The *FASTEST* Solutions for Piping Design and Analysis.

# Readme Supplement

# CAEPIPE™

## Version 7.70

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# Annexure A

# Code Compliance

## Allowable Pressure

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

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

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

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

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

where

$P_a$ = allowable pressure

SE = allowable stress as given in Appendix A of B31.1 (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 = $t_n$ × (1 - mill tolerance/100) - corrosion allowance

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

$t_n$ = nominal pipe thickness

$D_o$ = outside diameter of pipe

d = inside diameter of pipe

The Pressure coefficient Y is implemented as per Table 104.1.2 (A). In addition,

Y = 0.0, for cast iron

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

W = weld strength reduction factor as per Table 102.4.7. Refer to Annexure B for details on Weld strength reduction factor implemented in CAEPIPE.

For closely spaced miter bends, the allowable pressure is calculated from Eq. (C.3.1) of para.104.3.3.

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

where

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

R = equivalent bend radius of the miter

For widely spaced miter bends, the allowable pressure is calculated from Eq. (C.3.2) of para. 104.3.3.

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

Where, $\theta$ = miter half angle

## Sustained Stress

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

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

where

P = maximum of CAEPIPE pressures P1 through P10

$D_o$ = outside diameter

$t_n$ = nominal wall thickness

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

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

Z = uncorroded section modulus; for reduced outlets, effective section modulus as per para. 104.8.4

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

## Occasional Stress

The stress ($S_{Lo}$) due to occasional loads is calculated from Eq. 16 of para.104.8.2 as the sum of stress due to sustained loads ($S_L$) and stress due to occasional loads ($S_o$) such as earthquake or wind. Wind and earthquake are not considered concurrently.

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

where

$M_B$ = resultant bending moment on the cross-section due to occasional loads such as thrusts from relief / safety valve loads, from pressure and flow transients, earthquake, wind etc.

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

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

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

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

where

$M_C$ = resultant moment due to thermal expansion

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

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

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

$S_C$ = basic allowable stress 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)

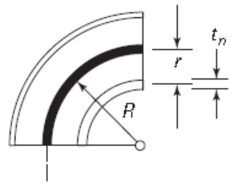
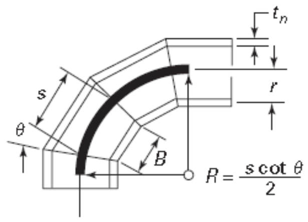
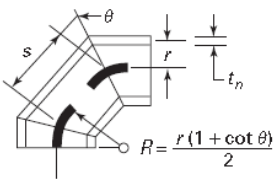
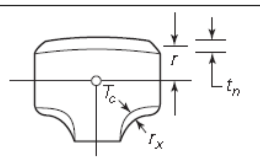
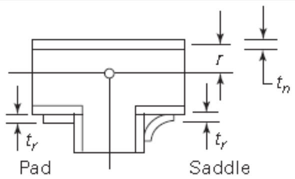
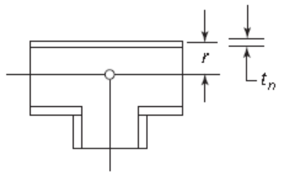
This is specified as an analysis option: “Use liberal allowable stresses”, in the menu Options->Analysis on the Code tab of CAEPIPE.

**Note:**

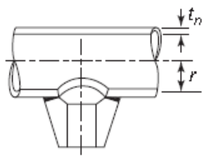
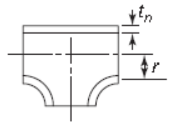
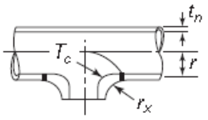
Refer Annexure C for the details of “Thickness” and the “Section Modulus” used by CAEPIPE for weight, pressure and stress calculations.

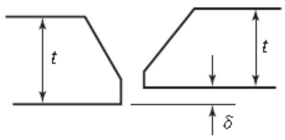
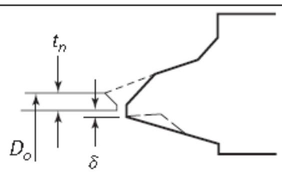
# MANDATORY APPENDIX D
# FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

## Table D-1 Flexibility and Stress Intensification Factors

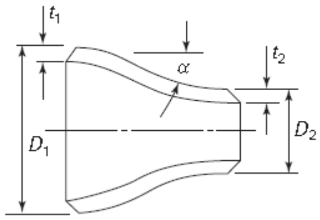
| Description | Flexibility Characteristic, $h$ | Flexibility Factor, $k$ | Stress Intensification Factor, $i$ | Sketch |
|---|---|---|---|---|
| Welding elbow or pipe bend [Notes (1), (2), (3), (4), (5)] | $\frac{t_n R}{r^2}$ | $\frac{1.65}{h}$ | $\frac{0.9}{h^{2/3}}$ |   |
| Closely spaced miter bend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

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

| Description | Flexibility Characteristic, $h$ | Flexibility Factor, $k$ | Stress Intensification Factor, $i$ | Sketch |
|---|---|---|---|---|
| Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)] | $\frac{3.3t_n}{r}$ | 1 | $\frac{0.9}{h^{2/3}}$ |   |
| Extruded outlet meeting the requirements of para. 104.3.1(G) [Notes (1), (2)] | $\frac{t_n}{r}$ | 1 | $\frac{0.9}{h^{2/3}}$ |   |
| Welded-in contour insert [Notes (1), (2), (7)] | $3.1\frac{t_n}{r}$ | 1 | $\frac{0.9}{h^{2/3}}$ |   |

| Description | Flexibility Factor, $k$ | Stress Intensification Factor, $i$ | Sketch |
|---|---|---|---|
| Branch connection [Notes (1), (10)] | 1 | For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$ | See Fig. D-1 |
| Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq \frac{1}{16}$ 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 | | |
| Fillet welds | 1 | 1.3 [Note (12)] | See Figs. 127.4.4(A), 127.4.4(B), and 127.4.4(C) |
| Tapered transition per para. 127.4.2(B) and ASME B16.25 [Note (1)] | 1 | 1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$ |   |

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

| Description | Flexibility Factor, $k$ | Stress Intensification Factor, $i$ | Sketch |
|---|---|---|---|
| Concentric reducer per ASME B16.9 [Notes (1), (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 | . . . |

GENERAL NOTE: The validity of the stress intensification and flexibility factor data in Table D-1 has been demonstrated for $D_o/t_n \leq 100$.

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)
- $D_1$ = outside diameter of reducer on large end, in. (mm)
- $D_2$ = outside diameter of reducer on small end, 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)
- $\alpha$ = reducer cone angle, deg
- $\delta$ = mismatch, in. (mm)
- $\theta$ = one-half angle between adjacent miter axes, deg

(2) The flexibility factors $k$ and stress intensification factors $i$ in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy centerlines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of $k$ and $i$ can be read directly from Chart D-1 by entering with the characteristic $h$ computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of $k$ and $i$ in Table D-1 shall be multiplied by the factor $c$ given below, which can be read directly from Chart D-2, entering with the computed $h$: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

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

(5) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of $k$ and $i$. Values from the Table may be corrected by dividing $k$ by

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

and dividing $i$ by

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

(6) Also includes single miter joints.

(7) If $r_x \geq D_{ob}/8$ and $T_c \geq 1.5t_n$, a flexibility characteristic, $h$, of $4.4t_n/r$ may be used.

(8) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

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

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

NOTES (Cont'd):

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

*(a)* The reinforcement area requirements of para. 104.3 are met.

*(b)* The axis of the branch pipe is normal to the surface of run pipe wall.

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

*(d)* The inside corner radius $r_1$ (see Fig. D-1) is between 10% and 50% of $t_{nh}$.

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

*(f)* The outer radius $r_3$ (see Fig. D-1) is not less than the larger of:

*(1)* $0.002\theta d_o$;

*(2)* $2(\sin\theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).

*(g)* $R_m/t_{nh} \le 50$ and $r'_m/R_m \le 0.5$.

(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. $\delta_{avg}$ 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 $\alpha$ does not exceed 60 deg, and the reducer is concentric.

