4 provided in Clause 11.5.3.

(A) Calculate PipeStress S_{MTS} due to Sustained Loads on Attachment

$$M_{TTS} = \max \left(\frac{M_{TS}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}; \frac{M_{TS}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_{tN}} + \frac{B_L M_{LS}}{Z_{tL}} + \frac{Q_{1S}}{2L_1 L_a} + \frac{Q_{2S}}{2L_2 L_b} + M_{TTS}$$

where

W_S , Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS} , M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate PipeStress S_{MTO} due to Occasional Loads on Attachment

$$M_{TTO} = \max \left(\frac{M_{TO}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}; \frac{M_{TO}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_{tN}} + \frac{B_L M_{LO}}{Z_{tL}} + \frac{Q_{1O}}{2L_1 L_a} + \frac{Q_{2O}}{2L_2 L_b} + M_{TTO}$$

where

W_O , Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO} , M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate Attachment Stresses: S_{NTE} and S_{PTE} due to Thermal Loads

$$M_{TTE} = \max \left(\frac{M_{TE}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}; \frac{M_{TE}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_{tN}} + \frac{C_L M_{LE}}{Z_{tL}} + \frac{Q_{1E}}{2L_1 L_a} + \frac{Q_{2E}}{2L_2 L_b} + M_{TTE}$$

$$S_{PTE} = K_T \cdot S_{NTE}$$

where

W_E , Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE} , M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads on Attachment

S_{MTR} = additional stress resulting from sustained loads = S_{MTS} calculated in Subsection A above

S_{PTR} = additional stress resulting from restrained thermal loads = S_{PTE} calculated in Subsection C above

(E) Calculate PipeStresses S_{MTC} and S_{PTC} due to Creep on Attachment

S_{MTC} = additional stress resulting from sustained loads = S_{MTS} calculated in Subsection A above

S_{PTC} = additional stress resulting from restrained thermal loads = S_{PTE} calculated in Subsection C above

(F) Calculate PipeStress S_{NT}^{} due to Abs. Max. Loads**

$$M_{TT}^{**} = \max \left(\frac{M_T^{**}}{L_c L_d T \left[1 + \left(\frac{L_c}{L_d} \right) \right]}, \frac{M_T^{**}}{\left[0.8 + 0.05 \left(\frac{L_d}{L_c} \right) \right] L_c^2 L_d} \right)$$

$$S_{NT}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N^{**}}{Z_T} + \frac{C_L M_L^{**}}{Z_T} + \frac{Q_1^{**}}{2L_1 L_a} + \frac{Q_2^{**}}{2L_2 L_b} + M_{TT}^{**}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SL}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

$S_{NT}^{**} \leq 2R_{eHt}$

$$\left| \frac{Q_1^{**}}{2L_1 L_a} + \frac{Q_2^{**}}{2L_2 L_b} + M_{TT}^{**} \right| \leq R_{eHt}$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SL}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

$$\text{Creep Stress } (S_{SC}) = S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$$

Additional Check

$$S_{NT}^{**} \leq 2R_{eHt}$$

$$\left| \frac{Q_1^{**}}{2L_1L_a} + \frac{Q_2^{**}}{2L_2L_b} + M_{TT}^{**} \right| \leq R_{eHt}$$

Note: Additional compliance checks as per Eq. 11.5.4-1 and Eq. 11.5.4-2 of Clause 11.5.4 are not performed in CAEPIPE at this time.

where,

S_1 = Sustained Stress on Run Pipe as per 12.3.2-1 of EN 13480-3 (2017)

S_2 = Sustained + Occasional Stress on Run Pipe as per 12.3.3-1 of EN 13480-3 (2017)

S_3 = Thermal Stress on Run Pipe as per 12.3.4-1 of EN 13480-3 (2017)

S_4 = Sustained + Thermal Stress on Run Pipe as per 12.3.4-2 of EN 13480-3 (2017)

S_5 = Settlement Stress on Run Pipe as per 12.3.5-1 of EN 13480-3 (2017)

S_{MTS} = Pipe Stress S_{MTS} computed in Subsection A above

S_{MTO} = Pipe Stress S_{MTO} computed in Subsection B above

S_{PTE} = Pipe Stress S_{PTE} computed in Subsection C above

S_{MTR} = Pipe Stress S_{MTR} computed in Subsection D above

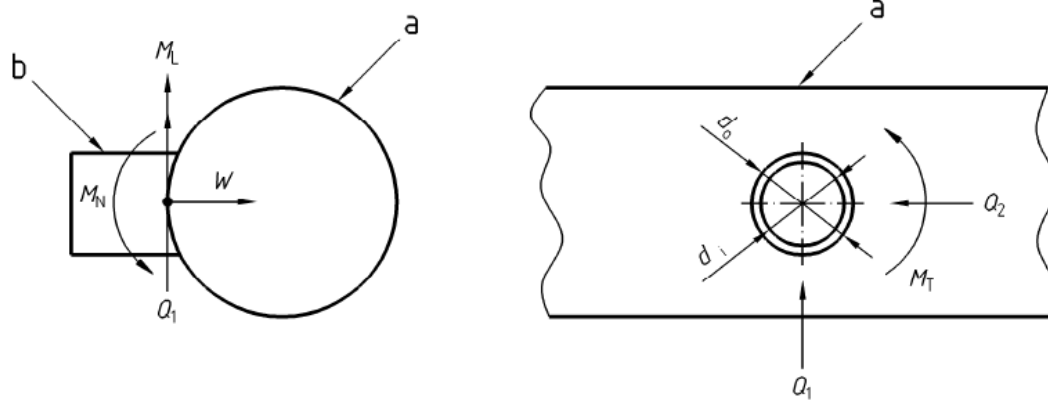
S_{PTR} = Pipe Stress S_{PTR} computed in Subsection D above

S_{MTC} = Pipe Stress S_{MTR} computed in Subsection E above

S_{PTC} = Pipe Stress S_{PTR} computed in Subsection E above

S_{NT}^{**} = Pipe Stress S_{NT}^{**} computed in Subsection F above

Hollow Circular Cross-section Welded Attachments



The symbols described below are used in the formulas for the design.

R = mean run pipe radius

R_o = run pipe outside diameter

r_o = attachment outside radius

r_i = attachment inside radius

D_o = outside diameter of run pipe

d_o = outside diameter of attachment

T = nominal run pipe wall thickness

t = nominal attachment wall thickness

$A_T = \pi(r_o^2 - r_i^2)$ = cross-sectional area of the circular attachment

$$I_T = \frac{\pi}{4}(r_o^4 - r_i^4)$$

$$Z_T = \frac{I_T}{r_o}$$

$$J = \min(\pi r_o^2 T, Z_T)$$

$$\gamma = \frac{R_o}{T}$$

$$\beta = \frac{d_o}{D_o}$$

$$\tau = \frac{t}{T}$$

Limits of Applicability

$$4.0 \leq \gamma \leq 50$$

$$0.2 \leq \tau \leq 1.0$$

$$0.3 \leq \beta \leq 1.0$$

- M_L = bending moment applied to the attachment as shown in figure above
 M_N = bending moment applied to the attachment as shown in figure above
 M_T = torsional moment applied to the attachment as shown in figure above
 Q_1 = shear load applied to the attachment as shown in figure above.
 Q_2 = shear load applied to the attachment as shown in figure above
 W = thrust load applied to the attachment as shown in figure above

M_L , M_N , M_T , Q_1 , Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L^{**} , M_N^{**} , M_T^{**} , Q_1^{**} , Q_2^{**} and W^{**} are absolute values of maximum loads occurring simultaneously under all service loading conditions.

$$C = A_o(2\gamma)^{n1}\beta^{n2}\tau^{n3} \text{ but not less than 1.0}$$

Equation for C is used to determine C_w , C_L and C_N based on the following Table. Maximum values of C_w , C_L and C_N among the values calculated for the pipe and the attachment are used subsequently.

Load	Index	Part	β range	A_o	n1	n2	n3
Thrust (W)	C_w	Pipe	0.3 to 1.0	1.40	0.81	(a)	1.33
		Attachment	0.3 to 1.0	4.00	0.55	(b)	1.00
Longitudinal Moment (M_L)	C_L	Pipe	0.3 to 1.0	0.46	0.60	-0.04	0.86
		Attachment	0.3 to 1.0	1.10	0.23	-0.38	0.38
Circumferential Moment (M_N)	C_N	Pipe	0.3 to 0.55	0.51	1.01	0.79	0.89
		Attachment	0.3 to 0.55	0.84	0.85	0.80	0.54
Circumferential Moment (M_N)	C_N	Pipe	>0.55 to 1.0	0.23	1.01	-0.62	0.89
		Attachment	>0.55 to 1.0	0.44	0.85	-0.28	0.54

(a) - Replace β^{n2} with $e^{-1.2\beta^3}$
 (b) - Replace β^{n2} with $e^{-1.35\beta^3}$

- $C_T = 1.0$ for $\beta \leq 0.55$
 $= C_N$ for $\beta = 1.0$, but not less than 1.0;
 C_T should be linearly interpolated for $0.55 \leq \beta < 1.0$, but not less than 1.0

- $B_W = 0.5 C_w$ but not less than 1.0
 $B_L = 0.5 C_L$ but not less than 1.0
 $B_N = 0.5 C_N$ but not less than 1.0
 $B_T = 0.5 C_T$ but not less than 1.0
 $K_T = 1.8$ for full penetration welds
 $= 2.0$ for fillet or partial penetration welds
 f_a = allowable stress range as defined in Clause 12.1.3 of EN 13480-3 (2017)
 S_c = allowable stress at ambient temperature
 f_h = allowable stress at max temperature as provided in Clause 12.1.3 of EN 13480-3 (2017)

f_{cr} = design stress in the creep range as defined in Clause 5.3 of EN 13480-3 (2017)
 R_{eHt} = yield stress

(A) Calculate PipeStress S_{MTS} due to Sustained Loads on Attachment

$$S_{MTS} = \frac{B_W W_S}{A_T} + \frac{B_N M_{NS}}{Z_T} + \frac{B_L M_{LS}}{Z_T} + \frac{2Q_{1S}}{A_T} + \frac{2Q_{2S}}{A_T} + \frac{B_T M_{TS}}{J}$$

where

W_S , Q_{1S} and Q_{2S} are the thrust load and shear forces applied at the attachment due to Weight and Other Sustained Loads

M_{TS} , M_{LS} and M_{NS} are the torsional moment and bending moments applied at the attachment due to Weight and Other Sustained Loads

Note: Absolute values of Forces and Moments are used while calculating S_{MTS} Stresses.

