The *FASTEST* Solutions for Piping Design and Analysis.

# Readme Supplement

# CAEPIPE

## Version 6.60

## Disclaimer

Please read the following carefully:

This software and this document have been developed and checked for correctness and accuracy by SST Systems, Inc. (SST) and InfoPlant Technologies Pvt. Ltd. (InfoPlant). However, no warranty, expressed or implied, is made by SST and InfoPlant as to the accuracy and correctness of this document or the functioning of the software and the accuracy, correctness and utilization of its calculations.

Users must carry out all necessary tests to assure the proper functioning of the software and the applicability of its results. All information presented by the software is for review, interpretation, approval and application by a Registered Professional Engineer.

CAEPIPE is a trademark of SST and InfoPlant.



---

SST Systems, Inc.
1798 Technology Drive, Suite 236
San Jose, California 95110
USA

Tel: (408) 452-8111
Fax: (408) 452-8388
Email: info@sstusa.com
www.sstusa.com

InfoPlant Technologies Pvt. Ltd.
7, Crescent Road
Bangalore – 560001
India

Tel: +91-80-40336999
Fax: +91-80-41494967
Email: iplant@vsnl.com
www.infoplantindia.com

# Annexure A

# ASME B31.x

# Code Compliance

## 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 $T_1$, $T_2$ and $T_3$

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

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

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

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

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

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

$t_n$ = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = pressure coefficient

For ductile non-ferrous materials and ferritic and austenitic steels,

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

For Cast Iron, Y = 0.0

## Sustained Stress (in corroded condition)

The stress ($S_L$) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para 502.3.2(d).

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

where

P = maximum of CAEPIPE input pressures $P_1$, $P_2$ and $P_3$

D = outside diameter

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

$i_i$ = in-plane stress intensification factor

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

$M_i$ = in-plane bending moment

$M_o =$ out-of-plane bending moment

$Z_c$ = corroded section modulus as per para 502.3.2 (d)

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

## 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)).

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

where

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

## Expansion Stress (in uncorroded condition)

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

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

where

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

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

$M_t$ = torsional moment

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

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

$f =$ stress range reduction factor from Figure 502.3.2

$S_{cold}$ = basic allowable stress at minimum of CAEPIPE input temperatures $T_1$, $T_2$, $T_3$ and $T_{ref}$

$S_{hot}$ = basic allowable stress at maximum of CAEPIPE input temperatures $T_1$, $T_2$, $T_3$ and $T_{ref}$

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

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

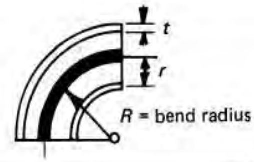
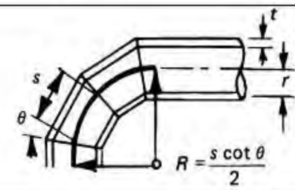
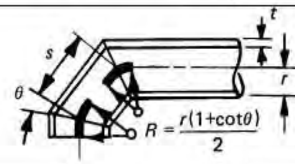
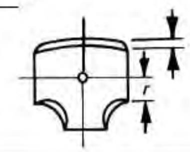
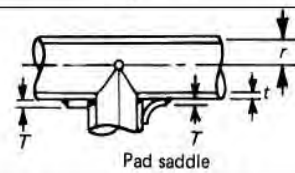
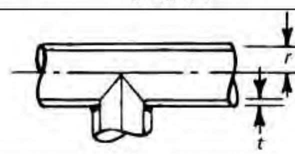
where, $S_h$ = basic allowable stress at maximum of CAEPIPE input temperatures $T_1$, $T_2$ and $T_3$

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

**Note:**

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

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

| Description | Flexibility Characteristic, $h$ | Flexibility Factor, $k$ | Stress Intensification Factor $i_i$ [Note (1)] | Stress Intensification Factor $i_o$ [Note (2)] | Illustration |
|---|---|---|---|---|---|
| Welding elbow or pipe bend [Notes (3), (4), (5), (6), and (7)] | $\frac{tR}{r^2}$ | $\frac{1.65}{h}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.75}{h^{2/3}}$ |  |
| Closely spaced miter bend [Notes (3), (4), (5), and (7)], $s < r(1 + \tan\theta)$ | $\frac{ts}{r^2}\left(\frac{\cot\theta}{2}\right)$ | $\frac{1.52}{h^{5/6}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.75}{h^{2/3}}$ |  |
| Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan\theta)$ | $\frac{t}{r}\left(\frac{1 + \cot\theta}{2}\right)$ | $\frac{1.52}{h^{5/6}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.75}{h^{2/3}}$ |  |
| Welding tee ASME B16.9 [Notes (3) and (4)] | $4.4\frac{t}{r}$ | 1 | $0.75i_o + 0.25$ | $\frac{0.9}{h^{2/3}}$ |  |
| Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)] | $\frac{(t + \frac{1}{2}T)^{5/2}}{t^{3/2}r}$ | 1 | $0.75i_o + 0.25$ | $\frac{0.9}{h^{2/3}}$ |  |
| Unreinforced fabricated tee [Notes (3) and (4)] | $\frac{t}{r}$ | 1 | $0.75i_o + 0.25$ | $\frac{0.9}{h^{2/3}}$ |  |
| Butt welded joint, reducer, or welding neck flange | ... | 1 | 1.0 | 1.0 | ... |
| Double-welded slip-on flange | ... | 1 | 1.2 | 1.2 | ... |

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

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

GENERAL NOTE: For reference, see Table 519.3.6 Illustration beginning on page 40.

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.

(4) 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 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 center line, in. (mm)
$T$ = pad or saddle thickness, in. (mm)
$t$ = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; mathing 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).
$\theta$ = one-half angle between adjacent miter axes, deg

(5) Where flanges are attached to one or both ends, the values of $k$ and $T$ in the Table shall be corrected by the factors $C_1$ given below, which can be read directly from Chart B; entering with the computed $h$: one end flanged, $h^{1/6} \geq 1$; both ends flanged, $h^{1/2} \geq 1$.

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

(7) In large-diameter thin-wall elbows and bends, pressure can significantly affect the magnitude of flexibility and stress intensification factors. To correct values obtained from the Table for the pressure effect, divide:

(a) flexibility factor, $k$, by

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

(b) stress intensification factor, $i$, by

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

where

$E_c$ = cold modulus of elasticity, ksi (MPa)
$P$ = gage pressure, psi gage (kPa gage)

(8) Also includes single-miter joint.

(9) When $T > 1.5t$, use $h = 4.05\ t/r$.

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

## Allowable Pressure

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

$$P = \frac{2SEt_a FT}{D}$$

where

P = allowable pressure

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

E = longitudinal joint factor (input as material property), obtained from Table 841.1.7-1

$t_a$ = available thickness for pressure design

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

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

$t_n$ = nominal pipe thickness

D = nominal outside diameter

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

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

## Stress due to Sustained and Occasional Loads (Unrestrained Piping)

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

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

## Sustained Stress $S_L$ (required to compute Expansion Stress Allowable $S_A$):

_For Pipes and Long Radius Bends_

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

_For other Fittings or Components._

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

## Sustained + Occasional Stress $S_{LO}$:

_For Pipes and Long Radius Bends_

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

_For Fittings or Components_

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

where

P = maximum operating pressure = max (P1, P2, P3)

$P_{peak}$ = Peak pressure factor x P

D = nominal outside diameter

$t_n$ = nominal thickness

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

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

$M_i =$ in-plane bending moment

$M_o =$ out-of-plane bending moment

$M_t$ = torsional moment

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

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

A = corroded cross-section area (i.e., after deducting for corrosion)

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

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

**Note:**

Young's modulus of elasticity corresponding to the lowest operating temperature [=min(T1,T2,T3,Tref)] is used to form the stiffness matrix for Sustained and Occasional load calculations.

## Expansion Stress (Unrestrained Piping)

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

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

where

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

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

$M_t$ = torsional moment

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

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

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

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

where f <= 1.0 (from para 833.8 (b)).