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

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

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

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

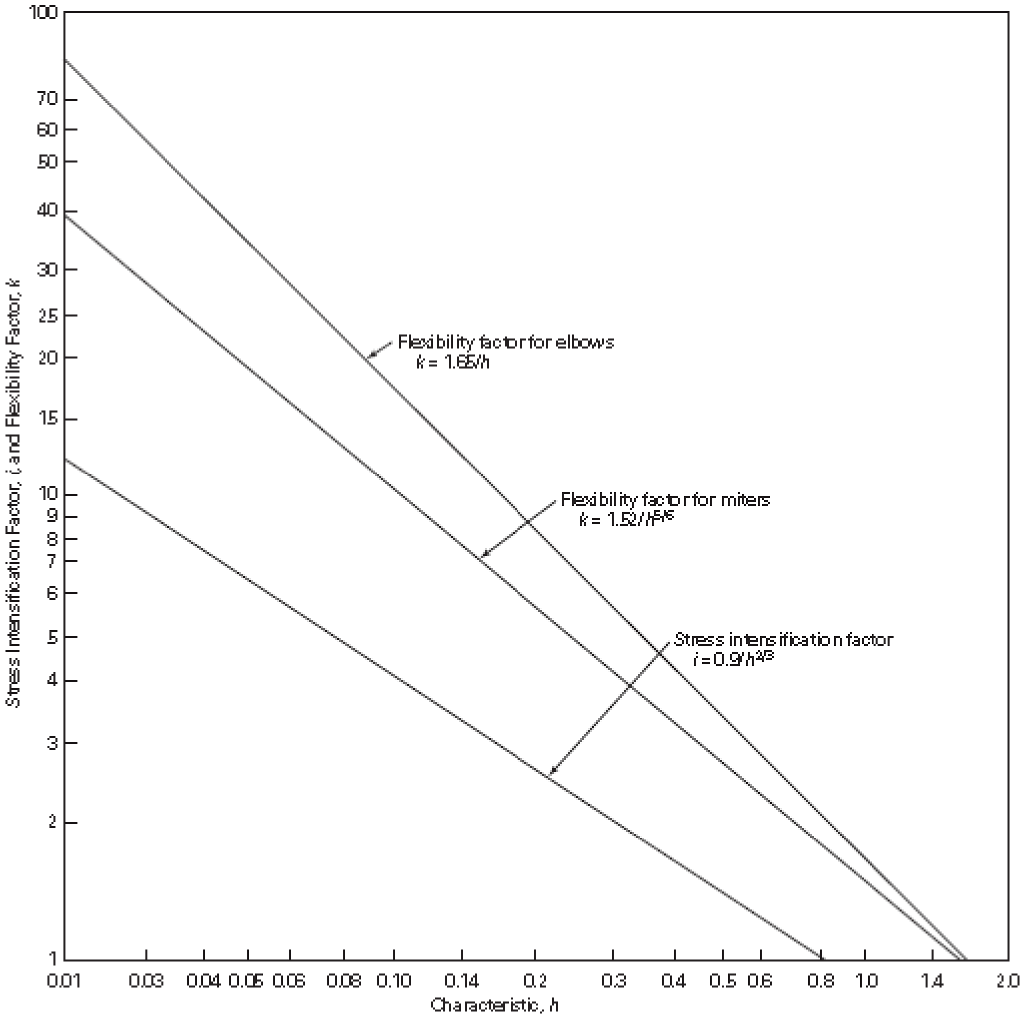
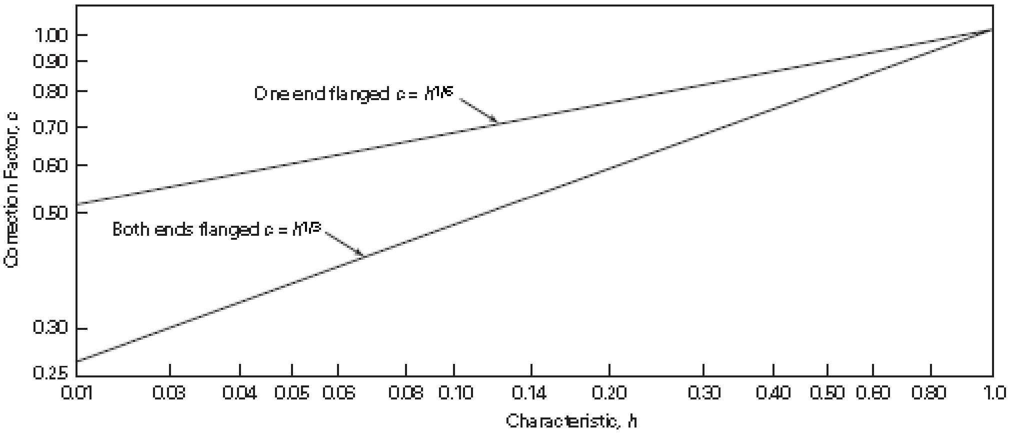


Chart D-2 Correction Factor, $c$



## Allowable 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)

= $t_n$ × (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 = $\dfrac{d}{d+D}$, for $4 \leq D/t_a < 6$

For Cast Iron, Y = 0.0

## Sustained Stress (in corroded condition)

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

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

where

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

D = outside diameter

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

$i_i$ = in-plane stress intensification factor

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

$M_i$ = in-plane bending moment

$M_o =$ out-of-plane bending moment

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

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

## Occasional Stress (in corroded condition)

The stress ($S_{Lo}$) due to occasional loads is calculated as the sum of stress due to sustained loads ($S_L$) and stress due to occasional loads ($S_o$) such as earthquake or wind. Wind and earthquake are not considered concurrently (see para. 502.3.3 (a)). Also, refer to Note 1 below.

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

where

$P_{peak}$ = peak pressure = (peak pressure factor in CAEPIPE) 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. Also see Note 2 below.

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

where

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

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

$M_t$ = torsional moment

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

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

$f =$ stress range reduction factor from Figure 502.3.2

$S_{Cold}$ = basic allowable stress at minimum metal temperature expected during the displacement cycle under analysis

$S_{hot}$ = 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

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

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.

**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-2$t_c$. 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 Annexure C for the details of "Thickness" and the "Section Modulus" used by CAEPIPE for weight, pressure and stress calculations.

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

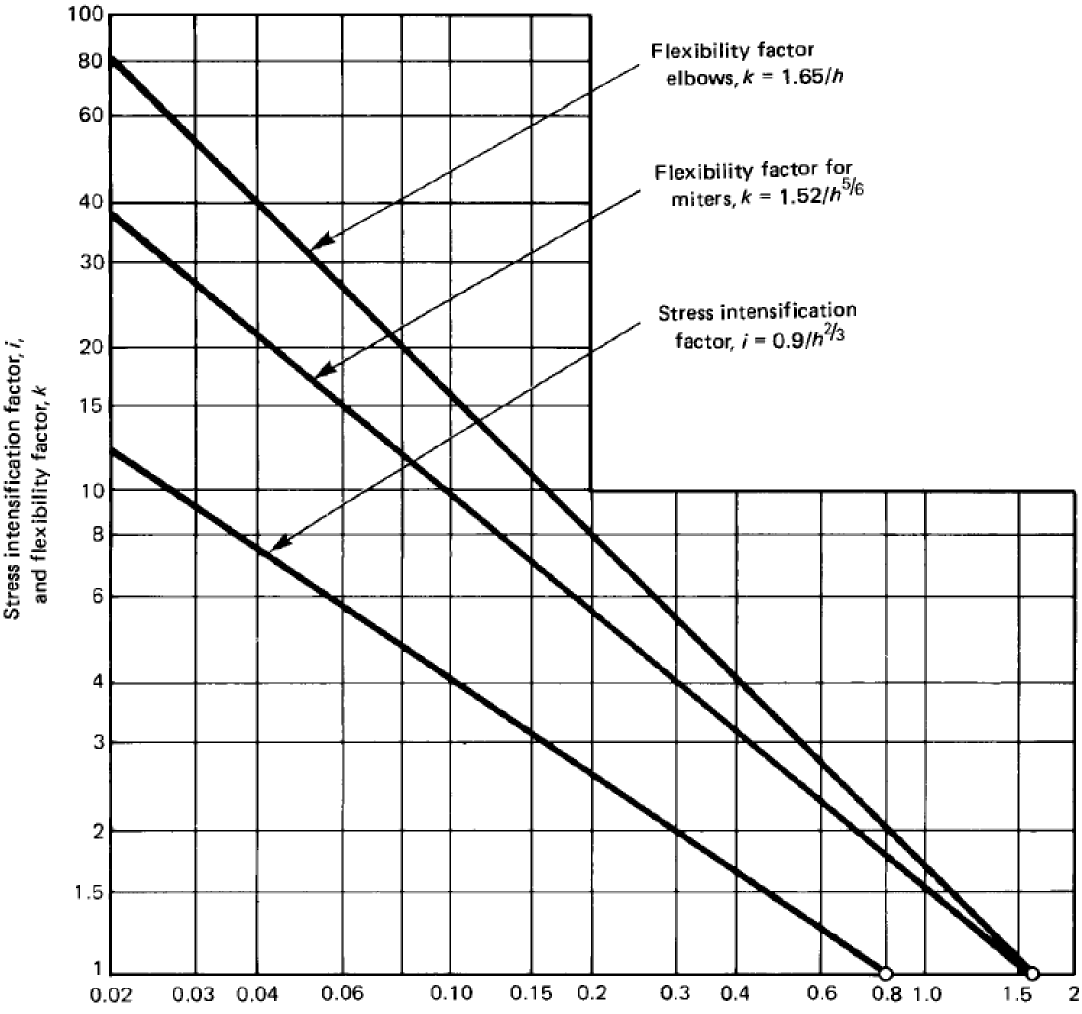



Chart A

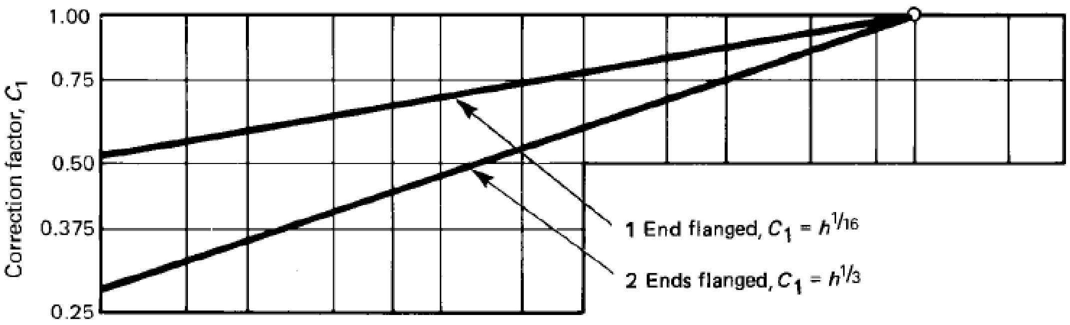
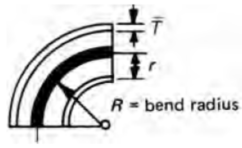
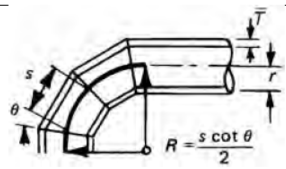
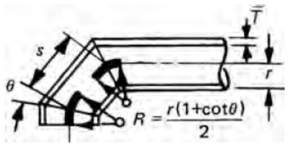
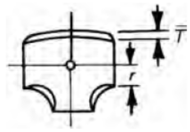
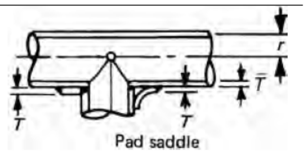
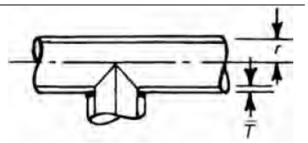