(B) Calculate Pipe Stress S_{MTO} due to Occasional Loads on Attachment

$$S_{MTO} = \frac{B_W W_O}{A_T} + \frac{B_N M_{NO}}{Z_T} + \frac{B_L M_{LO}}{Z_T} + \frac{2Q_{1O}}{A_T} + \frac{2Q_{2O}}{A_T} + \frac{B_T M_{TO}}{J}$$

where

W_O , Q_{1O} and Q_{2O} are the thrust load and shear forces applied at the attachment due to Occasional Loads such as Wind or Seismic

M_{TO} , M_{LO} and M_{NO} are the torsional moment and bending moments applied at the attachment due to Occasional Loads such as Wind or Seismic

Note: Absolute values of Forces and Moments are used while calculating S_{MTO} Stresses.

(C) Calculate PipeStresses S_{NTE} and S_{PTE} due to Thermal Loads on Attachment

$$S_{NTE} = \frac{C_W W_E}{A_T} + \frac{C_N M_{NE}}{Z_T} + \frac{C_L M_{LE}}{Z_T} + \frac{2Q_{1E}}{A_T} + \frac{2Q_{2E}}{A_T} + \frac{C_T M_{TE}}{J}$$

$$S_{PTE} = K_T \cdot S_{NTE}$$

where

W_E , Q_{1E} and Q_{2E} are the thrust load and shear forces applied at the attachment due to Thermal Loads

M_{TE} , M_{LE} and M_{NE} are the torsional moment and bending moments applied at the attachment due to Thermal Loads

Note: Absolute values of Forces and Moments are used while calculating S_{NTE} Stresses.

(D) Calculate PipeStresses S_{MTR} and S_{PTR} due to Sustained + Thermal Loads on Attachment

S_{MTR} = Stress S_{MTS} calculated in Subsection A above

S_{PTR} = Stress S_{PTE} calculated in Subsection C above

(E) Calculate PipeStresses S_{MTC} and S_{PTC} due to Creep on Attachment

S_{MTC} = Stress S_{MTS} calculated in Subsection A above

S_{PTC} = Stress S_{PTE} calculated in Subsection C above

(F) Calculate PipeStress S_{NT}^{} due to Abs. Max. Loads on Attachment**

$$S_{NT}^{**} = \frac{C_W W^{**}}{A_T} + \frac{C_N M_N^{**}}{Z_T} + \frac{C_L M_L^{**}}{Z_T} + \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{C_T M_T^{**}}{J}$$

Analysis of Attachment Welded to Pipe with a Full Penetration Weld

Sustained Stress (S_{SI}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

$$|S_{NT}^{**}| \leq 2.R_{eHt}$$

$$\left| \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{M_T^{**}}{J} \right| \leq R_{eHt}$$

Analysis of Attachment Welded to Pipe with a Fillet or Partial Penetration Weld

Sustained Stress (S_{SI}) = $S_1 + S_{MTS} \leq 1.5f_h$

Occasional Stress (S_{SO}) = $S_2 + S_{MTS} + S_{MTO} \leq 1.8f_h$

Thermal Stress (S_{SE}) = $S_3 + (S_{PTE} / 2.0) \leq f_a$

Sustained + Thermal Stress (S_{SR}) = $S_4 + S_{MTR} + (S_{PTR} / 2.0) \leq (f_h + f_a)$

Creep Stress (S_{SC}) = $S_4 + S_{MTC} + (S_{PTC} / 2.0) \leq 1.25f_{cr}$

Additional Check

$$|S_{NT}^{**}| \leq 2.R_{eHt}$$

$$\left| \frac{2Q_1^{**}}{A_T} + \frac{2Q_2^{**}}{A_T} + \frac{M_T^{**}}{J} \right| \leq R_{eHt}$$

Note: Additional compliance checks as per Eq. 11.4.4-1 and Eq. 11.4.4-2 of Clause 11.4.4 are not performed in CAEPIPE at this time

where,

S_1 = Sustained Stress on Run Pipe as per 12.3.2-1 of EN 13480-3 (2017)

S_2 = Sustained + Occasional Stress on Run Pipe as per 12.3.3-1 of EN 13480-3 (2017)

S_3 = Thermal Stress on Run Pipe as per 12.3.4-1 of EN 13480-3 (2017)

S_4 = Sustained + Thermal Stress on Run Pipe as per 12.3.4-2 of EN 13480-3 (2017)

S_5 = Settlement Stress on Run Pipe as per 12.3.5-1 of EN 13480-3 (2017)

$S_{M\text{TS}}$ = Pipe Stress $S_{M\text{TS}}$ computed in Subsection A above

$S_{M\text{TO}}$ = Pipe Stress $S_{M\text{TO}}$ computed in Subsection B above

$S_{P\text{TE}}$ = Pipe Stress $S_{P\text{TE}}$ computed in Subsection C above

$S_{M\text{TR}}$ = Pipe Stress $S_{M\text{TR}}$ computed in Subsection D above

$S_{P\text{TR}}$ = Pipe Stress $S_{P\text{TR}}$ computed in Subsection D above

$S_{M\text{TC}}$ = Pipe Stress $S_{M\text{TR}}$ computed in Subsection E above

$S_{P\text{TC}}$ = Pipe Stress $S_{P\text{TR}}$ computed in Subsection E above

$S_{N\text{T}}^{**}$ = Pipe Stress $S_{N\text{T}}^{**}$ computed in Subsection F above

Nozzle Evaluation

Local Loads on nozzles in spherical shells

Conditions of applicability

a) $0.001 \leq e_a/R \leq 0.1$

b) distances to any other local load in any direction shall be not less than $\sqrt{R \cdot e_c}$

c) nozzle thickness shall be maintained over a distance of $L \geq \sqrt{d \cdot e_b}$

where,

e = nominal shell thickness

e_a = analysis shell thickness = e – corrosion allowance

e_b = nozzle thickness

e_c = analysis thickness of the combined shell and reinforcing plate

= $e_a + e_2 \cdot \min(f_2/f, 1)$ when a reinforcing plate is fitted

= e_a when no reinforcing plate is fitted

R = mean shell radius at the nozzle

e_2 = reinforcing pad thickness

f_2 = allowable design stress of reinforcing pad plate

f = allowable design stress of shell material

Maximum allowable individual loads

Allowable axial nozzle load

Allowable axial nozzle load $F_{z,max}$ is computed using Eq. (16.4-7)

$$F_{z,max} = f \cdot e_c^2 (1.82 + 2.4\sqrt{1+k} \cdot \lambda_s + 0.91 \cdot k \cdot \lambda_s^2)$$

where

$$k = \min\left(\frac{2f_b e_b}{f e_c} \sqrt{\frac{e_b}{d}}; 1.0\right)$$

$$\lambda_s = \frac{d}{\sqrt{R e_c}}$$

d = mean nozzle diameter

f_b = allowable design stress of nozzle material

Allowable bending moment

Allowable bending moment $M_{B,max}$ is computed using Eq. (16.4-8)

$$M_{B,max} = f \cdot e_c^2 \frac{d}{4} (4.90 + 2.0\sqrt{1+k} \cdot \lambda_s + 0.91 \cdot k \cdot \lambda_s^2)$$

Local Loads on nozzles in cylindrical shells

Conditions of applicability

a) $0.001 \leq e_a/D \leq 0.1$

b) $\lambda_c = \frac{d}{\sqrt{De_c}}$

b) distances to any other local load in any direction shall be not less than $\sqrt{D \cdot e_c}$

c) nozzle thickness shall be maintained over a distance of $L \geq \sqrt{d \cdot e_b}$

where,

e = nominal shell thickness

e_a = analysis shell thickness = e – corrosion allowance

e_b = nozzle thickness

e_c = analysis thickness of the combined shell and reinforcing plate

= e_a + e₂ · min(f₂/f;1) when a reinforcing plate is fitted

= e_a when no reinforcing plate is fitted

D = mean shell diameter at the opening

e₂ = reinforcing pad thickness

f₂ = allowable design stress of reinforcing pad plate

f = allowable design stress of shell material

Maximum allowable individual loads

Allowable axial nozzle load

Allowable axial nozzle load F_{z,max} is computed using Eq. (16.5-3)

$$F_{z,max} = f \cdot e_c^2 \cdot C_1$$

where

$$C_1 = \max[(a_0 + a_1 \cdot \lambda_c + a_2 \cdot \lambda_c^2 + a_3 \cdot \lambda_c^3 + a_4 \cdot \lambda_c^4); 1.81] \text{ as per Eq. (16.5-4)}$$

Table 16.5-1 — Coefficients for C₁

e _b /e _c	a ₀	a ₁	a ₂	a ₃	a ₄
All	0,60072181	0,95196257	0,0051957881	-0,001406381	0

$$\lambda_c = \frac{d}{\sqrt{De_c}}$$

Allowable circumferential moment

Allowable bending moment $M_{X,max}$ is computed using Eq. (16.5-5)

$$M_{X,max} = f \cdot e_c^2 \frac{d}{4} C_2$$

where,

$$C_2 = \max[(a_0 + a_1 \cdot \lambda_c + a_2 \cdot \lambda_c^2 + a_3 \cdot \lambda_c^3 + a_4 \cdot \lambda_c^4); 4.90] \text{ as per Eq. (16.5-6)}$$

Table 16.5-2 — Coefficients for C_2

e_b / e_c	a_0	a_1	a_2	a_3	a_4
All	4,526315	0,064021889	0,15887638	-0,021419298	0,0010350407

Allowable longitudinal moment

Allowable longitudinal moment $M_{Y,max}$ is computed using Eq. (16.5-7)

$$M_{Y,max} = f \cdot e_c^2 \frac{d}{4} C_3$$

where,

$$C_3 = \max[(a_0 + a_1 \cdot \lambda_c + a_2 \cdot \lambda_c^2 + a_3 \cdot \lambda_c^3 + a_4 \cdot \lambda_c^4); 4.90] \text{ as per Eq. (16.5-8)}$$