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

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

where

$S_u$ = specified minimum <u>ultimate</u> tensile strength = **1.5 $S_y$ (assumed),** and

$S_{y}$ = specified minimum yield strength as per para. 841.11(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(T1,T2,T3,Tref)] is used to form the stiffness matrix for Expansion load calculations.

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

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

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

where

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

Thermal expansion stress = $S_T = E\alpha(T_i - T_o)$

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.*

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

Stress due to axial loading (other than temperature and pressure) = $S_X = \dfrac{R}{A}$

Where

P = maximum operating pressure = max(P1,P2,P3)

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

A = corroded cross-sectional area (i.e., after deducting for corrosion)

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

S = Specified Minimum Yield Strength (SMYS) from para 841.11 (a)

T = Temperature derating factor from para. 841.1.8 and Table 841.1.8-1

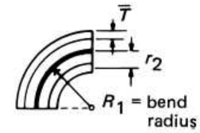
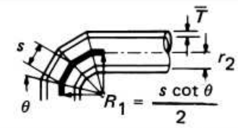
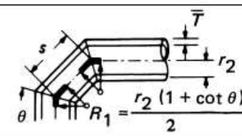
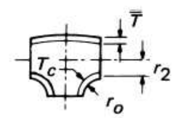
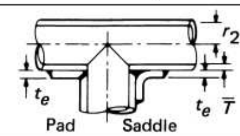
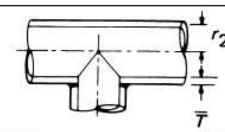
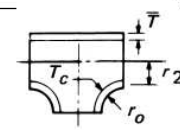
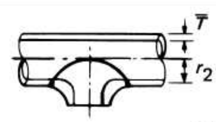
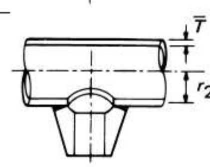
E = Young's modulus at ambient (reference) temperature

$T_i$ = installation temperature = $T_{ref}$ in CAEPIPE

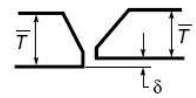
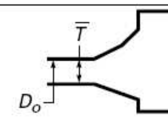
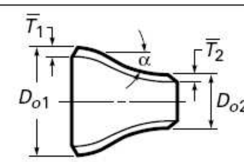
$T_o$ = warmest or coldest operating temperature

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

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

| Description | Flexibility Factor, $k$ | Stress Intensification Factor, $i$ [Notes (1) and (2)] Out-plane, $i_o$ | In-plane, $i_i$ | Flexibility Characteristic, $h$ | Sketch |
|---|---|---|---|---|---|
| Welding elbow or pipe bend [Notes (1)–(5)] | $\frac{1.65}{h}$ | $\frac{0.75}{h^{2/3}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{\bar{T} R_1}{r_2^2}$ |  |
| Closely spaced miter bend [Notes (1), (2), (3), and (5)] $s < r_2\ (1 + \tan\theta)$ | $\frac{1.52}{h^{5/6}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{\cot\theta}{2}\,\frac{\bar{T}s}{r_2^2}$ |  |
| Single miter bend or widely spaced miter bend $s \geq r_2\ (1 + \tan\theta)$ [Notes (1), (2), and (5)] | $\frac{1.52}{h^{5/6}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{1 + \cot\theta}{2}\,\frac{\bar{T}}{r_2}$ |  |
| Welding tee per ASME B16.9 with $r_o \geq d/8$ $T_c \geq 1.5\ \bar{T}$ [Notes (1), (2), and (6)] | 1 | $\frac{0.9}{h^{2/3}}$ | $^3/_4 i_o + ^1/_4$ | $4.4\,\frac{\bar{T}}{r_2}$ |  |
| Reinforced fabricated tee with pad or saddle [Notes (1), (2), (7)–(9)] | 1 | $\frac{0.9}{h^{2/3}}$ | $^3/_4\ i_o + ^1/_4$ | $\frac{(\bar{T} + ^1/_2\ t_e)^{5/2}}{\bar{T}^{3/2}\ r_2}$ |  |
| Unreinforced fabricated tee [Notes (1), (2), and (9)] | 1 | $\frac{0.9}{h^{2/3}}$ | $^3/_4\ i_o + ^1/_4$ | $\frac{\bar{T}}{r_2}$ |  |
| Extruded outlet $r_o \geq 0.05d$ $T_c < 1.5\ \bar{T}$ [Notes (1), (2), and (6)] | 1 | $\frac{0.9}{h^{2/3}}$ | $^3/_4\ i_o + ^1/_4$ | $\left(1 + \frac{r_o}{r_2}\right)\frac{\bar{T}}{r_2}$ |  |
| Welded-in contour insert $r_o \geq d/8$ $T_c \geq 1.5\ \bar{T}$ [Notes (1), (2), and (10)] | 1 | $\frac{0.9}{h^{2/3}}$ | $^3/_4\ i_o + ^1/_4$ | $4.4\,\frac{\bar{T}}{r_2}$ |  |
| Branch welded-on fitting (integrally reinforced) [Notes (1), (2), (9), and (11)] | 1 | $\frac{0.9}{h^{2/3}}$ | $\frac{0.9}{h^{2/3}}$ | $3.3\,\frac{\bar{T}}{r_2}$ |  |

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

| Description | Flexibility Factor, $k$ | Stress Intensification Factor, $i$ | Sketch |
|---|---|---|---|
| Buttweld [Notes (1) and (12)]<br>$\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.13$ | 1 | 1.0 | |
| Buttweld [Notes (1) and (12)]<br>$\bar{T} \geq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/8$ in. (3.18 mm), and $\delta_{avg}/\bar{T}$ = any value | 1 | 1.9 max. or $[0.9 + 2.7(\delta_{avg}/\bar{T})]$, but not less than 1.0 |  |
| Buttweld [Notes (1) and (12)]<br>$\bar{T} \leq 0.237$ in. (6.02 mm), $\delta_{max.} \leq 1/16$ in. (1.59 mm), and $\delta_{avg}/\bar{T} \leq 0.33$ | | | |
| Tapered transition per ASME B16.25 [Note (1)] | 1 | 1.9 max. or $1.3 + 0.0036 \frac{D_o}{\bar{T}} + 3.6 \frac{\delta}{\bar{T}}$ |  |
| Concentric reducer per ASME B16.9 [Notes (1) and (13)] | 1 | 2.0 max. or $0.5 + 0.01\alpha \left(\frac{D_{o2}}{\bar{T}_2}\right)^{1/2}$ |  |
| Double-welded slip-on flange [Note (14)] | 1 | 1.2 | |
| Socket welding flange or fitting [Notes (14) and (15)] | 1 | 2.1 max or 2.1 $\bar{T}/C_x$ but not less than 1.3 | |
| Lap joint flange (with ASME B16.9 lap joint stub) [Note (14)] | 1 | 1.6 | |
| Threaded pipe joint or threaded flange [Note (14)] | 1 | 2.3 | |
| Corrugated straight pipe, or corrugated or creased bend [Note (16)] | 5 | 2.5 | |