Chart B

**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 |
|---|---|---|---|---|---|
| Welding elbow or pipe bend [Notes (3)–(7)] | $\frac{\bar{T}R}{r^2}$ | $\frac{1.65}{h}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.75}{h^{2/3}}$ |  |
| Closely spaced miter bend [Notes (3), (4), (5), and (7)], $s < r(1 + \tan\theta)$ | $\frac{\bar{T}s}{r^2}\left(\frac{\cot\theta}{2}\right)$ | $\frac{1.52}{h^{5/6}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.75}{h^{2/3}}$ |  |
| Widely spaced miter bend [Notes (3), (4), (7), and (8)], $s \geq r(1 + \tan\theta)$ | $\frac{\bar{T}}{r}\left(\frac{1+\cot\theta}{2}\right)$ | $\frac{1.52}{h^{5/6}}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{0.75}{h^{2/3}}$ |  |
| Welding tee ASME B16.9 [Notes (3) and (4)] | $4.4\frac{\bar{T}}{r}$ | 1 | $0.75i_o + 0.25$ | $\frac{0.9}{h^{2/3}}$ |  |
| Reinforced fabricated tee with pad or saddle [Notes (3), (4), and (9)] | $\frac{(\bar{T} + {}^1/_2 T)^{5/2}}{t^{3/2} r}$ | 1 | $0.75i_o + 0.25$ | $\frac{0.9}{h^{2/3}}$ |  |
| Unreinforced fabricated tee [Notes (3) and (4)] | $\frac{\bar{T}}{r}$ | 1 | $0.75i_o + 0.25$ | $\frac{0.9}{h^{2/3}}$ |  |
| Butt welded joint, reducer, or welding neck flange | . . . | 1 | 1.0 | 1.0 | . . . |
| Double-welded slip-on flange | . . . | 1 | 1.2 | 1.2 | . . . |

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

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

GENERAL NOTE: For reference, see Table 519.3.6 figure 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)
- $\overline{T}$ = nominal wall thickness, in. (mm), of: part itself for elbows and curved or miter bends; matching pipe for welding tees; run or header for fabricated tees (provided that if thickness is greater than that of matching pipe, increased thickness must be maintained for at least one run outside diameter to each side of the branch outside diameter).
- $\theta$ = 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

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

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

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

where

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

(8) Also includes single-miter joint.

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

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

## Allowable Pressure

<u>For straight pipes and bends</u>, 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 (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)

= $t_n$ × (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

<u>For closely and widely spaced miter bends</u>, 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 $P_1$ 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 = uncorroded section modulus; for reduced outlets, effective section modulus

$S_h$ = hot allowable stress at maximum CAEPIPE temperatures [i.e., at max ($T_{ref}$, $T_1$ through $T_{10}$)]

## 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/N0.2, 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

$S_C$ = basic allowable stress as minimum metal temperature expected during the displacement cycle under analysis [i.e., at min ($T_{ref}$, $T_1$ through $T_{10}$)

$S_h$ = basic allowable stress as maximum metal temperature expected during the displacement cycle under analysis [i.e., at max ($T_{ref}$, $T_1$ through $T_{10}$)

When $S_h$ is greater than SL, 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.

### Allowable Pressure

For straight pipe, the design pressure for a given design wall thickness or the design wall thickness for a given design pressure shall be determined by the following design formula from Clause 4.3.5.1.

$$P = FLJT\left(\frac{2St}{D}\right)$$

where

$P$ = allowable pressure
$S$ = specified minimum yield strength
$t$ = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance
$F$ = design factor = 0.8 as per Clause 4.3.6.
$L$ = location factor (from Table 4.2)
$J$ = joint factor (from Table 4.3), input as material property in CAEPIPE
$T$ = temperature factor for steel pipe (from Table 4.4)
$D$ = outside diameter

### Sustained + Occasional Stress (Unrestrained Piping)

The sum of longitudinal pressure stress and the total bending stress due to sustained force (pressure, weight and other sustained mechanical loads) and wind loading 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 design pressure, as determined using the formula given in Clause 4.6.5
$= \frac{PD}{2t}$
$S_B$ = absolute value of beam bending compression stresses resulting from live and dead loads
$= \frac{iM_B}{Z_C}$
$P$ = design pressure
$D$ = outside diameter of pipe
$t$ = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance
$i$ = stress intensification factor (from Table 4.8)
$M_B$ = resultant bending moment due to live and dead loads
$Z_C$ = corroded section modulus
$S$ = 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)

### Expansion Stress (Unrestrained Piping)

The thermal expansion stress range $(S_E)$ for those portions of pipeline systems without axial restraint shall be combined in accordance with the formulae given in Clause 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)

### Combined Stress (Restrained 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.

$$S_h - S_L + s_B \leq ST$$

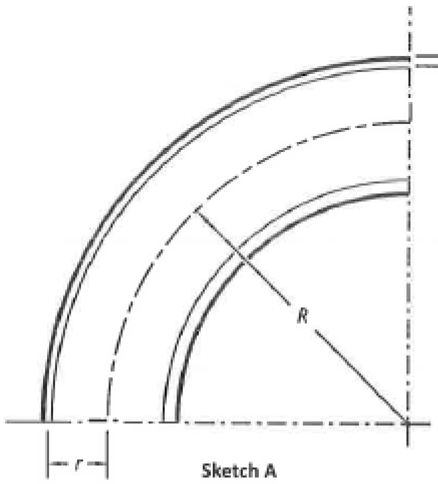
where

$S_h$ = hoop stress due to design pressure, as determined using the 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
=$S_L = \vartheta S_h - E_c\alpha(T_{opr} - T_{ref})$
$S_B$ = absolute value of beam bending compression stresses resulting from live and dead loads
= $\frac{iM_B}{Z_C}$
$P$ = design pressure
$D$ = outside diameter of pipe
$t$ = minimum wall thickness
= nominal wall thickness × (1 − mill tolerance/100) − corrosion allowance
$i$ = stress intensification factor (from Table 4.8)
$M_B$ = resultant bending moment due to live and dead loads
$Z_C$ = corroded section modulus
$\vartheta$ = Poisson's ratio
$E_c$ = modulus of elasticity of steel at $T_{ref}$
$T_{opr}$= operating temperature under consideration ($T_1$, $T_2$, $T_3$, … $T_{10}$ in CAEPIPE)
$T_{ref}$= ambient temperature at the time of restraint = Reference temperature in CAEPIPE
$\alpha$ = coefficient of thermal expansion at $T_{opr}$ defined above
$S$ = specified minimum yield strength
$T$ = temperature factor for steel pipe (from Table 4.4)

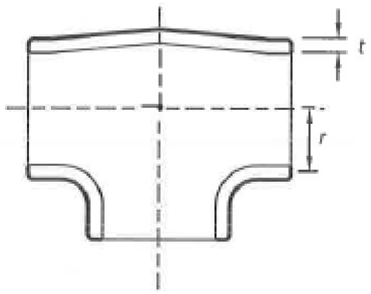
**Note:**

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).

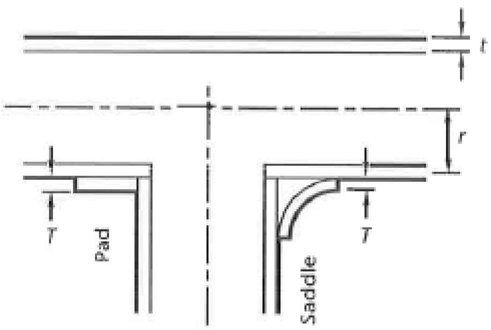
**Table 4.8**
**Flexibility and stress intensification factors**
(See Clauses 4.8.7, 11.14.2, and C.5.1.4.)



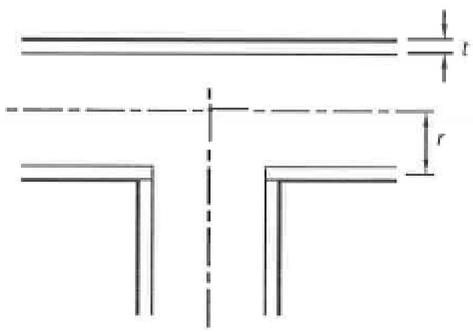

Sketch A




Sketch B




Sketch C




Sketch D

*(Continued)*

## Table 4.8 (Concluded)

| Description | Flexibility factor, $\kappa$* | Stress intensification factor, $i$* |
|---|---|---|
| Buttwelded joint, reducer, or welding neck flange | 1 | 1.0 |
| Double-welded slip-on or socket welding flange | 1 | 1.2 |
| Fillet-welded joint or single-welded socket welding flange | 1 | 1.3 |
| Lap joint flange (with ASME B16.9 lap joint stub) | 1 | 1.6 |
| Screwed pipe joint or screwed flange | 1 | 2.3 |
| Corrugated pipe, straight or curved, or creased bend‡ | 5 | 2.5 |

| Description | Flexibility factor, $\kappa$* | Stress intensification factor, $i$* | Flexibility characteristic, $h$ | See sketch |
|---|---|---|---|---|
| Welding elbow or pipe bend† | $\frac{1.65}{h}$ | $\frac{0.9}{h^{2/3}}$ | $\frac{tR}{r^2}$ | A |
| Welding tee per CSA Z245.11 | 1 | $\frac{0.9}{h^{2/3}}$ | $4.4\frac{t}{r}$ | B |
| Reinforced fabricated tee with pad or saddle | 1 | $\frac{0.9}{h^{2/3}}$ | $\frac{(t+1/2T)^{\frac{5}{2}}}{t^{3/2}r}$ | C |
| Unreinforced fabricated tee | 1 | $\frac{0.9}{h^{2/3}}$ | $\frac{t}{r}$ | D |