Table 16.5-3 — Coefficients for C_3

e_b / e_c	a_0	a_1	a_2	a_3	a_4
$\leq 0,2$	4,8517511	0,0251012	0,7428624	-0,0153153	0
$\geq 0,5$	4,8588639	2,1870887	1,4567053	-0,3316430	0,0253850

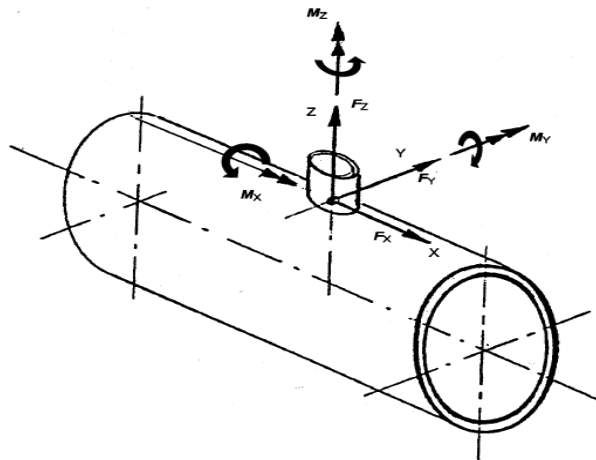


Figure 16.5-1 — Moment and Force Vectors

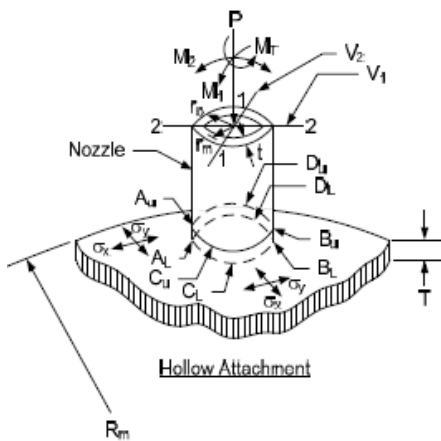
General

CAEPIPE computes Local Shell Stresses at Nozzles as per WRC Bulletin 537 (2013) and performs Stress Compliance as per ASME Section VIII Division 2 (2017).

As stated in ASME Section VIII Division 2 (2017) code, shell stresses computed for primary loads of Sustained and Sustained + Occasional should exclude the Radial and Tangential Bending Stresses. On the other hand, for Operating load which includes secondary loads due to temperature change and thermal anchor movements, Radial and Tangential Bending Stresses should be included for compliance as per ASME Section VIII Division 2 (2017). Refer to the extract from ASME Section VIII Division 2 (2017) provided at the end of this section for details on the implementation of Stress Compliance in CAEPIPE.

Local Stresses in Spherical Shells at Hollow Circular Attachments

As per Section 3.5.1 of WRC Bulletin 537, the below procedure provides one with a tool to compute stresses in the shell, but not in the nozzle. In some instances, stresses will be higher in the nozzle wall than they are in the vessel wall. This possibility is most likely if the nozzle opening is not reinforced, or if the reinforcement is placed on the vessel wall and not on the nozzle.



- V_1 concentrated external shear load in 2-2 direction
- V_2 concentrated external shear load in 1-1 direction
- M_1 external overturning moment in 1-1 direction
- M_2 external overturning moment in 2-2 direction
- R_m mean radius of spherical shell
- T thickness of spherical shell
- r_0 outside radius of cylindrical attachment
- r_m mean radius of hollow cylindrical attachment
- t thickness of hollow cylindrical attachment
- Υ r_m / t
- ρ T / t
- U $r_0 / \sqrt{R_m T}$
- N_x membrane force in shell wall in the radial direction, respectively (see Figure 1)
- N_y membrane force in shell wall in the circumferential direction (see Figure 1)
- M_x bending moment in shell wall in the radial direction (see Figure 1)
- M_y bending moment in shell wall in the circumferential direction (see Figure 1)
- σ_x normal stress in radial direction (see Figure 1)
- σ_y normal stress in circumferential direction (see Figure 1)
- τ_{xy} shear stress on the x-face in the y-direction
- τ_{yx} shear stress on the y-face in the x-direction
- τ_1 shear stress on the 1-1 face
- τ_2 shear stress on the 2-2 face

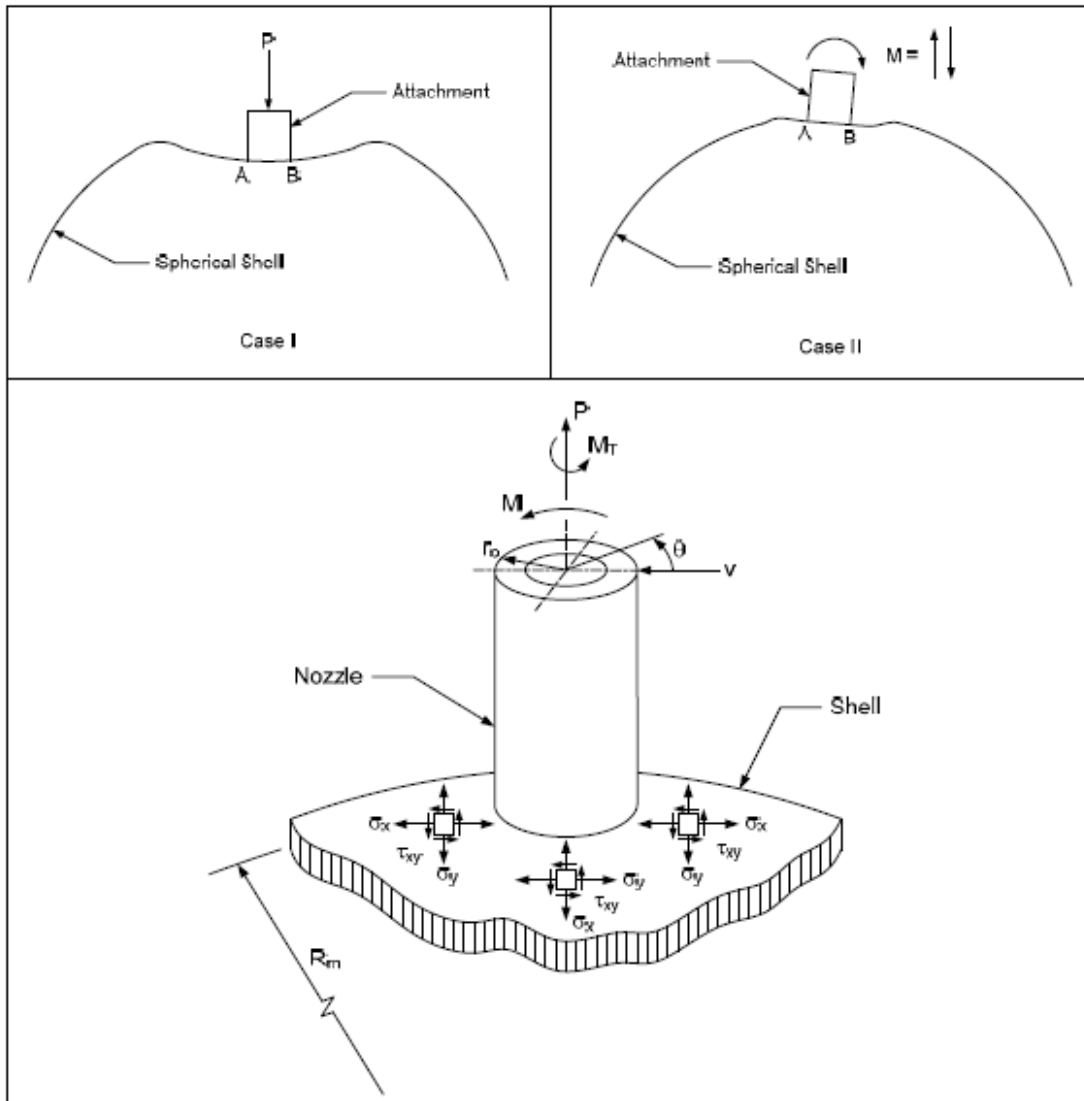


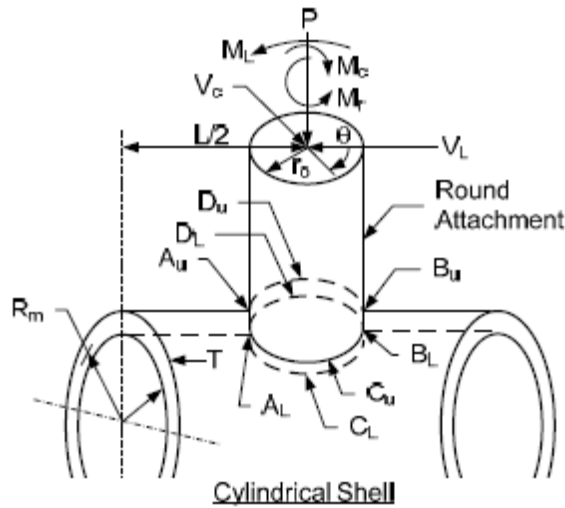
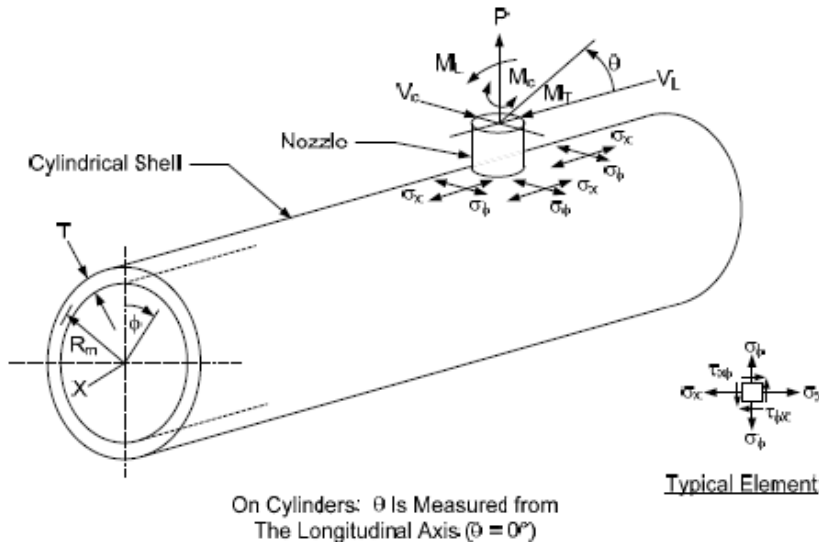
Figure 1 – Types of Loading Conditions at an Attachment to a Spherical Shell

