Readme Supplement

for

CAEPIPE Version 6.0

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Annexure A

ANSI B31.x Code Compliance

B31.1 (2007)

Allowable Pressure

For straight pipes and bends, the calculation of allowable pressure is based on Eq. 4 of para.104.1.2.

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

where

P_a = allowable pressure

SE = allowable stress, given in Appendix A of B31.1 (2007) Code, where

E = weld joint efficiency factor or casting quality factor

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

Y = 0.4 (Pressure coefficient), for cast iron and non-ferrous materials. For other materials, refer to Table 104.1.2(A) – Values of 'Y'.

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

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 104.3.3.

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

where

θ = miter half angle

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Eq. 11A 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, P2 and P3

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

Occasional Stress

The stress (S_{Lo}) due to occasional loads is calculated from Eq. 12A 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 due to occasional loads

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

Expansion Stress

The stress (S_E) due to thermal expansion is calculated from Eq. 13A 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)

$f =$ 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 = allowable stress at cold temperature

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

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

Note:

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

Allowable Internal Pressure

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

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

where

P_a = allowable pressure

S = allowable stress as provided in para. 302.3.1 (a)

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

W = Weld Joint Strength Reduction Factor from para. 302.3.5 (e)

W = 1.0 for all materials with Tempreature <= 950^0 F (or 510^0 C)

W = 0.5 for all materials with Tempreature >= 1500^0 F (or 815^0 C) and the value of W is linearly interpolated between 950^0 F and 1500^0 F or 510^0 C and 815^0 C.

t_a = available thickness for pressure design

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

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

t_n = nominal pipe thickness

D = outside diameter

d = inside diameter

Y = Pressure coefficient from Table 304.1.1, valid for t_a < D/6, and

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

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

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

where

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

R = effective bend radius of the miter (see para. 304.2.3 of code for definition)

For widely spaced miter bends, the allowable pressure is calculated using Eq. (4c) from para. 304.2.3 as

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

where

θ = miter half angle

Sustained Stress

The stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para 302.3.5(c).

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

where

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

D = outside diameter

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

t_s = nominal thickness – corrosion allowance

$i_i =$ 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_m = corroded section modulus; for reduced outlets, effective section modulus

S_h = hot allowable stress

W = defined above under “Allowable Internal Pressure”

Sustained plus Occasional Stress

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

For temp <= 427^0 C or 800^0 F

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

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

$$S_{Lo} = \frac{P_{peak} D}{4t_s} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_m}\right]_{sust} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z_m}\right]_{occasional} \leq 0.9 W S_y$$

where

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

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

S_y = yield strength at maximum temperature and

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

Expansion Stress

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

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

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

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

$f =$ stress range reduction factor from Eq. (1c) of para. 302.3.5 (d) = $6N^{-0.2}$

where f >= 0.15 and f <= 1.0

S_c = allowable stress at cold temperature

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

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

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

Note:

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

Allowable Pressure

For straight pipes and bends (including closely spaced and widely spaced miter bends), the allowable pressure is calculated from paras 404.1.2. and 404.2.1.

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

where

P_a = allowable pressure

S = allowable stress = 0.72 x E x specified minimum yield strength as per para. 402.3.1(a)

In setting the design factor 0.72, due consideration has been given to and allowance has been made for the under-thickness tolerance and maximum allowable depth of imperfections provided for in the specifications approved by the code.

E = joint factor (input as material property) from para. 402.3.1(a).

t_a = available thickness for pressure design

= t_n - corrosion allowance

(Any additional thickness required for threading, grooving, erosion, corrosion, etc., should be included in corrosion allowance; mill tolerance is indirectly included in allowable stress S above via the design factor 0.72)

t_n = nominal pipe thickness

D = outside diameter

Sustained Stress (Restrained and Unrestrained lines)

Restrained lines are those portions of the piping, which are buried in soil and are with substantial axial restraint.

Unrestrained lines are those portions of piping system, which are above ground and are not buried in soil and are without substantial axial restraint.

The sustained stress (S_L) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from para. 402.3.2(d) and para. 419.6.4(c), for both restrained and unrestrained lines

$$S_L = \frac{PD}{4t_n} + \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z} \leq 0.75 S_A$$

where

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

D = outside diameter

t_n = nominal wall thickness of pipe

$i_i =$ stress intensification factor under in-plane bending

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

$M_i =$ 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

S_A = allowable thermal stress range = k x specified minimum yield strength

where,

k = 0.90 for restrained lines from para 402.3.2 (c) and

k = 0.72 for unrestrained lines from para 402.3.2 (c).