* *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 $\kappa$ 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.*

# Annexure B

## Weld Strength Reduction Factors built into CAEPIPE

(as given in Table 102.4.7 of ASME B31.1 – 2016)

**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. | Steel Group | Weld Strength Reduction Factor for Temperature, Deg F (Deg C) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 700 | 750 | 800 | 850 | 900 | 950 | 1000 | 1050 | 1100 | 1150 | 1200 |
| | | (371) | (399) | (427) | (454) | (482) | (510) | (538) | (566) | (593) | (621) | (649) |
| 1 | Carbon Steel (CS) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2 | Ferritic Steels (FS) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 |
| 3 | Austenitic Steel (AS) [contd. in note 2 below] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.95 | 0.91 | 0.86 | 0.82 | 0.77 |
| 4 | Materials other than those stated from Sl. Nos. 1 to 3 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Notes:

1. NP = Not permitted
2. For Austenitic Steels (including 800H and 800 HT) the values upto 1500 deg F are as follows:

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

# Annexure C

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

| Particulars | Allowable Pressure | Pipe Weight | Sustained Stress | Expansion Stress | Occasional Stress |
|---|---|---|---|---|---|
| **B31.1 (2016)** | | | | | |
| 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 (2014)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness - Corrosion allowance | - | Nominal Thickness – Corrosion allowance |
| Section Modulus used | - | - | *Corroded* Section Modulus;<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 (2012)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<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 (2016)** | | | | | |
| 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 |

| Particulars | Allowable Pressure | Pipe Weight | Sustained Stress | Expansion Stress | Occasional Stress |
|---|---|---|---|---|---|
| **B31.8 (2012)** | | | | | |
| Pipe Thickness used | Nominal Thk. | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<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 (2014)** | | | | | |
| Pipe Thickness used | Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance | Nominal Thickness | Nominal Thickness | - | Nominal Thickness |
| Section Modulus used | - | - | Uncorroded Section Modulus;<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

# Annexure D

**ANSI/API Standard 610**

**Eleventh Edition, September 2010**

**ISO 13709: 2009, (Identical) Centrifugal pumps for petroleum, petrochemical and natural gas industries**

## 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 |

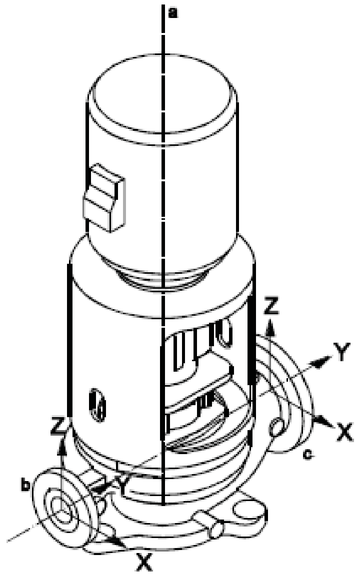
**Table 4 — Nozzle loadings** (*continued*)

| | 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.

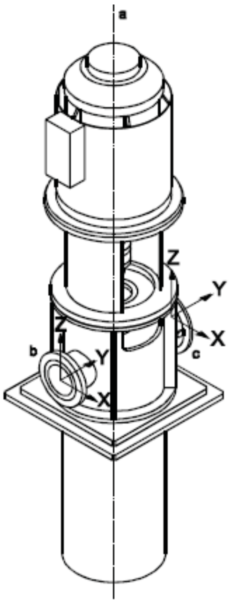



a Shaft centreline.

b Discharge.

c Suction.

**Figure 21 — Coordinate system for the forces and moments in Table 5 — Vertical in-line pumps**

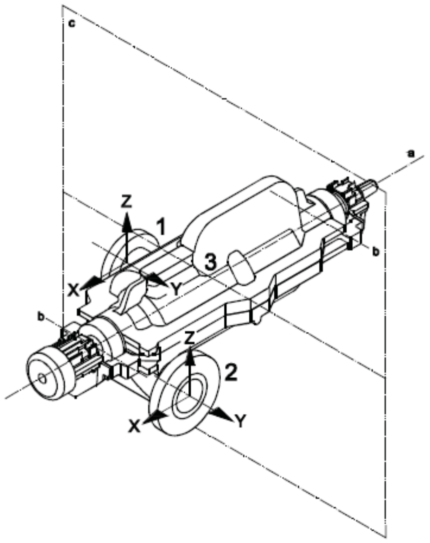



a Shaft centreline.

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

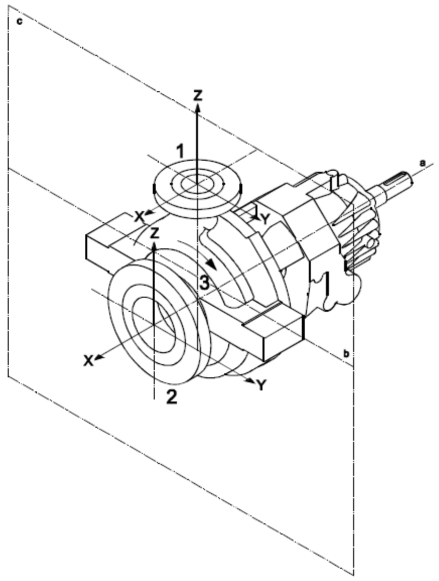
3 centre of pump

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

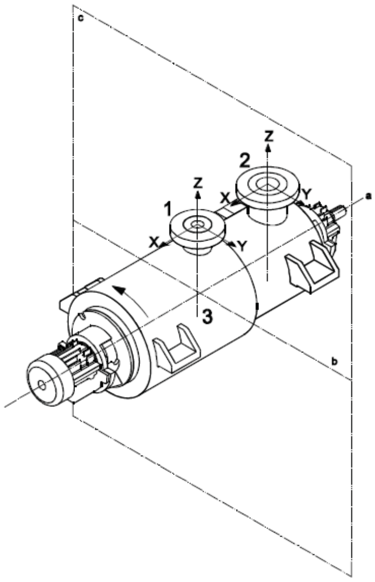
3 centre of pump

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):

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

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

c) The applied component forces and moments acting on each pump nozzle flange shall be translated to the centre of the pump. The magnitude of the resultant applied force, $F_{RCA}$, the resultant applied moment, $M_{RCA}$, and the applied moment shall be limited by 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.)

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

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

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

where

$$F_{RCA} = [(F_{XCA})^2 + (F_{YCA})^2 + (F_{ZCA})^2]^{0,5}$$

where

$$F_{XCA} = F_{XSA} + F_{XDA}$$

$$F_{YCA} = F_{YSA} + F_{YDA}$$

$$F_{ZCA} = F_{ZSA} + F_{ZDA}$$

$$M_{RCA} = [(M_{XCA})^2 + (M_{YCA})^2 + (M_{ZCA})^2]^{0,5}$$

where

$$M_{XCA} = M_{XSA} + M_{XDA} - [(F_{YSA})(zS) + (F_{YDA})(zD) - (F_{ZSA})(yS) - (F_{ZDA})(yD)]/1\,000$$

$$M_{YCA} = M_{YSA} + M_{YDA} + [(F_{XSA})(zS) + (F_{XDA})(zD) - (F_{ZSA})(xS) - (F_{ZDA})(xD)]/1\,000$$

$$M_{ZCA} = M_{ZSA} + M_{ZDA} - [(F_{XSA})(yS) + (F_{XDA})(yD) - (F_{YSA})(xS) - (F_{YDA})(xD)]/1\,000$$

In USC units, the constant 1 000 shall be changed to 12. This constant is the conversion factor to change millimetres to metres or inches to feet.

**F.1.3** Piping configurations that produce loads greater than those allowed in F.1.2 shall be approved by the purchaser and the vendor.

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/mm$^2$ (5 950 psi) in either nozzle. For calculation purposes, the section properties of the pump nozzles shall be based on Schedule 40 pipe whose nominal size is equal to that of the appropriate pump nozzle. Equation (F.6), Equation (F.7), and Equation (F.8) can be used to evaluate principal stress, longitudinal stress and shear stress, respectively, in the nozzles.

For SI units, the following equations apply:

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

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

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

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

$\sigma_p$ is the principal stress, expressed in MPa (lbf/in$^2$);

$\sigma_l$ is the longitudinal stress, expressed in MPa (lbf/in$^2$);

$\tau$ is the shear stress, expressed in MPa (lbf/in$^2$);

$F_X$ is the applied force on the X axis;

$F_Y$ is the applied force on the Y axis;

$F_Z$ is the applied force on the Z axis;

$M_X$ is the applied moment on the X axis;

$M_Y$ is the applied moment on the Y axis;

$M_Z$ is the applied moment on the Z axis;

$D_i$, $D_o$ are the inner and outer diameters of the nozzles, expressed in millimetres (inches).

$F_X$, $F_Y$, $F_Z$, $M_X$, $M_Y$, and $M_Z$ represent the applied loads acting on the suction or discharge nozzles; thus, subscripts $S_A$ and $D_A$ have been omitted to simplify the equations. The sign of $F_Y$ is positive if the load puts the nozzle in tension; the sign is negative if the load puts the nozzle in compression. One should refer to Figure 20 and the applied nozzle loads to determine whether the nozzle is in tension or compression. The absolute value of $M_Y$ should be used in Equations (F.8) to (F.11).