WRC Bulletin 537 (2013)

Reference Figure No.	Read Curves for	Calculate absolute values of stress and enter result	STRESSES - If load is opposite that shown, reverse signs shown							
			A _u	A _t	B _u	B _t	C _u	C _t	D _u	D _t
SP-1 to 10	$\frac{N_r T}{P} -$	$K_n \left(\frac{N_r T}{P} \right) \left(\frac{P}{T^2} \right) -$	-	-	-	-	-	-	-	-
	$\frac{M_x}{P} -$	$K_b \left(\frac{M_x}{P} \right) \left(\frac{6P}{T^2} \right) -$	-	+	-	+	-	+	-	+
SM-1 to 10	$\frac{N_r T \sqrt{R_n T}}{M_1} -$	$K_n \left(\frac{N_r T \sqrt{R_n T}}{M_1} \right) \left(\frac{M_1}{T^2 \sqrt{R_n T}} \right) -$					-	-	+	+
	$\frac{M_x \sqrt{R_n T}}{M_1} -$	$K_b \left(\frac{M_x \sqrt{R_n T}}{M_1} \right) \left(\frac{6M_1}{T^2 \sqrt{R_n T}} \right) -$					-	+	+	-
	$\frac{N_r T \sqrt{R_n T}}{M_2} -$	$K_n \left(\frac{N_r T \sqrt{R_n T}}{M_2} \right) \left(\frac{M_2}{T^2 \sqrt{R_n T}} \right) -$	-	-	+	+				
	$\frac{M_x \sqrt{R_n T}}{M_2} -$	$K_b \left(\frac{M_x \sqrt{R_n T}}{M_2} \right) \left(\frac{6M_2}{T^2 \sqrt{R_n T}} \right) -$	-	+	+	-				
Add algebraically for summation of radial stresses σ_x		$\sigma_x =$								
SP-1 to 10	$\frac{N_r T}{P} -$	$K_n \left(\frac{N_r T}{P} \right) \left(\frac{P}{T^2} \right) -$	-	-	-	-	-	-	-	-
	$\frac{M_x}{P} -$	$K_b \left(\frac{M_x}{P} \right) \left(\frac{6P}{T^2} \right) -$	-	+	-	+	-	+	-	+
SM-1 to 10	$\frac{N_r T \sqrt{R_n T}}{M_1} -$	$K_n \left(\frac{N_r T \sqrt{R_n T}}{M_1} \right) \left(\frac{M_1}{T^2 \sqrt{R_n T}} \right) =$					-	-	+	+
	$\frac{M_x \sqrt{R_n T}}{M_1} =$	$K_b \left(\frac{M_x \sqrt{R_n T}}{M_1} \right) \left(\frac{6M_1}{T^2 \sqrt{R_n T}} \right) -$					-	+	+	-
	$\frac{N_r T \sqrt{R_n T}}{M_2} -$	$K_n \left(\frac{N_r T \sqrt{R_n T}}{M_2} \right) \left(\frac{M_2}{T^2 \sqrt{R_n T}} \right) -$	-	-	+	+				
	$\frac{M_x \sqrt{R_n T}}{M_2} -$	$K_b \left(\frac{M_x \sqrt{R_n T}}{M_2} \right) \left(\frac{6M_2}{T^2 \sqrt{R_n T}} \right) -$	-	+		-				
Add algebraically for summation of tangential stresses σ_y		$\sigma_y =$								
Shear stress due to load V_1	$\tau_1 = \frac{V_1}{\pi r T} -$					-	-	+	+	
Shear stress due to load V_2	$\tau_2 = \frac{V_2}{\pi r T} -$		+	+	-	-				
Shear stress due to Torsion, M_T	$\tau_3 = \tau_1 = \frac{M_T}{2\pi r^2 T} -$		+	+	+	+	+	+	+	
Add algebraically for summation of shear stresses τ		$\tau =$								
COMBINED STRESS INTENSITY - S										
1) When $\tau \neq 0$, $S =$ largest absolute magnitude of either $S = \frac{1}{2} [\sigma_x + \sigma_y \pm \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}]$ or $\sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2}$										
2) When $\tau = 0$, $S =$ largest absolute magnitude of either $S = \sigma_x, \sigma_y, (\sigma_x - \sigma_y)$										

Local Stresses in Cylindrical Shells at Solid Circular Attachments

As per Section 4.5.3 of WRC Bulletin 537, the below procedure provides one with a tool to compute stresses in the shell, but not in the attachment. Under certain conditions, stresses may be higher in the attachment than they are in the vessel. For example, in the case of a nozzle, it is likely that the stresses will be higher in the nozzle wall than they are in the vessel wall if the nozzle opening is unreinforced or if the reinforcement is placed on the vessel wall and not on the nozzle.



- V_c concentrated shear load in the circumferential direction, lb
- V_L concentrated shear load in the longitudinal direction
- M_c external overturning moment in the circumferential direction with respect to the shell
- M_L external overturning moment in the longitudinal direction with respect to the shell
- R_m mean radius of cylindrical shell
- l length of cylindrical shell
- r_o outside radius of cylindrical attachment
- T wall thickness of cylindrical shell
- β attachment parameter

WRC Bulletin 537 (2013)

Reference Figure No.	Read Curves for	Calculate absolute values of stress and enter result	STRESSES - If load is opposite that shown, reverse signs shown							
			A _u	A _l	B _u	B _l	C _u	C _l	D _u	D _l
3C	$\frac{N_p}{P/R_u}$	$K_n \left(\frac{N_p}{P/R_u} \right) \left(\frac{P}{R_u T} \right)$	-	-	-	-	-	-	-	-
1C OR 2C-1	$\frac{M_p}{P}$	$K_b \left(\frac{M_p}{P} \right) \left(\frac{6P}{T^2} \right)$	-	+	-	+	-	+	-	+
3A	$\frac{N_p}{M_i/R_u^2\beta}$	$K_n \left(\frac{N_p}{M_i/R_u^2\beta} \right) \left(\frac{M_i}{R_u^2\beta T} \right)$					-	-	+	+
1A	$\frac{M_p}{M_i/R_u\beta}$	$K_b \left(\frac{M_p}{M_i/R_u\beta} \right) \left(\frac{6M_i}{R_u\beta T^2} \right)$					-	+	+	-
3B	$\frac{N_p}{M_i/R_u^2\beta}$	$K_n \left(\frac{N_p}{M_i/R_u^2\beta} \right) \left(\frac{M_i}{R_u^2\beta T} \right)$	-	-	+	+				
1B or 1B-1	$\frac{M_p}{M_i/R_u\beta}$	$K_b \left(\frac{M_p}{M_i/R_u\beta} \right) \left(\frac{6M_i}{R_u\beta T^2} \right)$	-	+	+	-				
Add algebraically for summation of ϕ stresses σ_ϕ			$\sigma_\phi =$							
4C	$\frac{N_p}{P/R_u}$	$K_n \left(\frac{N_p}{P/R_u} \right) \left(\frac{P}{R_u T} \right)$	-	-	-	-	-	-	-	-
1C-1 OR 2C	$\frac{M_p}{P}$	$K_b \left(\frac{M_p}{P} \right) \left(\frac{6P}{T^2} \right)$	-	+	-	+	-	+	-	+
4A	$\frac{N_p}{M_i/R_u^2\beta}$	$K_n \left(\frac{N_p}{M_i/R_u^2\beta} \right) \left(\frac{M_i}{R_u^2\beta T} \right)$					-	-	+	+
2A	$\frac{M_p}{M_i/R_u\beta}$	$K_b \left(\frac{M_p}{M_i/R_u\beta} \right) \left(\frac{6M_i}{R_u\beta T^2} \right)$					-	+	+	-
4B	$\frac{N_p}{M_i/R_u^2\beta}$	$K_n \left(\frac{N_p}{M_i/R_u^2\beta} \right) \left(\frac{M_i}{R_u^2\beta T} \right)$	-	-	+	+				
2B or 2B-1	$\frac{M_p}{M_i/R_u\beta}$	$K_b \left(\frac{M_p}{M_i/R_u\beta} \right) \left(\frac{6M_i}{R_u\beta T^2} \right)$	-	+	+	-				
Add algebraically for summation of x stresses σ_x			$\sigma_x =$							
Shear stress due to Torsion, M_T		$\tau_{xy} = \tau_{yx} = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
Shear stress due to load V_C		$\tau_{xy} = \frac{V_C}{\pi r_o T}$	+	+	-	-				
Shear stress due to load V_L		$\tau_{xy} = \frac{V_L}{\pi r_o T}$					-	-	+	+
Add algebraically for summation of shear stresses τ			$\tau =$							
COMBINED STRESS INTENSITY - S										
1) When σ_ϕ and σ_x have like signs $S = \frac{1}{2} \left[\sigma_\phi + \sigma_x \pm \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2} \right]$ or $\sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}$										
2) When $\tau=0$, $S =$ largest absolute magnitude of either $S = \sigma_\phi, \sigma_x$, or $|\sigma_\phi - \sigma_x|$										
3) When σ_ϕ and σ_x have unlike signs, $S = \sqrt{(\sigma_\phi - \sigma_x)^2 + 4\tau^2}$										

Note:

- Original Curves are referred for all figures. For example, 3C-Original is referred to read the parameters required for calculating Circumferential Membrane Stress due to P.
- Figure 2C-1 – Original is referred to calculate Circumferential Bending Stress due to P at Points A_U, A_L, B_U and B_L. Similarly, Figure 1C is referred to calculate Circumferential Bending Stress due to P at Points C_U, C_L, D_U and D_L.
- Figure 1C-1 – Original is referred to calculate Longitudinal Bending Stress due to P at Points A_U, A_L, B_U and B_L. Similarly, Figure 2C is referred to calculate Longitudinal Bending Stress due to P at Points C_U, C_L, D_U and D_L.