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

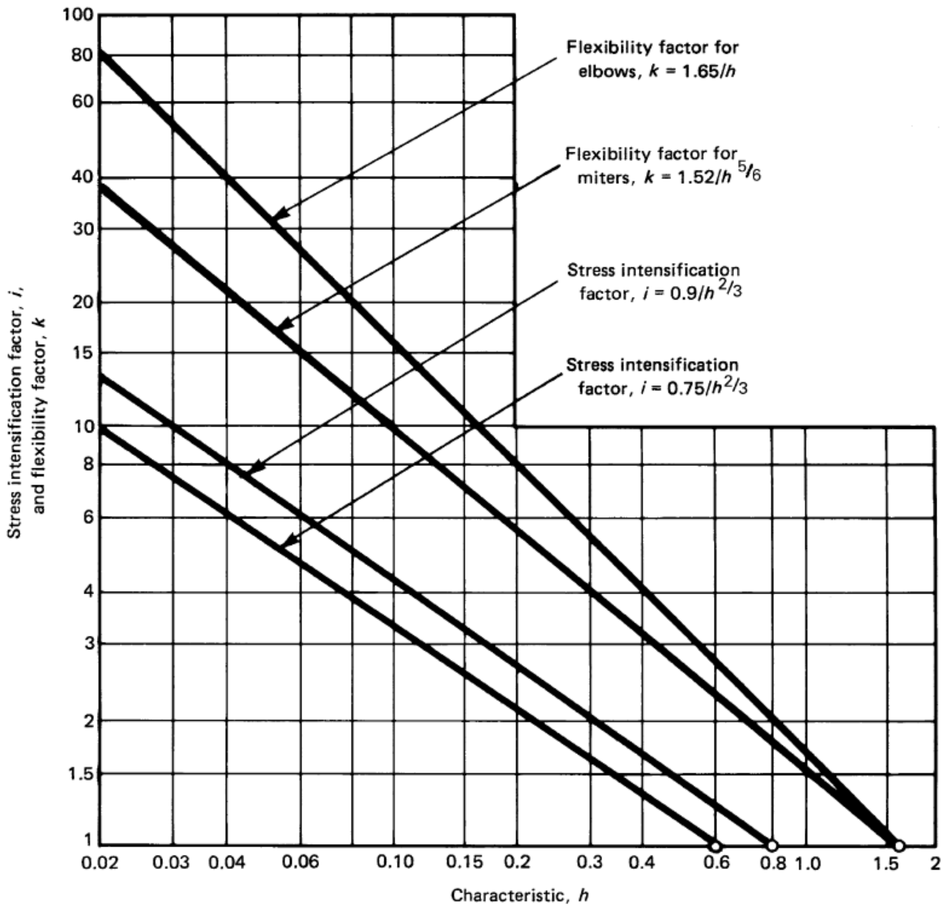



Chart A

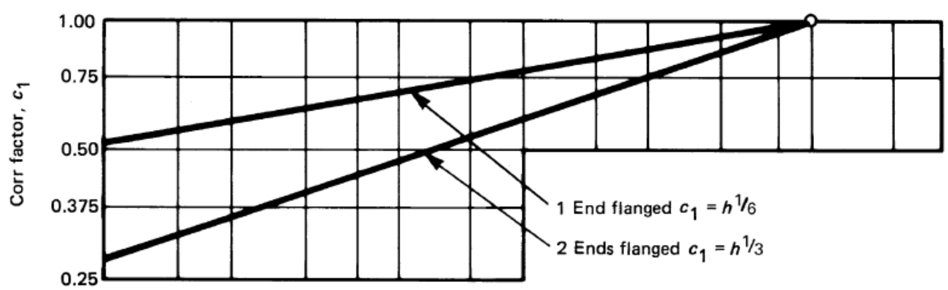



Chart B

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

NOTES:

(1) The nomenclature is as follows:

$d$ = outside diameter of branch, in. (mm)
$R_1$ = bend radius of welding elbow or pipe bend, in. (mm)
$r_o$ = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in. (mm)
$r_2$ = mean radius of matching pipe, in. (mm)
$s$ = miter spacing at centerline, in. (mm)
$\overline{T}$ = nominal wall thickness of piping component, in. (mm)
= for elbows and miter bends, the nominal wall thickness of the fitting, in. (mm)
= for welding tees, the nominal wall thickness of the matching pipe, in. (mm)
= for fabricated tees, the nominal wall thickness of the run or header (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter), in. (mm)
$T_c$ = the crotch thickness of tees, in. (mm)
$t_e$ = pad or saddle thickness, in. (mm)
$\alpha$ = reducer cone angle, deg
$\theta$ = one-half angle between adjacent miter axes, deg

(2) The flexibility factor, *k*, applies to bending in any plane. The flexibility factors, *k*, and stress intensification factors, *i*, shall not be less than unity; factors for torsion equal unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter bends and to the intersection point for tees.

The values of *k* and *i* can be read directly from Chart A by entering with the characteristic, *h*, computed from the formulas given.

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

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

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

$$\left[1 + 6\left(\frac{P}{E_e}\right)\left(\frac{r_2}{\overline{T}}\right)^{7/3}\left(\frac{R_1}{r_2}\right)^{1/3}\right]$$

divide *i* by

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

where

$E_e$ = cold modulus of elasticity, psi (MPa)
$P$ = gage pressure, psi (MPa)

(6) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.12/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

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

(8) The minimum value of the stress intensification factor shall be 1.2.

(9) When the branch-to-run diameter ratio exceeds 0.5, but is less than 1.0, and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively, unless the transition weld between the branch and run is blended to a smooth concave contour. If the transition weld is blended to a smooth concave contour, the stress intensification factors in the table still apply.

(10) If the number of displacement cycles is less than 200, the radius and thickness limits specified need not be met. When the radius and thickness limits are not met and the number of design displacement cycles exceeds 200, the out-plane and in-plane stress intensification factors shall be calculated as $1.8/h^{2/3}$ and $(0.67/h^{2/3}) + \frac{1}{4}$, respectively.

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

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

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

NOTES: (Cont'd)

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

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

(b) The larger of $D_{o1}/\overline{T}$ and $D_{o2}/\overline{T}$ does not exceed 100.

(c) The wall thickness is not less than $\overline{T}_1$ throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than $\overline{T}_2$.

(14) For some flanged joints, leakage may occur at expansion stresses otherwise permitted herein. The moment to produce leakage of a flanged joint with a gasket having no self-sealing characteristics can be estimated by the equation.

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

$A_b$ = total area of flange bolts, in.$^2$ (mm$^3$)
$A_p$ = area to outside of gasket contact, in.$^2$ (mm$^2$)
$C$ = bolt circle, in. (mm)
$M_L$ = moment to produce flange leakage, in.-lb (mm·N)
$P$ = internal pressure, psi (MPa)
$S_b$ = bolt stress, psi (MPa)

(15) $C_x$ is the fillet weld length. For unequal lengths, use the smaller leg for $C_x$.

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

## Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. 2 of paras.904.1.1 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 (2008) 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)

= $t_n$ × (1 - mill tolerance/100)

$t_n$ = nominal pipe thickness

A = corrosion allowance

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

D = outside diameter

For closely and widely spaced miter bends, the allowable pressure shall be the lower positive value calculated from Eqs. (3A) and (3B) of para 904.2.2 (a)

$$P = \frac{SET}{r}\left(\frac{T}{T + 0.64\tan\theta\sqrt{rT}}\right) \qquad \text{Eq. (3A)}$$

$$P = \frac{SET}{r}\left(\frac{R - r}{R - r/2}\right) \qquad \text{Eq. (3B)}$$

where

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

T = $t_m$ – A, where $t_m$ and A are defined above

R = effective bend radius of the miter

$\theta$ = miter half angle

## Sustained Stress (in uncorroded 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)

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

where

P = maximum of CAEPIPE pressures $P_1$, $P_2$ and $P_3$

$D_o$ = outside diameter

$t_n$ = nominal wall thickness

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

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

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

$S_h$ = hot allowable stress at maximum of CAEPIPE input temperatures $T_1$, $T_2$ and $T_3$

## Occasional Stress (in uncorroded 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.

$$S_{Lo} = \frac{P_{peak} D_o}{4t_n} + \frac{0.75 i M_A}{Z} + \frac{0.75 i M_B}{Z} \leq 1.33 S_h$$

where

$M_B$ = resultant bending moment due to occasional loads

$P_{peak}$ = peak pressure = (peak pressure factor) x P

## Expansion Stress (in uncorroded 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).

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

where

$M_C$ = resultant moment due to thermal expansion

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

$f =$ 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 $T_1$, $T_2$, $T_3$ and $T_{ref}$

When $S_h$ is greater than $S_L$, the allowable stress range SA 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 Annexure B for the details of “Thickness” and the “Section Modulus” used for weight, pressure and stress calculations.