## F.3 Nomenclature

The following definitions apply to the sample problems in F.4

where

C is the centre of the pump. For pump types OH2 and BB2 with two support pedestals, the centre is defined by the intersection of the pump shaft centreline and a vertical plane passing through the centre of the two pedestals (see Figure 23 and Figure 24). For pump types BB1, BB3, BB4 and BB5 with four support pedestals, the centre is defined by the intersection of the pump shaft centreline and a vertical plane passing midway between the four pedestals (see Figure 22);

D is the discharge nozzle;

$D_i$ is the inside diameter of Schedule 40 pipe whose nominal size is equal to that of the pump nozzle in question, expressed in millimetres (inches);

$D_o$ is the outside diameter of Schedule 40 pipe whose nominal size is equal to that of the pump nozzle in question, expressed in millimetres (inches);

$F$ is the force, expressed in newtons (pounds force);

$F_R$ is the resultant force. ($F_{RSA}$ and $F_{RDA}$ are calculated by the square root of the sum of the squares method using the applied component forces acting on the nozzle flange. $F_{RST4}$ and $F_{RDT4}$ are extracted from Table 4, using the appropriate nozzle size);

$M$ is the moment, expressed in newton metres (foot-pounds force);

$M_R$ is the resultant moment. ($M_{RSA}$ and $M_{RDA}$ are calculated by the square root of the squares method using the applied component moments acting on the nozzle flange. $M_{RST4}$ and $M_{RDT4}$ are extracted from Table 4 using the appropriate nozzle size);

$\sigma_p$ is the principal stress, expressed in megapascals (pounds force per square inch);

$\sigma_l$ is the longitudinal stress, expressed in newtons per square millimetre (pounds per square inch);

$\tau$ 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

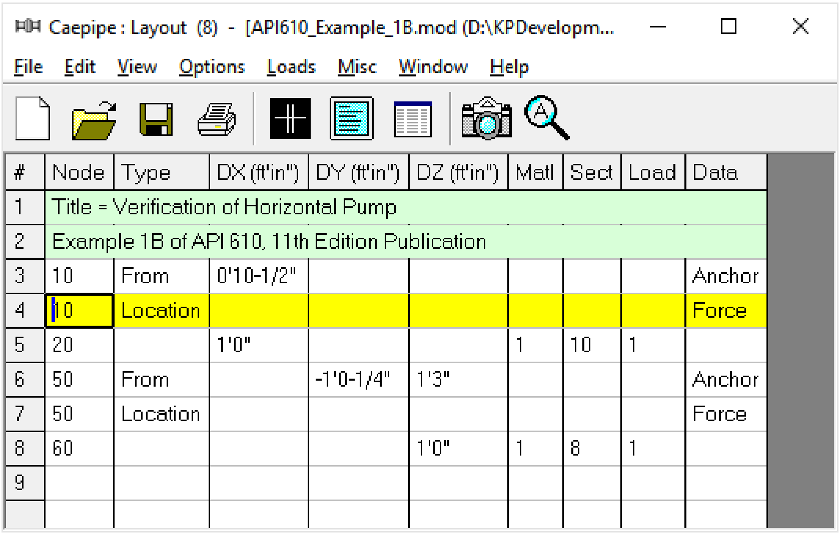
| Nozzle | Size | $x$ | $y$ | $z$ |
|---|---|---|---|---|
| Suction | 10 | +10,50 | 0 | 0 |
| Discharge | 8 | 0 | −12,25 | +15 |

**Table F.5 — Applied nozzle loadings for Example 1B**

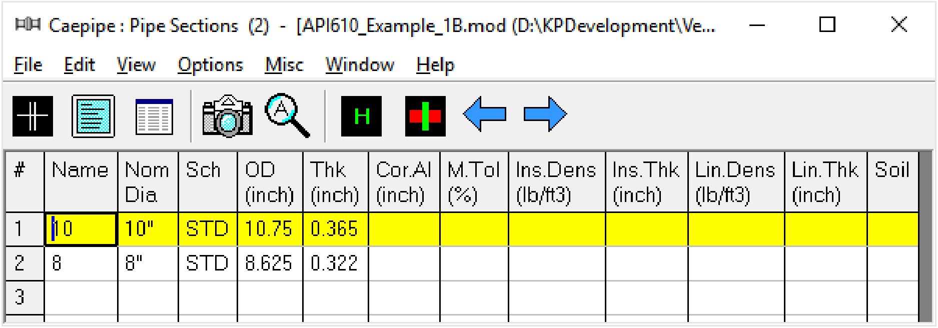
| Force | Value lbf | Moment | Value ft·lbf |
|---|---|---|---|
| — | — | Suction | — |
| $F_{XSA}$ | +2 900 | $M_{XSA}$ | −1 000 |
| $F_{YSA}$ | 0 | $M_{YSA}$ | −3 700[a] |
| $F_{ZSA}$ | −1 990 | $M_{ZSA}$ | −5 500 |
| — | — | Discharge | — |
| $F_{XDA}$ | +1 600 | $M_{XDA}$ | +500 |
| $F_{YDA}$ | −100 | $M_{YDA}$ | −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*




| # | Node | Type | DX (ft'in") | DY (ft'in") | DZ (ft'in") | Matl | 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...

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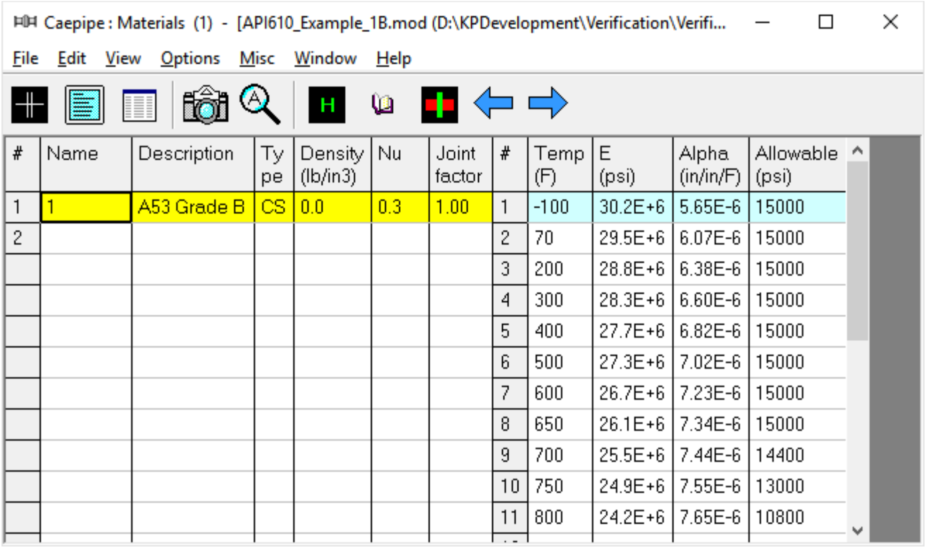
| # | Name | Nom Dia | Sch | OD (inch) | Thk (inch) | Cor.Al (inch) | M.Tol (%) | Ins.Dens (lb/ft3) | Ins.Thk (inch) | Lin.Dens (lb/ft3) | Lin.Thk (inch) | Soil |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 10" | STD | 10.75 | 0.365 | | | | | | | |
| 2 | 8 | 8" | STD | 8.625 | 0.322 | | | | | | | |
| 3 | | | | | | | | | | | | |



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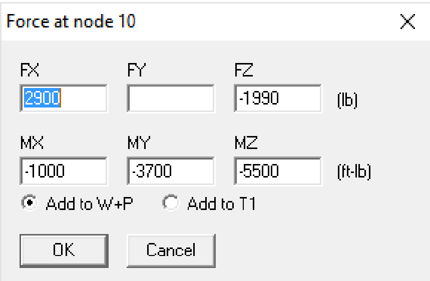
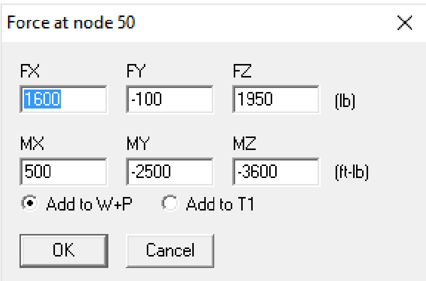
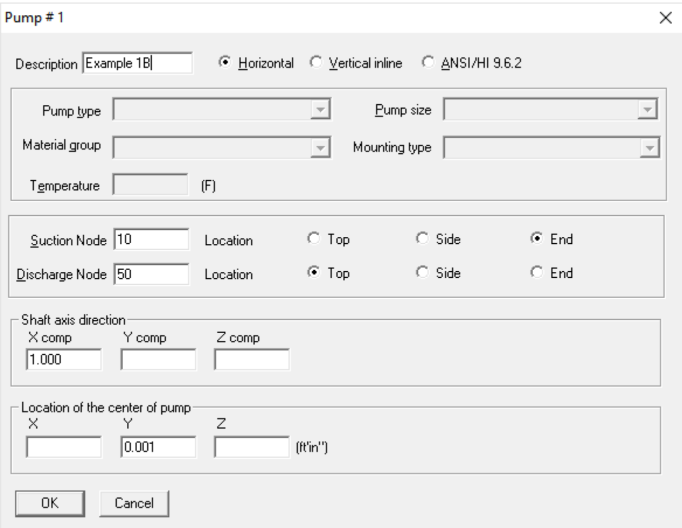
| # | Name | Description | Type | Density (lb/in3) | Nu | Joint factor | # | Temp (F) | E (psi) | Alpha (in/in/F) | Allowable (psi) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | A53 Grade B | CS | 0.0 | 0.3 | 1.00 | 1 | -100 | 30.2E+6 | 5.65E-6 | 15000 |
| 2 | | | | | | | 2 | 70 | 29.5E+6 | 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 |



## *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:

$|F_{XDA}/F_{XDT}| = |+1\,600/850| = 1{,}88 < 2{,}00$

$|F_{YDA}/F_{YDT}| = |-100/700| = 0{,}14 < 2{,}00$

$|F_{ZDA}/F_{ZDT4}| = |+1\,950/1\,100| = 1{,}77 < 2{,}00$

$|M_{XDA}/M_{XDT4}| = |+500/2\,600| = 0{,}19 < 2{,}00$

$|M_{YDA}/M_{YDT4}| = |-2\,500/1\,300| = 1{,}93 < 2{,}00$

$|M_{ZDA}/M_{ZDT4}| = |-3\,600/1\,900| = 1{,}89 < 2{,}00$

**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

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| 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 |

# Annexure E
# Response Spectrum Libraries

## Response Spectrum Libraries

Fourteen (14) new Response Spectrum Libraries have been added as per the following.