Stress Compliance of Local Shell Stresses at Nozzles

[Extract from ASME Section VIII Division 2 (2017)]

5.2.2.4 Assessment Procedure. To determine the acceptability of a component, the computed equivalent stresses given in 5.2.2.2 for a component subject to loads shall not exceed the specified allowable values. A schematic illustrating the categorization of equivalent stresses and their corresponding allowable values is shown in Figure 5.1. The following procedure is used to compute and categorize the equivalent stress at a point in a component (see 5.2.2.3), and to determine the acceptability of the resulting stress state.

Step 1. Determine the types of loads acting on the component. In general, separate load cases are analyzed to evaluate “load-controlled” loads such as pressure and externally applied reactions due to weight effects and “strain-controlled” loads resulting from thermal gradients and imposed displacements. The loads to be considered in the design shall include, but not be limited to, those given in Table 5.1. The load combinations that shall be considered for each loading condition shall include, but not be limited to those given in Table 5.3.

Step 2. At the point on the vessel that is being investigated, calculate the stress tensor (six unique components of stress) for each type of load. Assign each of the computed stress tensors to one or to a group of the categories defined below. Assistance in assigning each stress tensor to an appropriate category for a component can be obtained by using Figure 5.1 and Table 5.6. Note that the equivalent stresses Q and F do not need to be determined to evaluate protection against plastic collapse. However, these components are needed for fatigue and ratcheting evaluations that are based on elastic stress analysis (see 5.5.3 and 5.5.6, respectively).

- (a) General primary membrane equivalent stress - P_m
- (b) Local primary membrane equivalent stress - P_L
- (c) Primary bending equivalent stress - P_b
- (d) Secondary equivalent stress - Q
- (e) Additional equivalent stress produced by a stress concentration or a thermal stress over and above the nominal ($P + Q$) stress level - F

Step 3. Sum the stress tensors (stresses are added on a component basis) assigned to each equivalent stress category. The final result is a stress tensor representing the effects of all the loads assigned to each equivalent stress category. Note that in applying STEPs in this paragraph, a detailed stress analysis performed using a numerical method such as finite element analysis typically provides a combination of $P_L + P_b$ and $P_L + P_b + Q + F$ directly.

(a) If a load case is analyzed that includes only “load-controlled” loads (e.g., pressure and weight effects), the computed equivalent stresses shall be used to directly represent the P_m , $P_L + P_b$, or $P_L + P_b + Q$. For example, for a vessel subject to internal pressure with an elliptical head; P_m equivalent stresses occur away from the head to shell junction, and P_L and $P_L + P_b + Q$ equivalent stresses occur at the junction.

(b) If a load case is analyzed that includes only “strain-controlled” loads (e.g., thermal gradients), the computed equivalent stresses represent Q alone; the combination $P_L + P_b + Q$ shall be derived from load cases developed from both “load-controlled” and “strain-controlled” loads.

(c) If the stress in category F is produced by a stress concentration or thermal stress, the quantity F is the additional stress produced by the stress concentration in excess of the nominal membrane plus bending stress. For example, if a plate has a nominal primary membrane equivalent stress of S_e , and has a fatigue strength reduction characterized by a factor K_f , then: $P_m = S_e$, $P_b = 0$, $Q = 0$, and $F = P_m(K_f - 1)$. The total equivalent stress is $P_m + F$.

Step 4. Determine the principal stresses of the sum of the stress tensors assigned to the equivalent stress categories, and compute the equivalent stress using Eq. (5.1).

Step 5. To evaluate protection against plastic collapse, compare the computed equivalent stress to their corresponding allowable values (see 5.2.2.2).

The allowable limit on local primary membrane and local primary membrane plus bending, S_{PL} , is computed as the larger of the quantities shown below.

(a) 1.5 times the tabulated allowable stress for the material from Annex 3-A

(b) S_y for the material from Annex 3-A, except that the value from (a) shall be used when the ratio of the minimum specified yield strength to ultimate tensile strength exceeds 0.70, or the value of S is governed by time-dependent properties as indicated in Annex 3-A

$$P_m \leq S \quad (5.2)$$

$$P_L \leq S_{PL} \quad (5.3)$$

$$(P_L + P_b) \leq S_{PL} \quad (5.4)$$

5.5.6 RATCHETING ASSESSMENT — ELASTIC STRESS ANALYSIS

5.5.6.1 Elastic Ratcheting Analysis Method.

(a) To evaluate protection against ratcheting the following limit shall be satisfied.

$$\Delta S_{n,k} \leq S_{PS} \tag{5.78}$$

(b) The primary plus secondary equivalent stress range, $\Delta S_{n,k}$, is the equivalent stress range, derived from the highest value across the thickness of a section, of the combination of linearized general or local primary membrane stresses plus primary bending stresses plus secondary stresses ($P_L + P_b + Q$), produced by specified operating pressure and other specified mechanical loads and by general thermal effects. The effects of gross structural discontinuities but not of local structural discontinuities (stress concentrations) shall be included. Examples of this stress category for typical pressure vessel components are shown in Table 5.6.

(c) The maximum range of this equivalent stress is limited to S_{PS} . The quantity S_{PS} represents a limit on the primary plus secondary equivalent stress range and is defined in (d). In the determination of the maximum primary plus secondary equivalent stress range, it may be necessary to consider the effects of multiple cycles where the total stress range may be greater than the stress range of any of the individual cycles. In this case, the value of S_{PS} may vary with the specified cycle, or combination of cycles, being considered since the temperature extremes may be different in each case. Therefore, care shall be exercised to assure that the applicable value of S_{PS} for each cycle, or combination of cycles, is used (see 5.5.3).

(d) The allowable limit on the primary plus secondary stress range, S_{PS} , is computed as the larger of the quantities shown below.

(1) Three times the average of the S values for the material from Annex 3-A at the highest and lowest temperatures during the operational cycle.

(2) Two times the average of the S_y values for the material from Annex 3-D at the highest and lowest temperatures during the operational cycle, except that the value from (1) shall be used when the ratio of the minimum specified yield strength to ultimate tensile strength exceeds 0.70 or the value of S is governed by time-dependent properties as indicated in Annex 3-A.

S_{PL} = allowable limit on the local primary membrane and local primary membrane plus bending stress categories (see 5.2.2.4.)

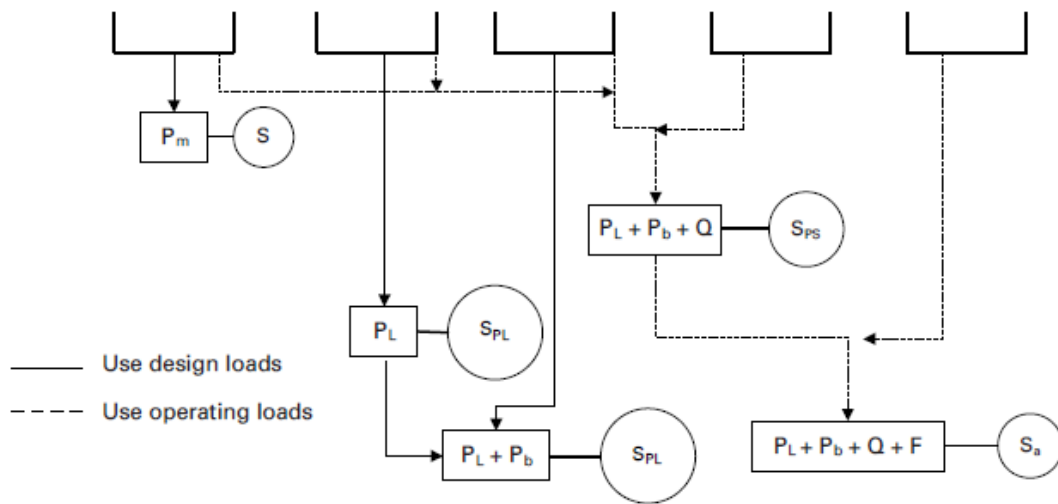
S_{PS} = allowable limit on the primary plus secondary stress range (see 5.5.6.)

**Table 5.6
Examples of Stress Classification**

Vessel Component	Location	Origin of Stress	Type of Stress	Classification
Any shell including cylinders, cones, spheres, and formed heads	Shell plate remote from discontinuities	Internal pressure	General membrane	P_m
			Gradient through plate thickness	Q
		Axial thermal gradient	Membrane	Q
			Bending	
	Near nozzle or other opening	Net-section axial force and/or bending moment applied to the nozzle, and/or internal pressure	Local membrane	P_L
			Bending	Q
			Peak (fillet or corner)	F
	Any location	Temperature difference between shell and head	Membrane	Q
			Bending	
	Shell distortions such as out-of-roundness and dents	Internal pressure	Membrane	P_m
Bending			Q	
Cylindrical or conical shell	Any section across entire vessel	Net-section axial force, bending moment applied to the cylinder or cone, and/or internal pressure	Membrane stress averaged through the thickness, remote from discontinuities; stress component perpendicular to cross section	P_m
			Bending stress through the thickness; stress component perpendicular to cross section	P_b
	Junction with head or flange	Internal pressure	Membrane	P_L
			Bending	Q

Figure 5.1
Stress Categories and Limits of Equivalent Stress

Stress Category	Primary			Secondary Membrane plus Bending	Peak
	General Membrane	Local Membrane	Bending		
Description (For examples, see Table 5.2)	Average primary stress across solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Average stress across any solid section. Considers discontinuities but not concentrations. Produced only by mechanical loads.	Component of primary stress proportional to distance from centroid of solid section. Excludes discontinuities and concentrations. Produced only by mechanical loads.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by mechanical load or by differential thermal expansion. Excludes local stress concentrations.	<ol style="list-style-type: none"> Increment added to primary or secondary stress by a concentration (notch). Certain thermal stresses which may cause fatigue but not distortion of vessel shape.
Symbol	P_m	P_L	P_b	Q	F



ASCE/SEI 7

Minimum Design Loads for Buildings

and

Other Structures

The Design Earthquake Load – ASCE/SEI 7-16

Chapter 13 titled “Seismic Design Requirements for Nonstructural Components” from ASCE/SEI 7-16 provides Seismic Design requirements for architectural, mechanical and electrical components including specific references to ASME boiler, pressure vessels and piping as detailed below.