# CODETI (2006)

## Allowable Pressure

The allowable pressure for straight pipes and bends is calculated from

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

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness x [1 - mill tolerance %/100] - corrosion allowance “c”

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

D = 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

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

R = radius of bend

<u>For closely spaced miter bends</u>, the allowable pressure is calculated from

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

<u>For widely spaced miter bends</u>, the allowable pressure is calculated from

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

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

where

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

$R_s$ = effective bend radius of the miter

$\theta$ = miter half angle

## Sustained Stress

The stress ($\sigma_1$) 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 = uncorroded section modulus; for reduced outlets / branch connections, effective section modulus

$f_h$ = hot allowable stress

## Sustained plus Occasional Stress

The stress ($\sigma_2$) 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 ($\sigma_3$) due to thermal expansion is calculated from

$$\sigma_3 = \frac{iM_C}{Z} \leq f_a$$

where

$M_C$ = resultant moment due to thermal expansion and alternating loads

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

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

$U =$ cyclic stress range reduction factor as mentioned below

| Number of cycle | Stress range reduction factor $U$ |
|---|---|
| <= 7000 | 1.0 |
| 7001 to 14000 | 0.9 |
| 14001 to 22000 | 0.8 |
| 22001 to 45000 | 0.7 |
| 45001 to 100000 | 0.6 |
| 100001 to 200000 | 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

If the above condition is not met, then the following may be used

$$\sigma_4 = \frac{PD_o}{4e} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_h + f_a$$

## Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, $\sigma_5$, due to sustained, thermal and alternating loadings shall satisfy the equation below.

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

where

$f_{cr}$ = allowable creep stress value

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte**

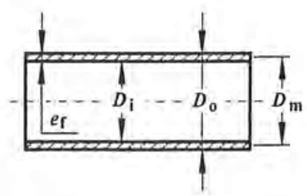
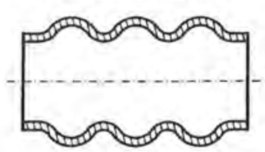
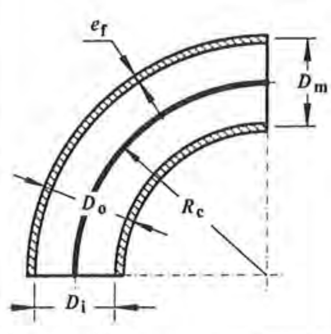
| Composant | Caractéristique de flexibilité<br>$h$ | Coefficient de flexibilité<br>$k$<br>Note (1) | Coefficients d'intensification de contrainte<br>$i$ | <br>$i_o$<br>hors du plan | <br>$i_i$<br>dans le plan | Module d'inertie |
|---|---|---|---|---|---|---|
| **1. Tuyau droit soudé bout-à-bout**<br> | | 1 | 1 | 1 | 1 | $\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$ |
| **2. Tuyau droit ondulé ou coude ondulé**<br> | | 5 | 2,5 | 2,5 | 2,5 | |
| **3. Coude ou cintre soudé bout-à-bout**<br><br>Note : Pour les intersections tubulure-coude voir § C2.2.7.4.4. | $\frac{4\ e_f\ R_c}{D_m^2}$ | $\frac{1,65}{h}$ | $\frac{0,9}{h^{2/3}}$<br>Notes (2) & (3) | $\frac{0,75}{h^{2/3}}$<br>Notes (2), (3) & (4) | $\frac{0,9}{h^{2/3}}$ | $\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$ |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

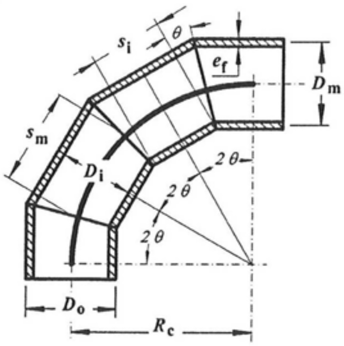
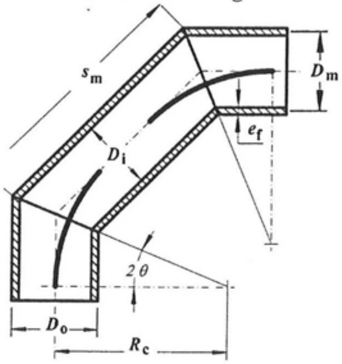
| Composant | Caractéristique de flexibilité<br>$h$ | Coefficient de flexibilité<br>$k$<br>Note (1) | Coefficients d'intensification de contrainte<br>$i$ | <br>$i_0$<br>hors du plan | <br>$i_i$<br>dans le plan | Module d'inertie |
|---|---|---|---|---|---|---|
| **4.1 Coude à sections rapprochées ou à sections multiples**<br><br>$s_m \le \frac{D_m}{2}\left(1+\tan\theta\right)$<br>$R_c = \frac{s_m \cot\theta}{2}$ | $\frac{4\,R_c\,e_f}{D_m^2}$ | $\frac{1{,}52}{h^{5/6}}$ | $\frac{0{,}9}{h^{2/3}}$<br>$s_i \ge 6\,e_f$<br>$\theta \le 22{,}5°$<br>Notes (2) & (3) | $\frac{0{,}9}{h^{2/3}}$<br>Notes (2),(3) & (4) | $\frac{0{,}9}{h^{2/3}}$ | $\frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$ |
| **4.2 Coude à sections espacées et coude à un onglet**<br><br>$s_m > \frac{D_m}{2}\left(1+\tan\theta\right)$<br>$R_c = \frac{D_m\left(1+\cot\theta\right)}{4}$ | $\frac{4\,R_c\,e_f}{D_m^2}$ | $\frac{1{,}52}{h^{5/6}}$ | $\frac{0{,}9}{h^{2/3}}$<br>$\theta \le 22{,}5°$<br>Note (2) | $\frac{0{,}9}{h^{2/3}}$<br>Notes (2), (3) & (4) | $\frac{0{,}9}{h^{2/3}}$ | $\frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$ |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

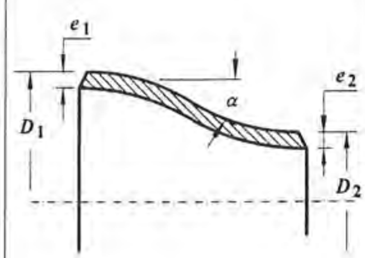
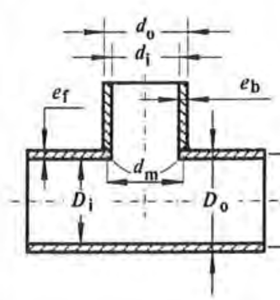
| Composant | Caracté-ristique de flexibilité | Coefficient de flexibilité | Coefficients d'intensification de contrainte | | | Module d'inertie |
|---|---|---|---|---|---|---|
| | $h$ | $k$ Note (1) | $i$ | $i_o$ hors du plan | $i_i$ dans le plan | |
| **5.1 Réduction forgée**   | | 1 | | $0{,}5 + \frac{\alpha}{100}\left(\frac{D_2}{e_2}\right)^{1/2}$<br>MAX = 2,0<br>($\alpha$ en °)<br>$\alpha \leq 60°$<br>$d_1/e_1 \leq 100$<br>$d_2/e_2 \leq 100$<br>Note (5) | | |
| **5.2 Réduction chaudronnée**<br>voir figure C2.2.4 | | | | Note (14) | | |
| **6. Té reconstitué non renforcé avec tubulure posée ou pénétrante**   | $\frac{2\,e_f}{D_m}$ | 1 | $\frac{0{,}9}{h^{2/3}}$<br>Notes (2) & (12) | $\frac{0{,}9}{h^{2/3}\left(\sin\alpha\right)^{3/2}}$<br>$\alpha$ = angle d'inclinaison de la tubulure par rapport au collecteur<br>Notes (2), (6), (7) & (11) | $\frac{3\,i_o}{4} + 0{,}25$ | Collecteur<br>$\frac{\pi}{32}\,\frac{D_e^4 - D_i^4}{D_e}$<br>Dérivation<br>$\frac{\pi}{4}\,d_m^2\,e_x$<br>$e_x$ = MIN ($e_f$ ; $i\,e_b$) |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