1. EL Centro May 18, 1940
2. Uniform Building Code (UBC) 1991 Edition and
3. Nuclear Regulatory Commission (NRC) Guide 1.60

## EL Centro

This spectrum data can be accessed by selecting the file “ELCentro_NS_May18_1940.spe” available in the folder “SpectrumLibrary” through Layout window > Misc > Spectrums > File > Library.

This predefined data is taken from “J’Bigs, Introduction to Structural Dynamics” and is based on the north-south component of the May 18, 1940 El Centro California earthquake. As stated in this document, the recorded maximum quantities were 0.33g, 13.7 in/sec, and 8.3 in. This is intended to apply to elastic systems having between 5 and 10 % critical damping. For the El Centro input given below, the three straight lines are defined by.

(1) $u_{max} = (y_{so})_{max} = 8.3 \text{ in.}$ small $f$

(2) $u_{max} = \dfrac{1.5(\dot{y}_{so})_{max}}{2\pi f} = \dfrac{3.3}{f} \text{ in.}$ intermediate $f$

(3) $u_{max} = \dfrac{2(\ddot{y}_{so})_{max}}{(2\pi f)^2} = \dfrac{6.6}{f^2} \text{ in.}$ large $f$

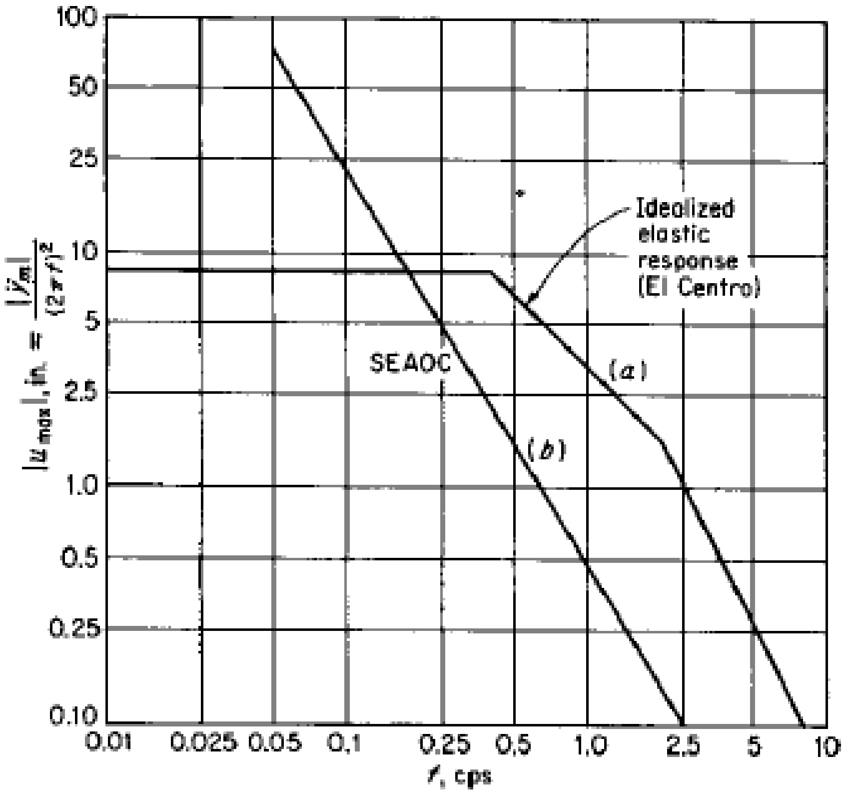



FIGURE 6.12 Idealized response spectrum for El Centro earthquake, May 18, 1940, N-S component and SEAOC recommendation.

## *Uniform Building Code (1991 Edition)*

This spectrum data can be accessed by selecting the file “UBC_1991.spe” available in the folder “SpectrumLibrary” through Layout window > Misc > Spectrums > File > Library. This library has predefined spectrums for three (3) types of soils as shown in the figure below (taken from Uniform Building Code 1991 Edition).

1. Rock and Stiff Soils (Soil Type 1) [Library Name in CAEPIPE: RASS (S1)]
2. Deep and Cohesionless or Stiff Clay Soils (Soil Type 2) [Library Name in CAEPIPE: DCSCS (S2)]
3. Soft to Medium Clays and Sands [Library Name in CAEPIPE: SMCS (S3)]

These spectrums must be scaled by the Zero Period Accelerations (ZPA), which is the product of Z and I, where Z is the seismic zone coefficient and I is the earthquake importance factor as given in UBC Tables 23-I and 23-L. They are reproduced from UBC code for easy reference. This product can be applied in CAEPIPE as a scale factor through Layout window > Loads > Spectrum > Factor (s).

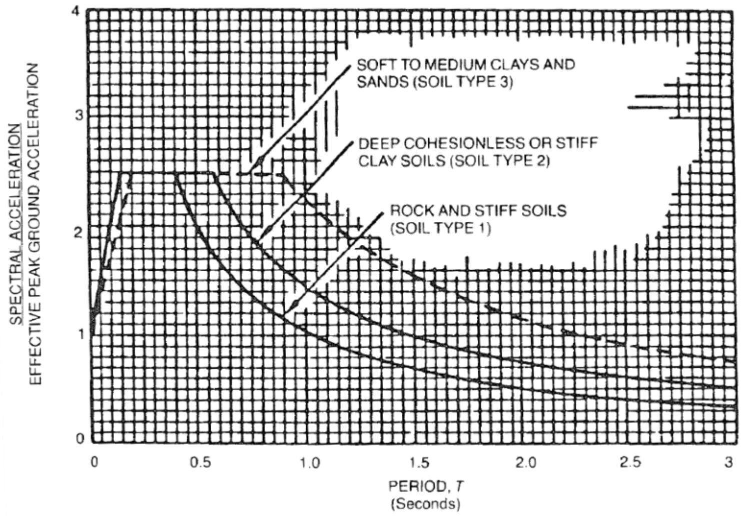



FIGURE NO. 23-3—NORMALIZED RESPONSE SPECTRA SHAPES

**TABLE NO. 23-I**
**SEISMIC ZONE FACTOR *Z***

| ZONE | 1 | 2A | 2B | 3 | 4 |
|---|---|---|---|---|---|
| Z | 0.075 | 0.15 | 0.20 | 0.30 | 0.40 |

The zone shall be determined from the seismic zone map in Figure No. 23-2.

**TABLE NO. 23-L—OCCUPANCY REQUIREMENTS**

| OCCUPANCY CATEGORY[1] | IMPORTANCE FACTOR *I* | |
|---|---|---|
| | Earthquake[2] | Wind |
| I. Essential facilities | 1.25 | 1.15 |
| II. Hazardous facilities | 1.25 | 1.15 |
| III. Special occupancy structures | 1.00 | 1.00 |
| IV. Standard occupancy structures | 1.00 | 1.00 |

[1]Occupancy types or functions of structures within each category are listed in Table No. 23-K and structural observation requirements are given in Sections 305, 306 and 307.
[2]For life-safety-related equipment, see Section 2336 (a).

### *Nuclear Regulatory Commission (NRC) Guide 1.60*

This spectrum data can be accessed by selecting the file “NRC_G1.6_2014.spe” available in the folder “SpectrumLibrary” through Layout window > Misc > Spectrums > File > Library. This library have ten (10) predefined spectrums are based upon Safe Shutdown Earthquake (SSE) for Horizontal and Vertical Design Response Spectra corresponding to 0.5, 2.0, 5.0, 7.0 and 10% Damping factors as shown in the figure below (taken from NRC Guide 1.60, July 2014, Revision 2)

These predefined spectrums are named in the CAPIPE spectrum library as follows.

1. **NRC-HDS-D0.5** (Horizontal Design Spectra with 0.5% Damping Factor)
2. **NRC-HDS-D2** (Horizontal Design Spectra with 2% Damping Factor)
3. **NRC-HDS-D5** (Horizontal Design Spectra with 5% Damping Factor)
4. **NRC-HDS-D7** (Horizontal Design Spectra with 7% Damping Factor)
5. **NRC-HDS-D10** (Horizontal Design Spectra with 10% Damping Factor)
6. **NRC-VDS-D0.5** (Vertical Design Spectra with 0.5% Damping Factor)
7. **NRC-VDS-D2** (Vertical Design Spectra with 2% Damping Factor)
8. **NRC-VDS-D5** (Vertical Design Spectra with 5% Damping Factor)
9. **NRC-VDS-D7** (Vertical Design Spectra with 7% Damping Factor)
10. **NRC-VDS-D10** (Vertical Design Spectra with 10% Damping Factor)

The horizontal and vertical component Design Response Spectra in Figures 1 and 2 correspond to a maximum horizontal ground acceleration of 1.0g. For sites with different acceleration values specified for the design earthquake, the Design Response Spectra should be linearly scaled from Figures 1 and 2 in proportion to the specified maximum horizontal ground acceleration. This proportion factor calculated can be applied in CAEPIPE as a scale factor through Layout window > Loads > Spectrum > Factor (s).