Site Coefficients and Risk-Targeted Maximum Considered Earthquake (MCE) Spectral Response Acceleration Parameters

The MCE spectral response acceleration parameter for Site Class effects shall be determined by Eq. 11.4-1.

$$S_{MS} = F_a S_s$$

where,

F_a = Site Coefficient defined in Table 11.4-1.

S_s = the mapped MCE spectral response acceleration parameter at short periods as determined in accordance with Section 11.4.1. The value of S_s can be retrieved from the USGS website <http://earthquake.usgs.gov/designmaps>.

Table 11.4-1 Site Coefficient, F_a
Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R)
Spectral Response Acceleration Parameter at Short

SITE CLASS	$S_s \leq 0.25$	$S_s = 0.5$	$S_s = 0.75$	$S_s = 1.0$	$S_s = 1.25$	$S_s \geq 1.5$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	See Section 11.4.8		
F	See Section 11.4.8					

Note: Site specific analysis is required for Site Class E with $S_s \geq 1.0$ and Site Class F,

Design Spectral Acceleration Parameters

Design earthquake spectral response acceleration parameter at short period, S_{DS} shall be determined from Eq. 11.4-3.

$$S_{DS} = \left(\frac{2}{3}\right) S_{MS}$$

Seismic Design Force

The horizontal seismic design force (F_p) shall be applied at the component’s center of gravity and distributed relative to the component’s mass distribution and shall be determined in accordance with Eq. 13.3-1 of para. 13.3.1.

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)} \left(1 + 2 \frac{z}{h}\right)$$

ASCE/SEI 7-16

F_p is not required to be taken as greater than

$$F_p = 1.6S_{DS}I_pW_p$$

F_p shall not be taken as less than

$$F_p = 0.3S_{DS}I_pW_p$$

where,

F_p = seismic design force

S_{DS} = spectral acceleration, short period, as determined above

S_{MS} = maximum MCE spectral acceleration at short periods

a_p = component amplification factor that varies from 1.00 to 2.50 (see Table 13.6-1 below)

I_p = component importance factor that varies from 1.00 to 1.50 (see Section 13.1.3)

W_p = component operating weight

R_p = component response modification factor that varies from 1.00 to 12 (see Table 13.6-1 below)

z = height in structure of point of attachment of component with respect to the base. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0.

h = average roof height of structure with respect to the base

Note:

As per 13.1.8, the earthquake loads determined in accordance with Section 13.3.1 shall be multiplied by a factor 0.7. This can be performed in CAEPIPE by entering the value as 0.70 for “All. Stress Factor ADS(a)” through “ASCE/SEI 7-16” Seismic parameter input dialog.

Vertical Seismic Force

As per para. 13.3.1, Vertical Seismic Force shall be computed as

$$V_p = 0.2S_{DS}W_p$$

where,

S_{DS} and W_p are as defined above.

ASCE/SEI 7-16

Table 13.6-1 Seismic Coefficients for Mechanical and Electrical Components

Components	a_p^a	R_p^b	Ω_0^c
MECHANICAL AND ELECTRICAL COMPONENTS			
Air-side HVACR, fans, air handlers, air conditioning units, cabinet heaters, air distribution boxes, and other mechanical components constructed of sheet metal framing	2½	6	2
Wet-side HVACR, boilers, furnaces, atmospheric tanks and bins, chillers, water heaters, heat exchangers, evaporators, air separators, manufacturing or process equipment, and other mechanical components constructed of high-deformability materials	1	2½	2
Air coolers (fin fans), air-cooled heat exchangers, condensing units, dry coolers, remote radiators and other mechanical components elevated on integral structural steel or sheet metal supports	2½	3	1½
Engines, turbines, pumps, compressors, and pressure vessels not supported on skirts and not within the scope of Chapter 15	1	2½	2
Skirt-supported pressure vessels not within the scope of Chapter 15	2½	2½	2
Elevator and escalator components	1	2½	2
Generators, batteries, inverters, motors, transformers, and other electrical components constructed of high-deformability materials	1	2½	2
Motor control centers, panel boards, switch gear, instrumentation cabinets, and other components constructed of sheet metal framing	2½	6	2
Communication equipment, computers, instrumentation, and controls	1	2½	2
Roof-mounted stacks, cooling and electrical towers laterally braced below their center of mass	2½	3	2
Roof-mounted stacks, cooling and electrical towers laterally braced above their center of mass	1	2½	2
Lighting fixtures	1	1½	2
Other mechanical or electrical components	1	1½	2
VIBRATION-ISOLATED COMPONENTS AND SYSTEMS^b			
Components and systems isolated using neoprene elements and neoprene isolated floors with built-in or separate elastomeric snubbing devices or resilient perimeter stops	2½	2½	2
Spring-isolated components and systems and vibration-isolated floors closely restrained using built-in or separate elastomeric snubbing devices or resilient perimeter stops	2½	2	2
Internally isolated components and systems	2½	2	2
Suspended vibration-isolated equipment including in-line duct devices and suspended internally isolated components	2½	2½	2
DISTRIBUTION SYSTEMS			
Piping in accordance with ASME B31 (2001, 2002, 2008, and 2010), including in-line components with joints made by welding or brazing	2½	12	2
Piping in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings	2½	6	2
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing	2½	9	2
Piping and tubing not in accordance with ASME B31, including in-line components, constructed of high- or limited-deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings	2½	4½	2
Piping and tubing constructed of low-deformability materials, such as cast iron, glass, and nonductile plastics	2½	3	2
Ductwork, including in-line components, constructed of high-deformability materials, with joints made by welding or brazing	2½	9	2
Ductwork, including in-line components, constructed of high- or limited-deformability materials with joints made by means other than welding or brazing	2½	6	2
Ductwork, including in-line components, constructed of low-deformability materials, such as cast iron, glass, and nonductile plastics	2½	3	2
Electrical conduit and cable trays	2½	6	2
Bus ducts	1	2½	2
Plumbing	1	2½	2
Pneumatic tube transport systems	2½	6	2

^aA lower value for a_p is permitted where justified by detailed dynamic analyses. The value for a_p shall not be less than 1. The value of a_p equal to 1 is for rigid components and rigidly attached components. The value of a_p equal to 2½ is for flexible components and flexibly attached components.

^bComponents mounted on vibration isolators shall have a bumper restraint or snubber in each horizontal direction. The design force shall be taken as $2F_p$ if the nominal clearance (air gap) between the equipment support frame and restraint is greater than 0.25 in. (6 mm). If the nominal clearance specified on the construction documents is not greater than 0.25 in. (6 mm), the design force is permitted to be taken as F_p .

^cOverstrength as required for anchorage to concrete and masonry. See Section 12.4.3 for seismic load effects including overstrength.

The Design Wind Load – ASCE/SEI 7-16

Chapter 26 titled “Wind Load: Generic Requirements” is used to determine basic parameters for determining wind loads and Chapter 29 titled “Wind Load on Other Structures and Building Appurtenances – MWFRS” of ASCE/SEI 7-16 provides a directional wind force determination procedure for building appurtenances and other structures. Details referred from these two (2) chapters for implementation in CAEPIPE are detailed below.

Type of Element Classification

Type of Element Classification = Other Structures

Figure 26.1-1 directs the ASCE 7 user to the appropriate method to determine wind forces for the particular building or structure the user is concerned with. The method most appropriate for industrial plant piping of any type is detailed in Chapter 29, “Wind Loads on Other Structures and Building Appurtenances – MWFRS”.

Wind Load Parameters

The following wind load parameters shall be determined in accordance with Chapter 26.

Basic Wind Speed (V):

The basic wind speed, V, used in the determination of design wind loads on buildings and other structures shall be determined from Fig. 26.5-1 as follows.

Fig. 26-5-1A can be referred for Risk Category I buildings and other structures.

Fig. 26-5-1B can be referred for Risk Category II buildings and other structures

Fig. 26.5-1C can be referred for Risk Category III buildings and other structures.

Fig. 26.5-1D can be referred for Risk Category IV Buildings and Other Structures.

Wind Directionality Factor K_d :

The wind directionality factor, K_d , shall be determined from Table 26.6-1 as given below.

Exposure Categories:

As detailed in Section 26.7.3 of ASCE/SEI 7-16, Exposure Categories can be B, C or D.

Topographical Factor K_{zt} :

As detailed in Section 26.8.2, Wind speed-up effects shall be included in the calculation of design wind loads by using the factor K_{zt} .

Figure 26.8-1 (given below) can be referred to compute the Topographical Factor K_{zt} .

$$K_{zt} = (1 + K_1 K_2 K_3)^2$$

where K_1 , K_2 and K_3 are given in Fig. 26.8-1.

If site conditions and locations of structures do not meet all the conditions specified in Section 26.8.1 then $K_{zt} = 1.0$

Velocity Pressure Exposure Coefficient K_z

Velocity pressure exposure coefficient K_z can be determined from Table 26.10.1 provided below.