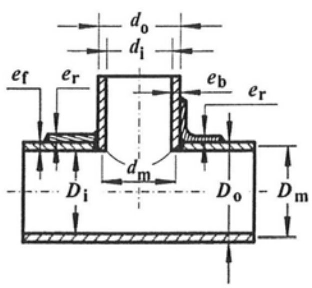
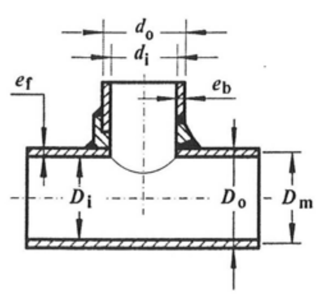
| Composant | Caractéristique de flexibilité<br>$h$ | Coefficient de flexibilité<br>$k$<br>Note (1) | Coefficients d'intensification de contrainte<br>$i$ | <br>$i_0$<br>hors du plan | <br>$i_i$<br>dans le plan | Module d'inertie |
|---|---|---|---|---|---|---|
| **7. Té reconstitué avec tubulure posée ou pénétrante et renforcé par anneau ou selle de renfort**<br><br>avec anneau renfort / avec selle de renfort | si $e_r \le 1,5\ e_f$<br>$\frac{2\left(e_f + 0,5\ e_r\right)^{5/2}}{e_f^{3/2}\ D_m}$<br>si $e_r > 1,5\ e_f$<br>$8\ \frac{e_r}{D_m}$ | 1 | $\frac{0,9}{h^{2/3}}$<br>Notes (2) & (12) | $\frac{0,9}{h^{2/3}\left(\sin \alpha\right)^{3/2}}$<br>$\alpha =$ angle d'inclinaison de la tubulure par rapport au collecteur<br>Notes (2), (6), (7) & (11) | $\frac{3\ i_0}{4} + 0,25$ | Collecteur<br>$\frac{\pi}{32}\frac{D_e^4 - D_i^4}{D_e}$<br>Dérivation<br>$\frac{\pi}{4} d_m^2\ e_x$<br>$e_x = \text{MIN}\ (e_f\ ;\ i\ e_b)$ |
| **8. Piquage avec pièces forgées**<br><br>Type manchon forgé / Type weldolets etc. | $6,6\ \frac{e_f}{D_m}$ | 1<br>Type manchon forgé | | 2,1 | 2,1 | |
| | | 1<br>Type weldolets etc. | | $\frac{0,9}{h^{2/3}}$<br>Notes (2), (6), (8) & (10) | $\frac{3\ i_0}{4} + 0,25$ | |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

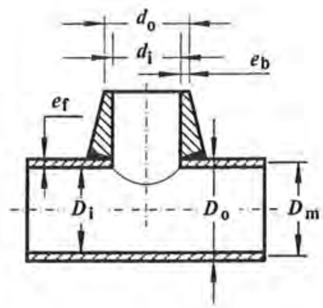
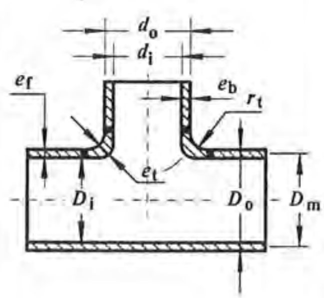
| Composant | Caracté-ristique de flexibilité | Coefficient de flexibilité | Coefficients d'intensification de contrainte | | | Module d'inertie |
|---|---|---|---|---|---|---|
| | $h$ | $k$<br>Note (1) | $i$ | $i_0$<br>hors du plan | $i_i$<br>dans le plan | |
| **9. Piquage posé intégralement renforcé**<br> | $6{,}6\,\dfrac{e_f}{D_m}$ | 1 | | $\dfrac{0{,}9}{h^{2/3}}$ | $\dfrac{0{,}9}{h^{2/3}}$ | |
| | | | | Notes<br>(2), (6), (8) & (10) | | |
| **10. Piquage avec selle de renfort insérée**<br> | $\dfrac{8{,}8\,e_f}{D_m}$ | 1 | $\dfrac{0{,}9}{h^{2/3}}$<br>et<br>Tableau C3.2.6-2 | $\dfrac{0{,}9}{h^{2/3}}$ | $\dfrac{3\,i_0}{4} + 0{,}25$ | |
| | | | | $r_t \geq d_o/8$<br>$e_t \geq 1{,}5\,e_f$<br>Notes<br>(2), (7), (8), (9) & (11) | | |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

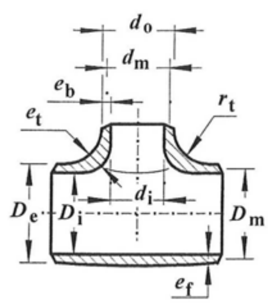
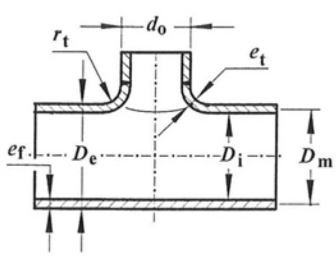
| Composant | Caractéristique de flexibilité $h$ | Coefficient de flexibilité $k$ Note (1) | Coefficients d'intensification de contrainte $i$ | $i_0$ hors du plan | $i_i$ dans le plan | Module d'inertie |
|---|---|---|---|---|---|---|
| **11. Té forgé**<br> | $\frac{8,8\, e_f}{D_m}$ | 1 | $\frac{0,9}{h^{2/3}}$ | $\frac{0,9}{h^{2/3}}$<br>$e_t \geq 1,5\, e_f$<br>Notes (2), (7), (8), (9) & (11) | $\frac{3\, i_0}{4} + 0,25$ | Collecteur<br>$\frac{\pi}{32} \frac{D_e^4 - D_i^4}{D_e}$<br>Dérivation<br>$\frac{\pi}{4} d_m^2\, e_x$<br>$e_x$ = MIN ($e_f$ ; $i\, e_b$) |
| **12. Té à souder extrudé**<br> | $\left(1+\frac{2\, r_t}{D_m}\right)\frac{2\, e_f}{D_m}$ | 1 | Note (13) | $\frac{0,9}{h^{2/3}}$<br>$r_t \geq 0,05\, d_o$<br>$e_t \leq 1,5\, e_f$<br>Notes (2) & (7) | $\frac{3\, i_0}{4} + 0,25$ | |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

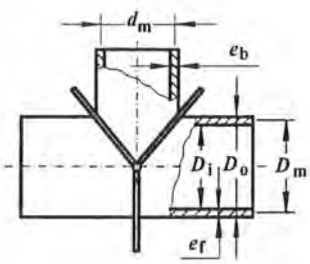
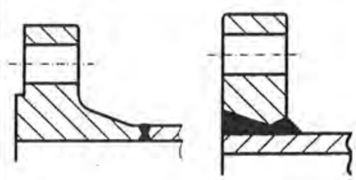
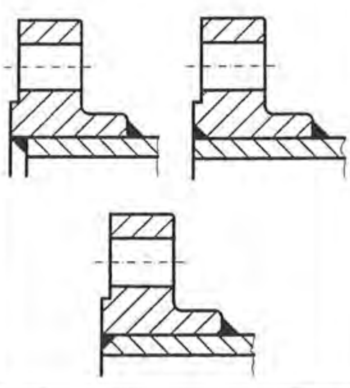
| Composant | Caracté-ristique de flexibilité | Coefficient de flexibilité | Coefficients d'intensification de contrainte | | | Module d'inertie |
|---|---|---|---|---|---|---|
| | $h$ | $k$ Note (1) | $i$ | $i_0$ hors du plan | $i_i$ dans le plan | |
| **13. Triform**   | $\frac{2\,e_f}{D_m}$ | 1 | Note (13) | $\frac{0{,}9}{h^{2/3}}$ | $\frac{3\,i_0}{4} + 0{,}25$ | Collecteur $\frac{\pi}{32}\frac{D_o^4 - D_i^4}{D_o}$ Dérivation $\frac{\pi}{4} d_m^2\, e_x$ $e_x = \text{MIN}\,(e_f\,;\, i\, e_b)$ |
| **14.1 Bride à assembler bout-à-bout**  | | 1 | 1 | | | |
| **14.2 Bride à emmancher et à souder** (soudée des deux côtés)  | | 1 | 1,2 | | | |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