Occasional Stress (for both Restrained and Unrestrained lines)

The stress (S_{Lo}) due to occasional loads is calculated from para. 402.3.3(a) 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 to occur concurrently.

$$S_{Lo} = \frac{P_{peak} D}{4t_n} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z}\right]_{sust} + \left[\frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2 + (M_t)^2}}{Z}\right]_{occasional} \leq 0.80 S_y$$

where

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

where P = maximum pressure, as defined above (under Sustained Stress)

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

S_y = specified minimum yield strength as given in Table 402.3.1(a)

Expansion Stress (Restrained and Unrestrained lines)

Unrestrained Lines

The stress (S_E) due to thermal expansion is calculated from para. 419.6.4(c) for unrestrained lines.

$$S_E = \sqrt{S_b^2 + 4S_t^2} \leq 0.72 S_y$$

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 (based on nominal dimensions); for reduced outlets, effective section modulus (Z_e), where

$$Z_e = \pi r_b^2 t_e$$

t_e = effective branch thickness, lessor 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

Restrained Lines

(i) When (algebraically) maximum operating temperature T_{opr} > reference temperature T_{ref}

The net axial compressive stress (S_{axial}) due to the combined effects of temperature rise and the fluid pressure is calculated from para. 419.6.4(b) for restrained lines

$$S_{axial} = E_{ref}\alpha(T_{opr} - T_{ref}) - \nu S_{\theta}$$

with S_{axial} (as computed from the above equation) should be greater than 0.0 and where,

S_{θ} = hoop stress due to fluid pressure = $\dfrac{PD}{2t_n}$

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

D = outside diameter

t_n = nominal thickness

T_{ref} = temperature at time of installation = reference temperature in CAEPIPE

T_{opr} = algebraic maximum of CAEPIPE input temperatures T_1, T_2 and T_3 (with $T_{opr} > T_{ref}$)

E_{ref} = modulus of elasticity of steel at reference temperature

α = linear coefficient of thermal expansion at the concerned operating temperature

ν = nu = Poisson's ratio = 0.30 for steel

Then, as per para. 419.6.4(b), the equivalent tensile stress S_E (using Mohr's circle formulation) due to thermal expansion of restrained lines when maximum $T_{opr} > T_{ref}$ and $S_{axial} > 0$ is

$$S_E = S_{axial} + S_{\theta}$$

(ii) When (algebraically) minimum operating temperature T_{opr} < reference temperature T_{ref}

The net axial tensile stress (S_{axial}) due to the combined effects of temperature drop and the fluid pressure is calculated from para.419.6.4(b) for restrained lines

$$S_{axial} = \left| E_{ref}\alpha(T_{opr} - T_{ref}) - \nu S_{\theta} \right|$$

where,

T_{opr} = algebraic minimum of CAEPIPE input temperatures T_1, T_2 and T_3 (with $T_{opr} < T_{ref}$)

Then, as per para. 419.6.4 (b), the equivalent tensile stress S_E due to thermal contraction of restrained lines when minimum $T_{opr} < T_{ref}$ is

$$S_E = S_{axial}$$

Then, as per para 402.3.2(c) and para. 419.6.4(b) the thermal stress S_E should comply with

$$S_E \leq 0.90 S_y$$

S_y = specified minimum yield strength as given in Table 402.3.1(a)

Note: Maximum of the two S_E values calculated using (i) and (ii) above will be shown as Expansion Stress S_E in CAEPIPE stress results.

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

Lastly, for restrained lines, axial force will not be included in the above S_E calculations even when the option "Include axial force in stress calculations" is turned ON in the Options->Analysis menu.

Annexure B

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

Particulars	**Allowable Pressure**	**Pipe Weight**	**Sustained Stress**	**Expansion Stress**	**Occasional Stress**
B31.1 (2007)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus
B31.3 (2006)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness - Corrosion allowance	-	Nominal Thickness – Corrosion allowance
Section Modulus used	-	-	*Corroded* Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	*Corroded* Section Modulus; For Branch, effective section modulus
B31.4 (2006)					
Pipe Thickness used	Nominal Thk – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch effective section modulus
B31.5 (2001)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion	Nominal Thickness	Nominal Thickness	-	Nominal Thickness

Particulars	Allowable Pressure	Pipe Weight	Sustained Stress	Expansion Stress	Occasional Stress
	allowance				
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus
B31.8 (2003)					
Pipe Thickness used	Nominal Thk. x (1-mill tolerance/100) – Corrosion allowance	Nominal Thickness	Nominal Thickness	-	Nominal Thickness
Section Modulus used	-	-	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus	Uncorroded Section Modulus; For Branch, effective section modulus

Note:

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

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

3. Corroded section modulus = section modulus calculated using the "corroded thickness"

Corroded thickness = nominal thickness – corrosion allowance

4. Effective section modulus = section modulus calculated using effective branch thickness, which is lesser of $i_i t_b$ or t_h
where, t_b = branch nominal thickness, t_h = header nominal thickness, i_i = in-plane SIF at branch