Velocity Pressure

Velocity pressure, q_z , evaluated at height z shall be calculated by the following equation:

$$q_z = 0.00256K_zK_{zt}K_dK_eV^2 \text{ (lb/ft}^2\text{)}$$

where

K_d = wind directionality factor as defined above

K_{zt} = velocity pressure exposure coefficient as defined above

K_z = topographic factor as defined above

K_e = ground elevation factor to adjust air density permitted $K_e = 1$

V = basic wind speed as defined above

Design Wind Loads – Other Structures

The design wind force for other structures (chimneys, tanks, rooftop equipment for $h > 60$, and similar structures, open signs, lattice frameworks, and trussed towers) shall be determined by section 29.4, ASCE 7-16, with the following equation:

$$F = q_zC_fGA_f \text{ (lb)}$$

where

q_z = velocity pressure evaluated at height z as defined above of the centroid of area A_f

G = gust-effect factor for a rigid building or other structure is permitted to be taken as 0.85

C_f = force coefficients from Fig. 29.4-1 given below

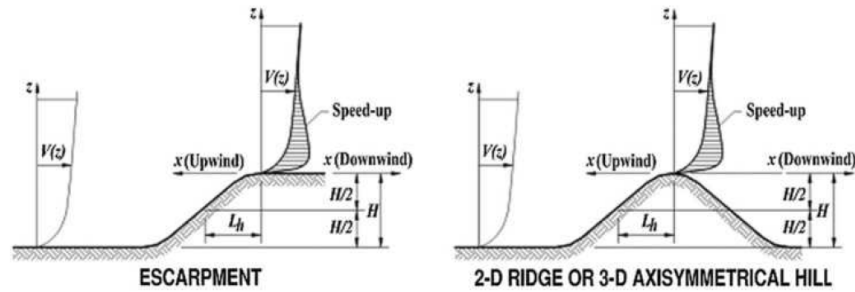
A_f = projected area normal to the wind except where C_f is specified for the actual surface area in ft^2

Table 26.6-1 Wind Directionality Factor, K_d

Structure Type	Directionality Factor K_d
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0 ^a
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0 ^a
Round	1.0 ^a
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

^aDirectionality factor $K_d = 0.95$ shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

Diagrams



Topographic Multipliers for Exposure $C^{a,b,c}$

H/L_h	K_1 Multiplier			x/L_h	K_2 Multiplier			K_2 Multiplier		
	2D Ridge	2D Escarpment	3D Axisymmetrical Hill		2D Escarpment	All Other Cases	z/L_h	2D Ridge	2D Escarpment	3D Axisymmetrical Hill
0.20	0.29	0.17	0.21	0.00	1.00	1.00	0.00	1.00	1.00	1.00
0.25	0.36	0.21	0.26	0.50	0.88	0.67	0.10	0.74	0.78	0.67
0.30	0.43	0.26	0.32	1.00	0.75	0.33	0.20	0.55	0.61	0.45
0.35	0.51	0.30	0.37	1.50	0.63	0.00	0.30	0.41	0.47	0.30
0.40	0.58	0.34	0.42	2.00	0.50	0.00	0.40	0.30	0.37	0.20
0.45	0.65	0.38	0.47	2.50	0.38	0.00	0.50	0.22	0.29	0.14
0.50	0.72	0.43	0.53	3.00	0.25	0.00	0.60	0.17	0.22	0.09
				3.50	0.13	0.00	0.70	0.12	0.17	0.06
				4.00	0.00	0.00	0.80	0.09	0.14	0.04
							0.90	0.07	0.11	0.03
							1.00	0.05	0.08	0.02
							0.50	0.01	0.02	0.00
							2.00	0.00	0.00	0.00

^aFor values of H/L_h , x/L_h , and z/L_h other than those shown, linear interpolation is permitted.
^bFor $H/L_h > 0.5$, assume that $H/L_h = 0.5$ for evaluating K_1 and substitute $2H$ for L_h for evaluating K_2 and K_3 .
^cMultipliers are based on the assumption that wind approaches the hill or escarpment along the direction of maximum slope.

Notation

- H = Height of hill or escarpment relative to the upwind terrain, in ft (m).
- K_1 = Factor to account for shape of topographic feature and maximum speed-up effect.
- K_2 = Factor to account for reduction in speed-up with distance upwind or downwind of crest.
- K_3 = Factor to account for reduction in speed-up with height above local terrain.
- L_h = Distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment, in ft (m).
- x = Distance (upwind or downwind) from the crest to the site of the building or other structure, in ft (m).
- z = Height above ground surface at the site of the building or other structure, in ft (m).
- μ = Horizontal attenuation factor.
- γ = Height attenuation factor.

Equations

$$K_{zt} = (1 + K_1 K_2 K_3)^2$$

$$K_1 = \text{determined from table below}$$

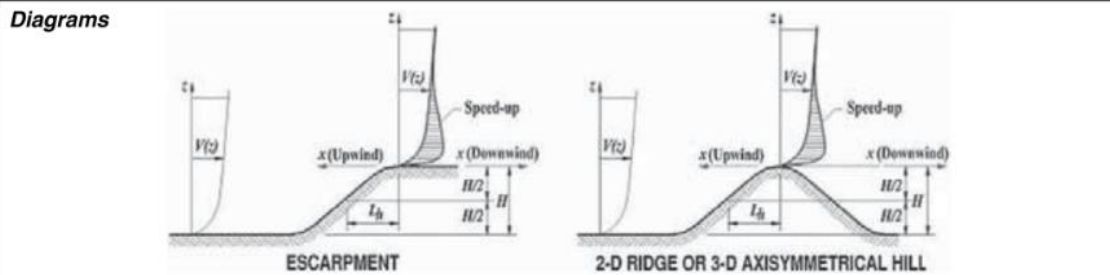
$$K_2 = (1 - |x|/\mu L_h)$$

$$K_3 = e^{-\gamma z/L_h}$$

Parameters for Speed-Up over Hills and Escarpments

Hill Shape	$K_1/(H/L_h)$			γ	μ	
	Exposure				Upwind of Crest	Downwind of Crest
	B	C	D			
2D ridges (or valleys with negative H in $K_1/(H/L_h)$)	1.30	1.45	1.55	3	1.5	1.5
2D escarpments	0.75	0.85	0.95	2.5	1.5	4
3D axisymmetrical hill	0.95	1.05	1.15	4	1.5	1.5

FIGURE 26.8-1 Topographic Factor, K_{zt}



Topographic Multipliers for Exposure C^{a,b,c}

H/L _h	K ₁ Multiplier			x/L _h	K ₂ Multiplier			z/L _h	K ₃ Multiplier		
	2D Ridge	2D Escarpment	3D Axisymmetrical Hill		2D Escarpment	All Other Cases	2D Ridge		2D Escarpment	3D Axisymmetrical Hill	
0.20	0.29	0.17	0.21	0.00	1.00	1.00	0.00	1.00	1.00	1.00	
0.25	0.36	0.21	0.26	0.50	0.88	0.67	0.10	0.74	0.78	0.67	
0.30	0.43	0.26	0.32	1.00	0.75	0.33	0.20	0.55	0.61	0.45	
0.35	0.51	0.30	0.37	1.50	0.63	0.00	0.30	0.41	0.47	0.30	
0.40	0.58	0.34	0.42	2.00	0.50	0.00	0.40	0.30	0.37	0.20	
0.45	0.65	0.38	0.47	2.50	0.38	0.00	0.50	0.22	0.29	0.14	
0.50	0.72	0.43	0.53	3.00	0.25	0.00	0.60	0.17	0.22	0.09	
				3.50	0.13	0.00	0.70	0.12	0.17	0.06	
				4.00	0.00	0.00	0.80	0.09	0.14	0.04	
							0.90	0.07	0.11	0.03	
							1.00	0.05	0.08	0.02	
							0.50	0.01	0.02	0.00	
							2.00	0.00	0.00	0.00	

^aFor values of H/L_h, x/L_h, and z/L_h other than those shown, linear interpolation is permitted.
^bFor H/L_h > 0.5, assume that H/L_h = 0.5 for evaluating K₁ and substitute 2H for L_h for evaluating K₂ and K₃.
^cMultipliers are based on the assumption that wind approaches the hill or escarpment along the direction of maximum slope.

Notation

- H = Height of hill or escarpment relative to the upwind terrain, in ft (m).
- K₁ = Factor to account for shape of topographic feature and maximum speed-up effect.
- K₂ = Factor to account for reduction in speed-up with distance upwind or downwind of crest.
- K₃ = Factor to account for reduction in speed-up with height above local terrain.
- L_h = Distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment, in ft (m).
- x = Distance (upwind or downwind) from the crest to the site of the building or other structure, in ft (m).
- z = Height above ground surface at the site of the building or other structure, in ft (m).
- μ = Horizontal attenuation factor.
- γ = Height attenuation factor.

Table 26.11-1 Terrain Exposure Constants

Customary Units										
Exposure	α	z _g (ft)	$\bar{\alpha}$	\bar{b}	$\bar{\alpha}$	\bar{b}	c	r (ft)	\bar{z}	z _{min} (ft) ^a
B	7.0	1,200	1/70	0.84	1/4.0	0.45	0.30	320	1/3.0	30
C	9.5	900	1/9.5	1.00	1/6.5	0.65	0.20	500	1/5.0	15
D	11.5	700	1/11.5	1.07	1/9.0	0.80	0.15	650	1/8.0	7
S.I. Units										
Exposure	α	z _g (m)	$\bar{\alpha}$	\bar{b}	$\bar{\alpha}$	\bar{b}	c	r (m)	\bar{z}	z _{min} (m) ^a
B	7.0	365.76	1/7	0.84	1/4.0	0.45	0.30	97.54	1/3.0	9.14
C	9.5	274.32	1/9.5	1.00	1/6.5	0.65	0.20	152.40	1/5.0	4.57
D	11.5	213.36	1/11.5	1.07	1/9.0	0.80	0.15	198.12	1/8.0	2.13

^az_{min} = minimum height used to ensure that the equivalent height \bar{z} is the greater of 0.6h or z_{min}. For buildings or other structures with h ≤ z_{min}, \bar{z} shall be taken as z_{min}.

Table 26.10-1 Velocity Pressure Exposure Coefficients, K_h and K_z

Height above Ground Level, z		Exposure		
ft	m	B	C	D
0–15	0–4.6	0.57 (0.70) ^a	0.85	1.03
20	6.1	0.62 (0.70) ^a	0.90	1.08
25	7.6	0.66 (0.70) ^a	0.94	1.12
30	9.1	0.70	0.98	1.16
40	12.2	0.76	1.04	1.22
50	15.2	0.81	1.09	1.27
60	18.0	0.85	1.13	1.31
70	21.3	0.89	1.17	1.34
80	24.4	0.93	1.21	1.38
90	27.4	0.96	1.24	1.40
100	30.5	0.99	1.26	1.43
120	36.6	1.04	1.31	1.48
140	42.7	1.09	1.36	1.52
160	48.8	1.13	1.39	1.55
180	54.9	1.17	1.43	1.58
200	61.0	1.20	1.46	1.61
250	76.2	1.28	1.53	1.68
300	91.4	1.35	1.59	1.73
350	106.7	1.41	1.64	1.78
400	121.9	1.47	1.69	1.82
450	137.2	1.52	1.73	1.86
500	152.4	1.56	1.77	1.89

^aUse 0.70 in Chapter 28, Exposure B, when $z < 30$ ft (9.1 m).