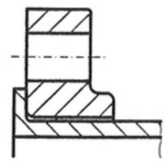
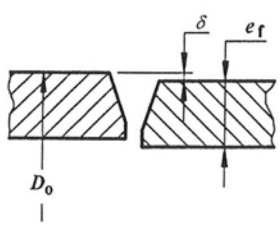
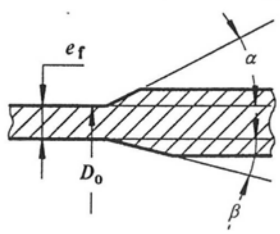
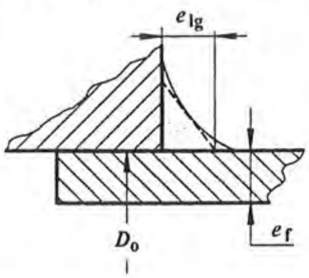
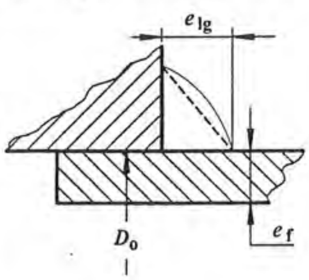
| Composant | Caracté-ristique de flexibilité | Coefficient de flexibilité | Coefficients d'intensification de contrainte | | | Module d'inertie |
|---|---|---|---|---|---|---|
| | $h$ | $k$<br>Note (1) | $i$ | $i_0$<br>hors du plan | $i_i$<br>dans le plan | |
| **14.3 Bride tournantes**<br> | | 1 | 1,6 | | | |
| **14.4 Bride à visser**<br>Voir figure C2.2.8.3.7-2 | | 1 | 2,3 | | | |
| **15.1 Soudure bout-à-bout**<br> | | | 1<br>$e_n \geq 5$ mm<br>et $\delta \leq 0,1\ e_f$<br>Note (15) | | | $\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$ |
| | | | 1,8<br>$e_n < 5$ mm ou<br>$\delta > 0,1\ e_f$<br>Note (15) | | | |
| **15.2 Transition d'épaisseur de paroi**<br><br>$\alpha \leq 30°$ $\beta \leq 15°$ | | | $1,3 + 0,0036\ D_0 / e_f + 3,6\ \delta / e_f$<br>avec un maximum de 1,9<br>Note (15)<br><br>sans soudure circonférentielle au niveau de la transition $\delta = 0$ | | | $\frac{\pi}{32} \frac{D_o^4 - D_i^4}{D_o}$ |

**Tableau C3.2.6-1 - Caractéristique de flexibilité, coefficient de flexibilité et coefficients d'intensification de contrainte (suite)**

| Composant | Caracté-ristique de flexibilité <br> $h$ | Coefficient de flexibilité <br> $k$ <br> Note (1) | Coefficients d'intensification de contrainte <br> $i$ | <br> $i_0$ <br> hors du plan | <br> $i_i$ <br> dans le plan | Module d'inertie |
|---|---|---|---|---|---|---|
| **15.3 Composant emmanché-soudé** <br>   <br> forme concave avec raccordement régulier au tuyau | | 1 | 1,3 | $\frac{2{,}1\ e_f}{e_{lg}}$ <br> avec un minimum de 1,3 et un maximum de 2,1 | | $\frac{\pi}{32}\frac{D_o^4 - D}{D_o}$ <br> $\frac{\pi}{4} D_o^2 e_f$ |
| **15.4 Composant emmanché-soudé** <br>   <br> forme convexe | | 1 | 2,1 | $\frac{2{,}1\ e_f}{e_{lg}}$ <br> avec un minimum de 1,3 et un maximum de 2,1 | | $\frac{\pi}{32}\frac{D_o^4 - D}{D_o}$ <br> $\frac{\pi}{4} D_o^2 e_f$ |

## Notes du tableau C3.2.6-1

(1) Le coefficient de flexibilité $k$ s'applique à la flexion dans tous les plans. Le coefficient pour la torsion est égal à 1 dans tous les cas à l'exception du cas 2 (tuyau droit et coude ondulé) pour lequel il est égal à 0,9.

(2) Les coefficients $k$, $i$, $i_0$, $i_1$ s'appliquent sur toute la longueur effective des coudes et des cintres (ligne épaissie sur les schémas) et à l'intersection des axes pour les tés et les piquages.

(3) Si ces composants sont munis :

- d'une bride à l'une de leurs extrémités, $k$, $i$, $i_0$, $i_1$ sont à multiplier par $h^{1/6}$,
- d'une bride à leurs deux extrémités, $k$, $i$, $i_0$, $i_1$ sont à multiplier par $h^{1/3}$.

(4) Si la pression est susceptible d'apporter une correction d'ovalisation (grand diamètre, petite épaisseur), les coefficients sont divisés par :

- $1 + 6\left(\frac{P}{E}\right)\left(\frac{r_m}{e_r}\right)^{7/3}\left(\frac{R_c}{r_m}\right)^{1/3}$ pour le coefficient $k$.
- $1 + 3{,}25\left(\frac{P}{E}\right)\left(\frac{r_m}{e_r}\right)^{5/2}\left(\frac{R_c}{r_m}\right)^{2/3}$ pour les coefficients $i$, $i_0$, $i_1$.

$P$ étant la pression de service et $E$ le module d'élasticité à 20 °C.

(5) L'épaisseur de la paroi de la réduction ne doit pas être inférieure à $e_1$ sauf au voisinage de l'extrémité de petit diamètre où, toutefois, l'épaisseur de la paroi ne doit pas être inférieure à $e_2$.

(6) Le coefficient d'intensification de contrainte « hors du plan », pour un piquage dont le rapport des diamètres de la tubulure et du collecteur est supérieur à 0,5, peut être non-conservatif. Par ailleurs, il a été démontré qu'un raccordement régulier par une soudure de forme concave réduit la valeur de ce coefficient. Le choix d'une valeur appropriée pour ce coefficient reste donc de la responsabilité du Concepteur.

(7) Les coefficients d'intensification de contrainte pour les raccordements de tubulures sont basés sur des essais avec au moins deux diamètres de tuyau droit de chaque coté de l'axe de la tubulure. Le cas de tubulures plus proches requiert une attention particulière.

(8) Les pièces forgées utilisées doivent être appropriées aux conditions de service.

(9) Lorsque les limitations portant sur le rayon et l'épaisseur ne sont pas respectées et en l'absence de données fiables la caractéristique de flexibilité doit être prise égale à $\frac{2\,e_f}{D_m}$.

(10) Le Concepteur doit vérifier que le dimensionnement en fonction de la pression est au moins équivalent à celui du tuyau droit.

(11) Les coefficients ne s'appliquent qu'aux piquages à axes concourants.

(12) D'autres valeurs peuvent être utilisées sous réserve de justification.

(13) En l'absence de données fiables, la détermination des coefficients est de la responsabilité du Concepteur.

(14) En l'absence de données plus précises, les coefficients d'intensification de contrainte peuvent être pris égaux à 2,5.

(15) Le coefficient s'applique dans le cas où les tolérances de fabrication (voir partie F) sont respectées. Dans le cas contraire, la détermination des coefficients est de la responsabilité du Concepteur.

## Allowable Pressure

The allowable pressure for straight pipes is calculated from equation 6.1-1 or 6.1-3 depending on the ratio between inner and outer diameter.