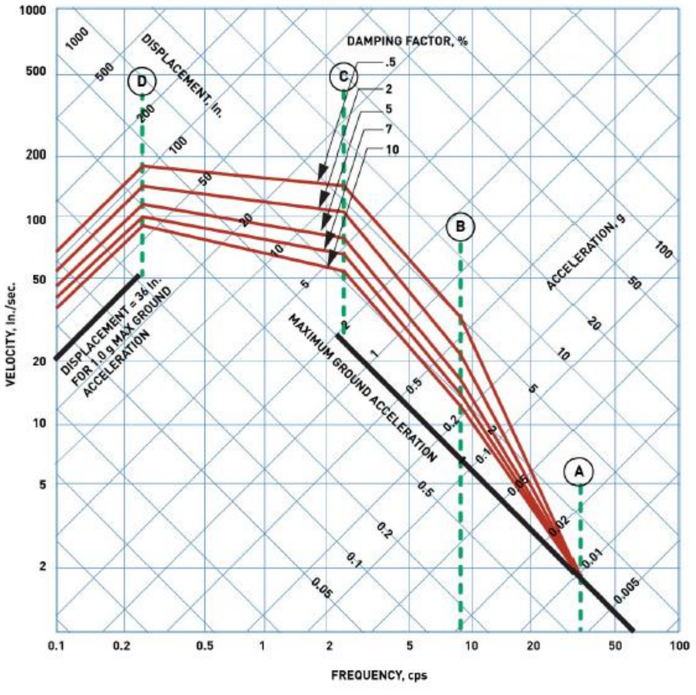



Figure 1. Horizontal Design Response Spectra Scaled to 1 g Horizontal Ground Acceleration

### *Horizontal Component:*

The numerical values of design displacements, velocities, and accelerations for the horizontal component Design Response Spectra are obtained by multiplying the corresponding values of the maximum ground displacement and acceleration by the factors given in Table 1 given below. In Figure 1, the base diagram consists of three parts: the bottom line on the left part represents the maximum ground displacement, the bottom line on the right part represents the maximum acceleration, and the middle part depends on the maximum velocity. The horizontal component Design Response Spectra in Figure 1 of this guide correspond to a maximum horizontal ground acceleration of 1.0g. The maximum ground displacement is taken proportional to the maximum ground acceleration, and is set at 36 inches for a ground acceleration of 1.0 g. The displacement region lines of the Design Response Spectra are parallel to the maximum ground displacement line and are shown on the left of Figure 1. The velocity region lines slope downward from a frequency of 0.25 cycles per second (cps) or Hertz (Hz) (control point D) to a frequency of 2.5 cps (control point C) and are shown at the top. The remaining two sets of lines between the frequencies of 2.5 cps and 33 cps (control point A), with a break at a frequency of 9 cps (control point B), constitute the acceleration region of the horizontal Design Response Spectra. For frequencies higher than 33 cps, the maximum ground acceleration line represents the Design Response Spectra.

**Table 1. Horizontal Design Response Spectra**

**Relative Values of Spectrum Amplification Factors for Control Points**

| Percent of Critical Damping | Amplification Factors for Control Points | | | |
|---|---|---|---|---|
| | Acceleration[a,b] | | | Displacement[a,b] |
| | A (33 cps) | B (9 cps) | C (2.5 cps) | D (0.25 cps) |
| 0.5 | 1.0 | 4.96 | 5.95 | 3.20 |
| 2.0 | 1.0 | 3.54 | 4.25 | 2.50 |
| 5.0 | 1.0 | 2.61 | 3.13 | 2.05 |
| 7.0 | 1.0 | 2.27 | 2.72 | 1.88 |
| 10.0 | 1.0 | 1.90 | 2.28 | 1.70 |

a. Maximum ground displacement is taken proportional to maximum ground acceleration, and is 36 in. for ground acceleration of 1.0 gravity.

b. Acceleration and displacement amplification factor are taken from recommendations given in *Newmark, N. M., John A. Blume, and Kanwar K. Kapur, "Design Response Spectra for Nuclear Power Plants," American Society of Civil Engineers (ASCE) Structural Engineering Meeting, San Francisco, April 1973, (ADAMS Accession No. ML13207A044).*

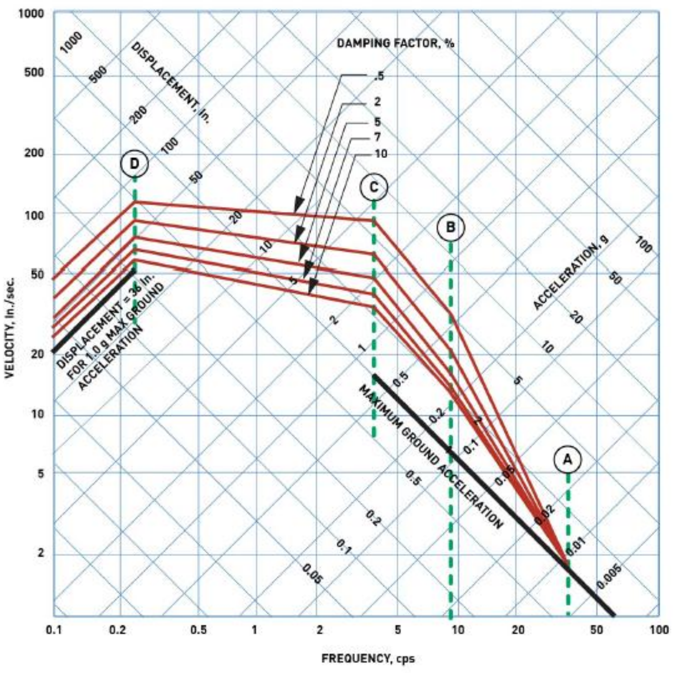



**Figure 2. Vertical Design Response Spectra scaled to 1 g Horizontal Ground Acceleration**

Table 2. Vertical Design Response Spectra

Relative Values of Spectrum Amplification Factors for Control Points

| Percent of Critical Damping | Amplification Factors for Control Points | | | |
|---|---|---|---|---|
| | Acceleration[a,b] | | | Displacement[a,b] |
| | A (33 cps) | B (9 cps) | C (3.5 cps) | D (0.25 cps) |
| 0.5 | 1.0 | 4.96 | 5.67[c] | 2.13 |
| 2.0 | 1.0 | 3.54 | 4.05 | 1.67 |
| 5.0 | 1.0 | 2.61 | 2.98 | 1.37 |
| 7.0 | 1.0 | 2.27 | 2.59 | 1.25 |
| 10.0 | 1.0 | 1.90 | 2.17 | 1.13 |

a. Maximum ground displacement is taken proportional to maximum ground acceleration and is 36 in. for ground acceleration of 1.0 gravity.

b. Acceleration amplification factors for the vertical design response spectra are equal to those for horizontal design response spectra at a given frequency, whereas displacement amplification factors are 2/3 those for horizontal design response spectra. These ratios between the amplification factors for the two design response spectra are in agreement with those recommended in *Newmark, N. M., John A. Blume, and Kanwar K. Kapur, "Design Response Spectra for Nuclear Power Plants," American Society of Civil Engineers (ASCE) Structural Engineering Meeting, San Francisco, April 1973, (ADAMS Accession No. ML13207A044)*.

## *The Vertical Component*

The numerical values of design displacements, velocities, and accelerations in these spectra are obtained by multiplying the corresponding values of the maximum horizontal ground motion (acceleration = 1.0 g and displacement = 36 in.) by the factors given in Table 2.

The vertical component Design Response Spectra corresponding to the maximum horizontal ground acceleration of 1.0 g are shown in Figure 2. The displacement region lines of the Design Response Spectra are parallel to the maximum ground displacement line and are shown on the left of Figure 2. The velocity region lines slope downward from a frequency of 0.25 cps (control point D) to a frequency of 3.5 cps (control point C) and are shown at the top. The remaining two sets of lines between the frequencies of 3.5 cps and 33 cps (control point A), with a break at the frequency of 9 cps (control point B), constitute the acceleration region of the vertical Design Response Spectra. It should be noted that the vertical Design Response Spectra values are 2/3 those of the horizontal Design Response Spectra for frequencies less than 0.25; for frequencies higher than 3.5, they are the same, while the ratio varies between 2/3 and 1 for frequencies between 0.25 and 3.5. For frequencies higher than 33 cps, the Design Response Spectra follow the maximum ground acceleration line.

**Note**:

Since the acceleration values below 2.5 cps and 3.5 cps for Horizontal Design Response Spectra and Vertical Design Response Spectra respectively are NOT given in the Figures 1 and 2 above, the acceleration values corresponding to 2.5 cps (for Horizontal Design Response Spectra) and 3.5 cps (for Vertical Design Response Spectra) are entered for 0.1 cps in the respective directions.

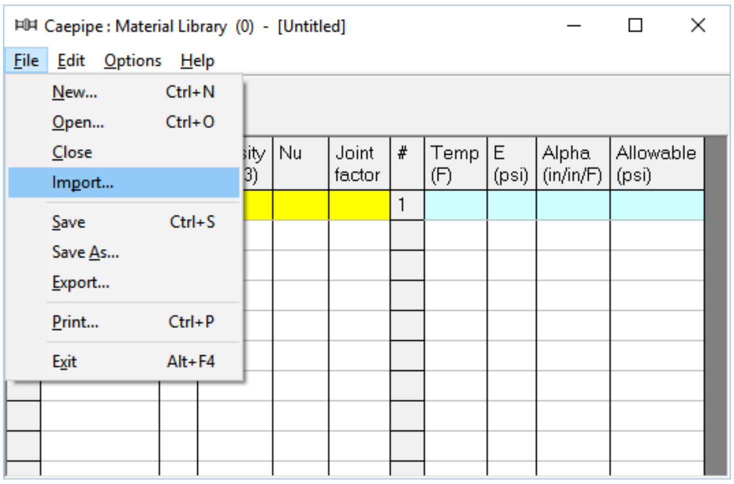
Similarly, the accelerations values above 33 cps and up to 60 cps are entered as 1.0 g in the respective directions.