Notes

- The velocity pressure exposure coefficient K_z may be determined from the following formula:
 For $15 \text{ ft (4.6 m)} \leq z \leq z_g$ $K_z = 2.01(z/z_g)^{2/\alpha}$
 For $z < 15 \text{ ft (4.6 m)}$ $K_z = 2.01(15/z_g)^{2/\alpha}$
- α and z_g are tabulated in Table 26.11-1.
- Linear interpolation for intermediate values of height z is acceptable.
- Exposure categories are defined in Section 26.7.

Force Coefficients, C_f

Cross Section	Type of Surface	h/D		
		1	7	25
Square (wind normal to face)	All	1.3	1.4	2.0
Square (wind along diagonal)	All	1.0	1.1	1.5
Hexagonal or octagonal	All	1.0	1.2	1.4
Round, $D\sqrt{q_z} > 2.5$	Moderately smooth	0.5	0.6	0.7
$D\sqrt{q_z} > 5.3$ (in S.I.)	Rough ($D'/D=0.02$)	0.7	0.8	0.9
	Very rough ($D'/D=0.08$)	0.8	1.0	1.2
Round, $D\sqrt{q_z} \leq 2.5$	All	0.7	0.8	1.2
$D\sqrt{q_z} \leq 5.3$ (in S.I.)	All	0.7	0.8	1.2

Notation

D = Diameter of circular cross section and least horizontal dimension of square, hexagonal, or octagonal cross sections at elevation under consideration, in ft (m)

D' = Depth of protruding elements such as ribs and spoilers, in ft (m)

h = Height of structure, in ft (m)

q_z = Velocity pressure evaluated at height z above ground, in lb/ft² (N/m²).

Notes

1. The design wind force shall be calculated based on the area of the structure projected on a vertical plane normal to the wind direction.
The force shall be assumed to act parallel to the wind direction.
2. Linear interpolation is permitted for h/D values other than shown.

FIGURE 29.4-1 Other Structures (All Heights): Force Coefficients, C_f , for Chimneys, Tanks, and Similar Structures

EN 1991-1-4 (2010)

General actions - Wind actions

The Design Wind Load

Section 4 titled “Wind velocity and velocity pressure” is used to compute Peak Velocity Pressure at a given elevation.

Basic Values

The fundamental value of the basic wind velocity, $V_{b,Q}$, is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

The basic wind velocity shall be calculated from Expression (4.1) of EN 1991-1-4 (2010) as given below.

$$V_{b,Q} = C_{dir} \cdot V_b \cdot C_{Season}$$

where

V_b is the basic wind velocity, defined as a function of wind direction and time of year at 10m above ground of terrain category II.

$V_{b,Q}$ is the fundamental value of the basic wind velocity

C_{dir} is the directional factor, the recommended value is 1.0.

C_{season} is the season factor, the recommended value is 1.0.

Mean Wind

The mean wind velocity $V_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, V_b , and is determined using Expression (4.3) of EN 1991-1-4 (2010) as given below.

$$V_m(z) = C_r(z) \cdot V_b \cdot C_o(z)$$

Where

$C_r(z)$ is the terrain roughness factor. This can be computed as given below.

$C_o(z)$ is the orography factor, the recommended value is 1.0. See Section 4.3.3 of EN 1991-1-4 (2010) for further details.

Terrain Roughness Factor[$C_r(z)$]

The roughness factor, $C_r(z)$, accounts for the variability of the mean wind velocity at the site of the structure due to:

- a. height above ground level
- b. ground roughness of the terrain upwind of the structure in the wind direction considered.

$$C_r(z) = K_r \cdot \ln\left(\frac{z}{z_0}\right) \text{ for } z_{min} < z < z_{max}$$

$$C_r(z) = C_r(z_{min}) \text{ for } z < z_{min}$$

where

$$K_r = 0.19 \cdot \left(\frac{z}{z_{0,II}} \right)^{0.07}$$

where

$z_{0,II} = 0,05$ m [terrain category II, as per Table 4.1 of EN 1991-1-4 (2010)]

z_{min} is the minimum height defined in Table 4.1 of EN 1991-1-4 (2010)

z_{max} is to be taken as 200 m

Table 4.1 — Terrain categories and terrain parameters

Terrain category		z_0 m	z_{min} m
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10

NOTE: The terrain categories are illustrated in A.1.

Wind Turbulence

The turbulence intensity $I_v(z)$ at height z is defined as the standard deviation of the turbulence divided by the mean wind velocity.

$$I_v(z) = \frac{K_t}{C_0(z) \cdot \ln\left(\frac{z}{z_0}\right)} \quad \text{for } z_{min} < z < z_{max}$$

$$I_v(z) = I_v(z_{min}) \quad \text{for } z < z_{min}$$

where

K_t is the turbulence factor. The value may be given in the National Annex. The recommended value for K_t is 1.0.

$C_0(z)$ is the orography factor as explained above.

z_0 is the roughness length as given in Table 4.1 of EN 1991-1-4 (2010).

Peak Velocity Pressure [Qp(z)]

The peak velocity pressure $Q_p(z)$ at height z , which includes mean and short-term velocity fluctuations, is determined using Expression (4.8) of EN 1991-1-4 (2010) as given below.

$$Q_p(z) = [1 + 7 \cdot I_v(z)] \cdot \frac{1}{2} \cdot \rho \cdot V_m^2(z) = C_e(z) \cdot Q_b$$

where

ρ is the air density, which depends on the altitude, temperature and barometric pressure to be expected in the region during wind storms

$C_e(z)$ is the exposure factor = $\frac{Q_p(z)}{Q_b}$

Q_b is the basic velocity pressure = $\frac{1}{2} \cdot \rho \cdot V_b^2$

Design Wind Loads

The design wind force is then determined as given below.

$$F = Q_p(z) \cdot A_f$$

where

$Q_p(z)$ = peak velocity pressure evaluated at height z

A_f = projected area normal to the wind

Note:

In Expression 5.3, Wind Force is computed by multiplying the above $Q_p(z)$ with $C_s C_d$ and C_f . From Section 6.2(d), for chimneys with circular cross-sections (similar to the flow around circular pipes), $C_s C_d$ is specified as 1.0. So, the only factor that is NOT yet applied in computing the design wind loads above is C_f .

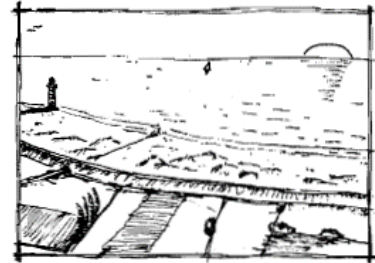
From Section 7.9 for Circular Cylinders, for most piping systems, C_f should be of between 0.7 and 1.0. Surface roughness factors (k) provided in Section 7.9.2 and end-effect factors provided in Section 7.13 (used for computing C_f) are mostly related to structural elements. Since piping elements are connected to either adjoining pipe elements or fittings or components or equipment, the end-effect factor for any element in a pipe stress model should be 1.0; it is equivalent to saying that, from fluid flow point of view, each element in a pipe stress model is behaving as an infinitely long element. Hence, it does not cause the kind of end flow effect created by finite length elements.

In view of the above, applying only Eq. 4.8 to compute design wind force is conservative. Hence, in the current version of CAEPIPE, Expression 5.3 is not implemented to calculate Design Wind Loads.

A.1 Illustrations of the upper roughness of each terrain category

Terrain category 0

Sea, coastal area exposed to the open sea



Terrain category I

Lakes or area with negligible vegetation and without obstacles



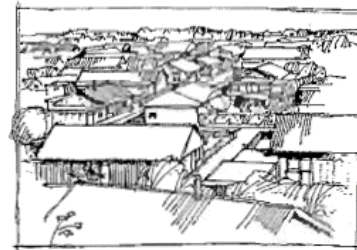
Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights



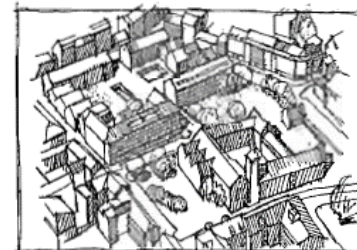
Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)



Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m



Index

Index

A

ANSI B31.1 (1967) code, 21
ANSI/HI 9.6.2 report, 360
API 610 report, 347
API 617 report, 376
ASME (1980) code, 166
ASME (1986) code, 171
ASME (1992) code, 176
ASME (2015) code, 183
ASME (2017) code, 191
ASME Sec VIII Div 2 (2017), 435
ASMEB31J (2017) code, 149
ASMEND (2017) code, 199

B

B31.1 (2016) code, 11
B31.1 (2018) code, 1
B31.1 (2020) code, 1
B31.12 (2014) code, 139
B31.12 (2019) code, 128
B31.3 (2014) code, 46
B31.3 (2016) code, 35
B31.3 (2018) code, 24
B31.4 (2012) code, 71
B31.4 (2016) code, 63
B31.4 (2019) code, 55
B31.5 (2016) code, 78
B31.8 (2012) code, 103
B31.8 (2016) code, 93
B31.8 (2018) code, 83
B31.9 (2014) code, 120
B31.9 (2017) code, 112
BS 806 code, 207

C

CODETI (2006) code, 295
CODETI (2013) code, 281
CSA Z662 code 2015, 326
CSA Z662 code 2019, 321

E

EN 13480 (2012) code, 247
EN 13480 (2017) code, 240
EN 13480-3
2017/A2
2020 code, 228
EN1991-1-4 (2010) code, 449
External Pressure Design, 402

F

Flange Qualification, 379
FRP Stress, 331

I

IGEM (2012) code, 211
Integral flanges, 381
Internal Pressure Design, 397

L

Loose type flanges, 381
Loose type flanges without
hubs, 381

N

NDE, 338

NEMA SM-23 report, 374
Norwegian (1983) code, 257
Norwegian (1990) code, 265
Number of thermal cycles, 266

O

Operating Stress for NDE/Impact
Test, 338
Optional type flanges, 382

P

Pressure Design, 397

R

RCC-M (1985) code, 276
Reverse flanges, 383

S

Stoomwezen code, 307
Swedish code, 309

T

thermal cycles, 266

V

Von Mises Stress, 332

Z

Z183 code, 313
Z184 code, 317