For $D_o / D_i \leq 1.7$

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

For $D_o / D_i > 1.7$

$$P = fz\frac{(1-a^2)}{(1+a^2)}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness x [1 - mill tolerance %/100] - corrosion allowance “c”

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

$D_o$ = outside diameter

$D_i$ = inside diameter

$$a = 1 - \frac{2e}{D_o}$$

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness $e_{equi}$.

$$e_{equi} = \frac{e}{t_f}$$

Where

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

R = radius of bend

For closely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1 and 6.3.4-2.

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

For widely spaced miter bends, the allowable pressure is calculated from equations 6.3.4-1, 6.3.4-2 and 6.3.5-1

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

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

Where

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

$R_s$ = effective bend radius of the miter

$\theta$ = miter half angle

## Sustained Stress

The stress ($\sigma_1$) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from equation (12.3.2-1)

$$\sigma_1 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} \le f_h$$

where

P = maximum of CAEPIPE input pressures P1, P2 and P3

$D_o$ = outside diameter

$e_n$ = nominal pipe thickness

$i =$ stress intensification factor; the product of 0.75i shall not be less than 1.0

$M_A =$ resulting bending moment due to sustained loads

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

$f_h$ = hot allowable stress

## Sustained plus Occasional Stress

The stress ($\sigma_2$) due to sustained and occasional loads is calculated from equation (12.3.3-1) as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently.

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

$M_B$=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 ($\sigma_3$) due to thermal expansion is calculated from equation (12.3.4-1)

$$\sigma_3 = \frac{iM_C}{Z} \le f_a$$

where

$M_C$ = resultant moment due to thermal expansion and alternating loads

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

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

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

$f_C$ = 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

If the above condition in equation (12.3.4-1) is not met, equation (12.3.4-2) may be used.

$$\sigma_4 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_h + f_a$$

## Additional Conditions for the Creep Range

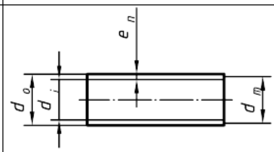
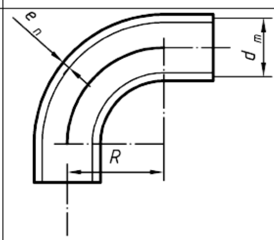
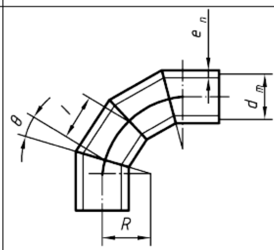
For piping operating within the creep range, the stress, $\sigma_5$, due to sustained, thermal and alternating loadings shall satisfy the equation (12.3.5-1) below.

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

where

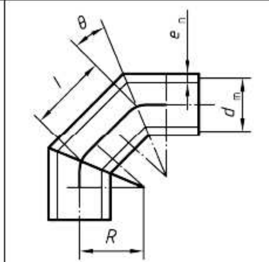
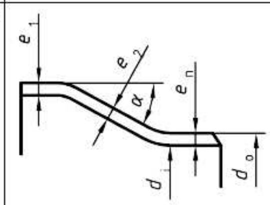
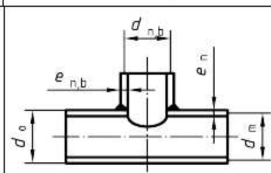
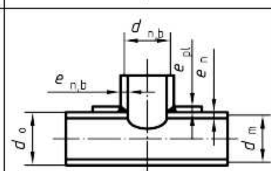
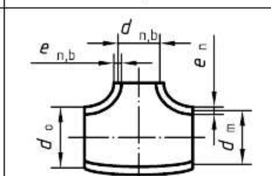
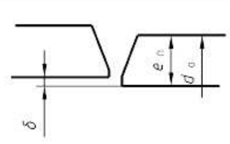
$f_{cr}$ = allowable creep stress value

**Table H.1 — Flexibility characteristics, flexibility and stress intensification factors and section moduli for general cases**

| N° | Designation | Sketch | Flexibility characteristic *h* | Flexibility factor $k_B$ [a] | Stress intensification factor *i* | Section modulus *Z* |
|---|---|---|---|---|---|---|
| 1 | straight pipe |  | 1 | 1 | 1 | |
| 2 | plain bend |  | $\frac{4Re_n}{d_m^2}$ | $\frac{1{,}65}{h}$ | $\frac{0{,}9}{h^{2/3}}$ [b c] | $\frac{\pi}{32}\frac{d_o^4 - d_i^4}{d_o}$ |
| 3 | Closely spaced mitre bend<br>$l < r(1 + \tan\theta)$<br>($l = 2R\tan\theta$) |  | $\frac{4Re_n}{d_m^2}$<br>with<br>$R = \frac{l\cot\theta}{2}$ | $\frac{1{,}52}{h^{5/6}}$ | $\frac{0{,}9}{h^{2/3}}$ [b c] | |

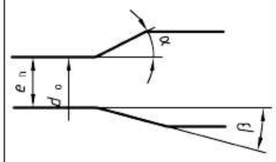
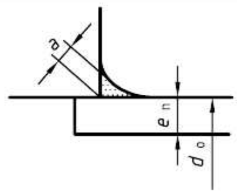
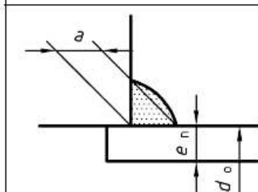
*(to be continued)*

**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<br>$l \geq r\,(1 + \tan\theta)$ |  | $\frac{4Re_n}{d_m^2}$<br>with<br>$R = \frac{d_m(1+\cot\theta)}{4}$ | $\frac{1{,}52}{h^{5/6}}$ | $\frac{0{,}9}{h^{2/3}}$ [b] | |
| 5 | forged welded-in reducer |  | Shape conditions :<br>$\alpha \leq 60°$<br>$e_n \geq d_o/100$<br>$e_2 \geq e_1$ | 1 | $0{,}5 + \frac{\alpha}{100}\left(\frac{d_o}{e_n}\right)^{1/2}$<br>max. 2,0<br>($\alpha$ in deg.) [d] | |
| 6 | tee with welded-on, welded-in or extruded nozzle |  | $\frac{2e_n}{d_m}$ | 1 | $\frac{0{,}9}{h^{2/3}}$ [b e] | Header :<br>$\frac{\pi}{32}\frac{d_o^4 - d_i^4}{d_o}$ |
| 7 | as above, however, with additional reinforcing ring |  | $\frac{2(e_n + 0{,}5e_{pl})^{5/2}}{d_m e_n^{3/2}}$<br>with $e_{pl} \leq e_n$ | 1 | $\frac{0{,}9}{h^{2/3}}$ [b e] | Nozzle<br>$\frac{\pi}{4} d_{n,b}^2 e_x$ |
| 8 | forged welded-in tee with $e_n$ and $e_{n,b}$ as connecting wall thickness |  | $\frac{8{,}8e_n}{d_m}$ | 1 | $\frac{0{,}9}{h^{2/3}}$ [b g] | with $e_x$ as smaller value of<br>$e_{x1} = e_n$ and<br>$e_{x2} = i\, e_{n,b}$<br>resp. |
| 9 | butt weld |  | $e_n \leq 5$mm and $\delta \leq 0{,}1e_n$ [f]<br>$e_n < 5$mm and $\delta > 0{,}1e_n$ [f] | 1<br>1 | 1,0 [f]<br>1,8 [f] | |

*(to be continued)*

**Table H.1** *(concluded)*

| N° | Designation | Sketch | Flexibility characteristic *h* | Flexibility factor $k_B$ [a] | Stress intensification factor *i* | Section modulus *Z* |
|---|---|---|---|---|---|---|
| 10 | wall thickness transitions |  | $\alpha \leq 30°$<br>$\beta \leq 15°$<br>(without circumferential weld at transitions $\delta = 0$) | 1 | $1{,}3 + 0{,}0036\dfrac{d_o}{e_n} + 3{,}6\dfrac{\delta}{e_n}$<br>max 1,9 [f] | $\dfrac{\pi}{32}\dfrac{d_o^4 - d_i^4}{d_o}$ |
| 11 | fillet welds at set-in connections |  | concave shape with continuous transition to pipe | 1 | 1,3 | smaller value of<br>$\dfrac{\pi}{32}\dfrac{d_o^4 - d_i^4}{d_o}$<br>and<br>$\dfrac{\pi}{4}d_o^2 a$ |
| 12 | |  | | 1 | 2,1 | |

[a] The flexibility factor $k_B$ applies to bending in all planes. The factor related to torsion is equal to 1 in all cases.