# Annexure F
# Import / Export of Material Library

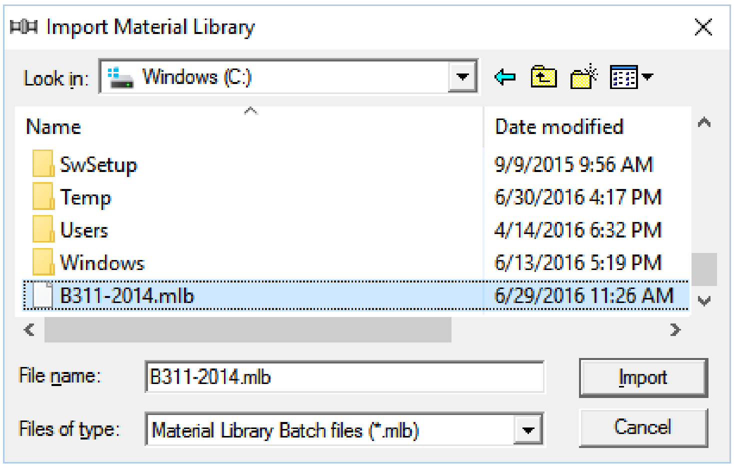
## Import

CAEPIPE can import material properties created using a text file (batch file) into the Material Library. The text file may be created using a text editor and should have the extension: .mlb (material library batch file). The text file may also be created for an existing material library using the Export command from the Material Library window.

To import a material properties into the material library, select the menu command File > New > Material Library. From the Material Library window > File > Import…




The Import Material Library dialog is shown.




Select the material library batch file (.mlb) and then click on the Import button. The batch file will be read and the material properties thus imported are then shown in the Layout window, which can be further modified.

The input data is given in the following order. The start of each section is indicated by a keyword. The data for that section follow. Only the first five characters of the keyword are significant.

Format of Material Library Batch file (.mlb) is given below

**<u>OPTIONS</u>**

***Piping Code, Units***

Piping Codes that can be entered are given below. Example, enter B311 to define the Piping Code as “ASME B31.1”.

Units can be “SI” or “English”. If this field is left blank, then CAEPIPE will set the default units as “English”

**OPTIONS Example**

```
OPTIONS

B311,SI
```

### Piping codes

| | |
|---|---|
| B311 | ANSI B31.1 |
| B311-67 | USAS B31.1 (1967) |
| B313 | ANSI B31.3 |
| B314 | ANSI B31.4 |
| B315 | ANSI B31.5 |
| B318 | ANSI B31.8 |
| B319 | ANSI B31.9 |
| ASME | ASME Section III, Class 2 (1980) |
| ASME-86 | ASME Section III, Class 2 (1986) |
| ASME-92 | ASME Section III, Class 2 (1992) |
| BS806 | British code |
| NORWEGIAN-83 | Norwegian code (1983) |
| NORWEGIAN-90 | Norwegian code (1990) |
| RCC-M | French code (1985) |
| SNCT | CODETI (1995) |
| SWEDISH | Swedish code (1978) |
| STOOMWEZEN | Dutch code (1989) |
| Z183 | Z183 (1990) |
| Z184 | Z184 (1992) |
| EUROPEAN | EN 13480 (2002) |

## MATERIAL

**English units**

### First line:

*Description (32 Characters), Density (lb/in3), Poisson's ratio, [Long. joint factor], [circ. joint factor], [material type], [tensile strength (psi)]*

### Following lines:

*Description, Temp (F), E (psi), alfa (in/in/F), [allowable stress (psi)], [yield stress (psi)], [rupture stress (psi)], [hoop modulus (psi)], [shear modulus (psi)]*

.

.

.

**SI units**

### First line:

*Description (32 Characters), Density (kg/m3), Poisson's ratio, [Long. joint factor], [circ.joint factor], [material type], [tensile strength (N/mm$^2$)]*

**Following lines:**

*Description, Temp (C), E (N/mm²), alfa (mm/mm/C), [allowable stress (N/mm²)], [yield stress (N/mm²)], [rupture stress (N/mm²)], [hoop modulus (N/mm²)], [shear modulus (N/mm²)]*

.

.

.

**MATERIAL Example (SI units)**

```
OPTIONS
EUROPEAN,SI
MATERIAL
EN 1.0345 (P235GH) max 60 mm,7850,0.300,1.00,1.00,CSS,360.0
EN 1.0345 (P235GH) max 60 mm,20,212000,11.90E-6,120.0,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,50,209500,12.20E-6,120.0,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,100,207000,12.50E-6,120.0,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,150,203000,12.75E-6,120.0,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,200,199000,13.00E-6,113.0,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,250,195500,13.30E-6,100.0,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,300,192000,13.60E-6,86.70,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,350,188000,13.85E-6,80.00,0.000,0.000,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,400,184000,14.10E-6,74.70,0.000,94.00,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,410,183100,14.14E-6,74.16,0.000,85.30,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,420,182200,14.18E-6,73.62,0.000,76.00,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,430,181300,14.22E-6,66.70,0.000,66.70,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,440,180400,14.26E-6,58.70,0.000,58.70,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,450,179500,14.30E-6,51.30,0.000,51.30,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,460,178600,14.34E-6,44.00,0.000,44.00,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,470,177700,14.38E-6,37.30,0.000,37.30,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,480,176800,14.42E-6,31.30,0.000,31.30,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,490,175900,14.46E-6,26.00,0.000,26.00,0.000,0.000
EN 1.0345 (P235GH) max 60 mm,500,175000,14.50E-6,21.30,0.000,21.30,0.000,0.000
```

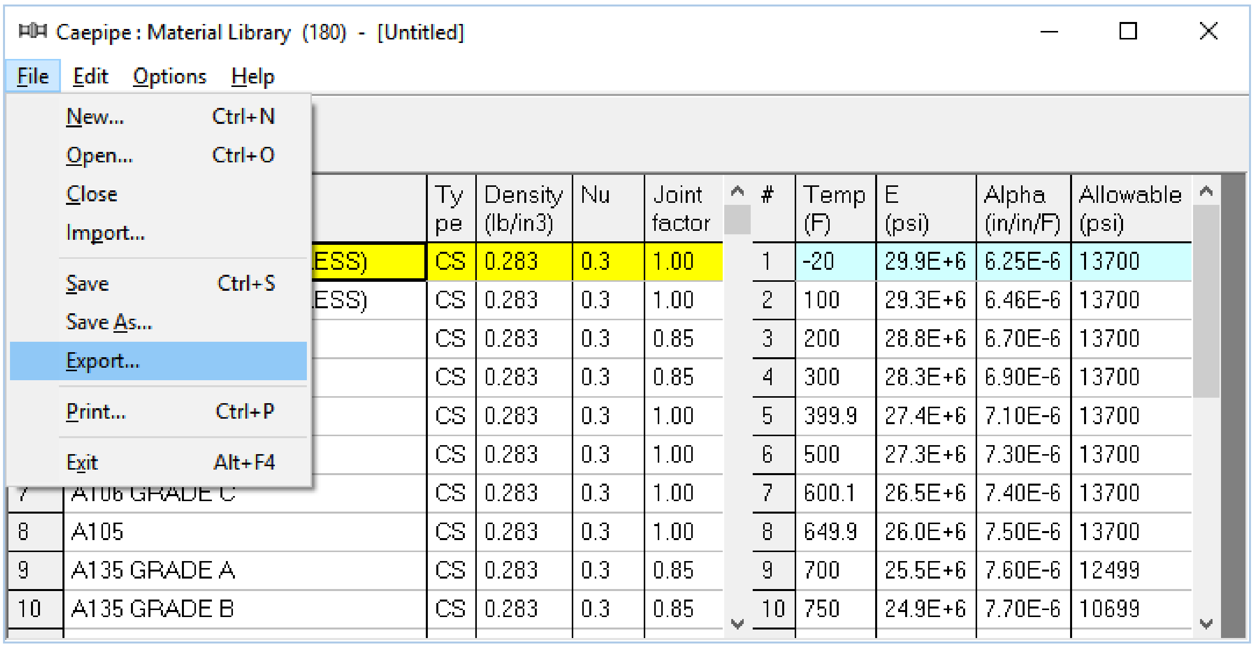
**MATERIAL Example (English units)**

```
OPTIONS
B311
MATERIAL
A53 GRADE A (SEAMLESS),0.283,0.300,1.00,1.00,CS,29994
A53 GRADE A (SEAMLESS),-20,29.9E+6,6.25E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),100,29.3E+6,6.46E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),200,28.8E+6,6.70E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),300,28.3E+6,6.90E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),399.9,27.4E+6,7.10E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),500,27.3E+6,7.30E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),600.1,26.5E+6,7.40E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),649.9,26.0E+6,7.50E-6,13700,0,0,0,0
A53 GRADE A (SEAMLESS),700,25.5E+6,7.60E-6,12499,0,0,0,0
A53 GRADE A (SEAMLESS),750,24.9E+6,7.70E-6,10699,0,0,0,0
A53 GRADE A (SEAMLESS),800.1,24.2E+6,7.80E-6,9000,0,0,0,0
```

## Export

CAEPIPE can export material properties to a batch text file with the extension .mlb (material library batch file). The text file may be edited using a text editor / using MS Excel. The edited text file may be read back into CAEPIPE by using the Import feature.

To export the material properties, select the menu command File > Export from the Material Library Layout window.



The Export Material Library dialog is shown. Click on the Export button to write to the batch file.