[b] The factors $k_B$ and *i* apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[c] If these components are fitted with :

- flange at one extremity, $k_B$ and *i* are multiplied by $h^{1/6}$;
- flange at each of the extremities, $k_B$ and *i* are multiplied by $h^{1/3}$.

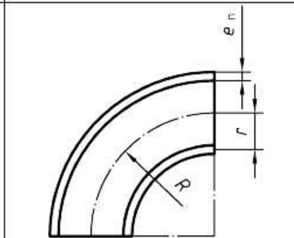
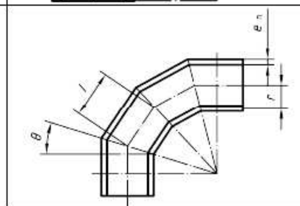
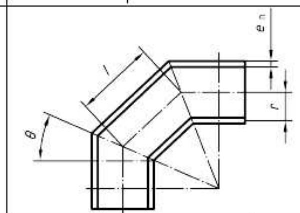
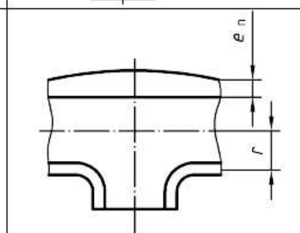
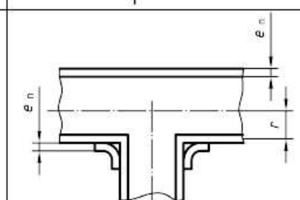
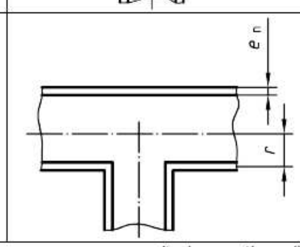
[d] The wall thickness of the reducer is not less than $e_1$ except in the vicinity of the small end where however the thickness is not less than $e_n$.

[e] Other values may be used subject to justification.

[f] The factor applies if the fabrication tolerances are met. Otherwise the determination of the factors is the responsibility of the designer.

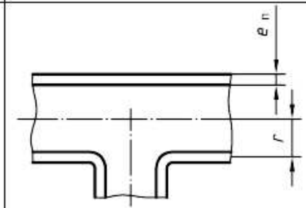
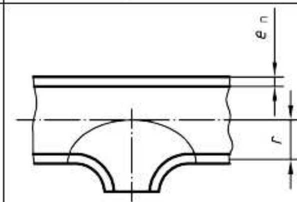
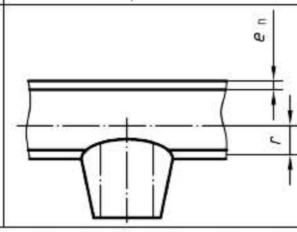
[g] The factors only apply to nozzles with convergent axes.

**Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bendin**

| Component description | Out-of-plane $i_o$ | In-plane $i_i$ | Flexibility characteristic | Sketch |
|---|---|---|---|---|
| Welding elbow or pipe bend | $\frac{0,75}{h^{2/3}}$ a b c | $\frac{0,9}{h^{2/3}}$ a b c | $\frac{e_n R}{r^2}$ |  |
| Closely spaced mitre bend $l < r(1 + \tan\theta)$ $(l = 2R\tan\theta)$ | $\frac{0,9}{h^{2/3}}$ a b c | $\frac{0,9}{h^{2/3}}$ a b c | $\frac{\cot\theta}{2}\frac{e_n l}{r^2}$ |  |
| Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$ | $\frac{0,9}{h^{2/3}}$ a b c | $\frac{0,9}{h^{2/3}}$ a b c | $\frac{e_n}{r}\left(\frac{1+\cot\theta}{2}\right)$ |  |
| Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes | $\frac{0,9}{h^{2/3}}$ a e f g i | $0,75 i_o + 0,25$ a e f g i | $\frac{4,4 e_n}{r}$ |  |
| Reinforced fabricated tee with pad or saddle | $\frac{0,9}{h^{2/3}}$ a d e i | $0,75 i_o + 0,25$ a d e i | $\frac{(e_n + 0,5e_r)^{5/2}}{r(e_n^{3/2})}$ |  |
| Unreinforced fabricated tee | $\frac{0,9}{h^{2/3}}$ a d e i | $0,75 i_o + 0,25$ a d e i | $\frac{e_n}{r}$ |  |

*(to be continued)*

**Table H.3** (*concluded*)

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

[a] The factors $i_o$ and $i_i$ apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[b] If these components are fitted with :

- flange at one extremity, $i_o$ and $i_i$ are multiplied by $h^{1/6}$;
- flange at each of the extremities, $i_o$ and $i_i$ are multiplied by $h^{1/3}$.

[c] If the pressure is likely to correct ovality (large diameter, small thickness), the factors $i_o$ and $i_i$ shall be divided by $1 + 3{,}25\left(\frac{P}{E}\right)\left(\frac{r_m}{e_r}\right)^{5/2}\left(\frac{R}{r_m}\right)^{2/3}$, where $P$ is the operating pressure and $E$ the modulus of elasticity at 20 °C.

[d] For a nozzle with a ratio of branch diameter to pipe diameter exceeding 0,5, the out-of-plane stress intensification factor may be non-conservative. In addition a smooth transition by a concave shaped weld is proved to reduce the value of this factor. Consequently the selection of an appropriate value for this factor remains the responsibility of the designer.

[e] The stress intensification factors regarding the branch connections are based on tests carried out with at least two diameters of straight pipe on either side of the branch axis. The case of closer branches requires a particular attention.

[f] The forgings shall be suitable with regard to the operating conditions.

[g] When the limitations with respect to radius and thickness are not met and reliable data are not available, the flexibility characteristic is taken as $\frac{e_n}{r}$.

[h] The designer shall check that the design against pressure is at least equivalent to that for a straight pipe.

[i] The factors only apply to nozzles with convergent axes.

## Annexure B

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

| Particulars | Allowable Pressure | Pipe Weight | Sustained Stress | Expansion Stress | Occasional Stress |
|---|---|---|---|---|---|
| **B31.1 (2010)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus |
| **B31.3 (2010)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness - Corrosion allowance | - | Nominal Thickness – Corrosion allowance |
| Section Modulus used | - | - | *Corroded* Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus | *Corroded* Section Modulus;<br>For Branch, effective section modulus |
| **B31.4 (2009)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch effective section modulus |
| **B31.5 (2010)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness – Corrosion allowance | - | Nominal Thickness – Corrosion allowance |

| Particulars | Allowable Pressure | Pipe Weight | Sustained Stress | Expansion Stress | Occasional Stress |
|---|---|---|---|---|---|
| Section Modulus used | - | - | Corroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Corroded Section Modulus;<br>For Branch, effective section modulus |
| **B31.8 (2010)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus |
| **B31.9 (2008)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus | Uncorroded Section Modulus;<br>For Branch, effective section modulus |

**Note:**

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

2. Uncorroded section modulus = section modulus calculated using the nominal thickness.

3. Corroded section modulus = section modulus calculated using the “corroded thickness”

corroded thickness = nominal thickness – corrosion allowance

4. Effective section modulus = section modulus calculated using effective branch thickness, which is lesser of $i_i t_b$ or $t_h$

where, $t_b$ = branch nominal thickness, $t_h$ = header nominal thickness, $i_i$ = in-plane SIF at branch