3.3.7 EQUIVALENT TENSILE STRESS CATEGORY

AutoPIPE calculates the Equivalent Tensile stress (ASME B31.4 (2006) – 419.6.4 (b), and ASME B31.4 (2009 and onwards) – 402.7) using maximum shear stress theory (Tresca stresses) which includes bending, torsion and shear stresses using the following equation:

$$S_{eq} = Max[ABS(\sigma_1), ABS(\sigma_2), ABS(\sigma_1 - \sigma_2)]$$

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Where:

S_{eq} = Equivalent tensile stress, psi

σ_1 = Maximum principle stress, psi

$$\sigma_1 = \frac{S_H + S_L}{2} + \sqrt{\left(\frac{S_H - S_L}{2}\right)^2 + \tau^2}$$

Where:

S_H = Hoop pressure stress, psi

$$S_H = \frac{P \cdot D_o}{2 \cdot t} - P \cdot Y_{fac}$$

Where:

P = Design pressure, psi

$$P = P_{xx} \cdot f_{dp}$$

P_{xx} = Internal pressure at a given node for the selected pressure case (or temperature case if no explicit pressure case is defined in the combination), psi

f_{dp} = Design pressure factor (Result Model Option "Design pressure factor"), default = 1.00

D_o = Pipe outside diameter, in

t = Pipe wall thickness used for calculations, in

$t = t_n$ When the Result Model Option "Use nominal thickness" is checked, where t_n is the nominal pipe wall thickness (Pipe Properties dialog "Wall thickness" field)

$t = t_c$ When the Result Model Option "Use nominal thickness" is unchecked

$$t_c = t_n - c$$

t_n = Nominal pipe wall thickness (Pipe Properties dialog "Wall thickness" field)

c = Corrosion allowance (Pipe Properties dialog "Corrosion Allowance" field)

Y_{fac} = Y factor for hoop stress calculations (Result Model Option "Y factor"), default = 0.00

S_L = Longitudinal stress including pressure, gravity and expansion stresses, psi

$$S_L = S_P - S_{AX} + S_B$$

Where:

S_P = Longitudinal pressure stress, psi

$$S_P = \frac{P \cdot A_p}{A_s}$$

Where:

P = Design pressure, psi

$$P = P_{xx} \cdot f_{dp}$$

P_{xx} = Internal pressure at a given node for the selected pressure case (or temperature case if no explicit pressure case is defined in the combination), psi

f_{dp} = Design pressure factor (Result Model Option "Design pressure factor"), default = 1.00

A_p = Pressure area of pipe, in^2

$$A_p = \frac{\pi}{4} \cdot {d_i}^2$$

$d_i = D_o - 2 \cdot t_n$ Independent of any Result Model Option

A_s = Cross sectional area of pipe, in^2

$$A_s = \frac{\pi}{4} \cdot ({D_o}^2 - {d_i}^2)$$

$d_i = D_o - 2 \cdot t_n$ Independent of any Result Model Option

When pressure extension analysis is performed, AutoPIPE will subtract the stress due to axial pressure force from the longitudinal pressure stress as shown below:

$$S_{Px} = S_P - \frac{F_{axp}}{A_s} \cdot f_{dp}$$

Where:

S_{Px} = Longitudinal pressure stress including the effects of axial pressure extension, psi (S_P on the right hand side of the equation above is longitudinal pressure stress calculated in the section above)

S_P = Longitudinal pressure stress (longitudinal pressure stress calculated in the section above), psi

F_{axp} = Axial force due to pressure extension, lbf

A_s = Cross sectional area of pipe, in^2

$$A_s = \frac{\pi}{4} \cdot (D_o{}^2 - d_i{}^2)$$

$d_i = D_o - 2 \cdot t_n$ Independent of any Result Model Option

f_{dp} = Design pressure factor (Result Model Option "Design pressure factor"), default = 1.00

Note: Any other axial affects, i.e. concentrated force, added to a pressure case (provided the same pressure case is being used for axial forces), will also be included in the axial force due to pressure.

S_{AX} = Axial stress due to gravity and thermal axial forces, psi

$$S_{AX} = \frac{F_{axl}}{A_s}$$

Where:

F_{axl} = Axial force due to gravity and expansion, lbf

A_s = Cross sectional area of pipe, in^2

$$A_s = \frac{\pi}{4} \cdot (D_o{}^2 - d_i{}^2)$$

$d_i = D_o - 2 \cdot t_n$ Independent of any Result Model Option

Note that AutoPIPE considers compressive axial pipe force as negative e.g. if the axial pipe forces due to gravity and expansion are compressive, then the stresses due to gravity and expansion will be added to the Longitudinal Pressure stress (causing compressive axial pipe force). Otherwise, if the axial stress due to gravity and expansion forces is tensile in nature, then this stress will be subtracted from the Longitudinal Pressure Stress.

S_B = Bending stress due to gravity and thermal moments, psi

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

Where:

i_i = In-plane SIF

M_i = In-plane moment, lbf-in

i_o = Out-plane SIF

M_o = Out-plane moment, lbf-in

Z = Section modulus, in^3

$$Z = \frac{\pi}{32} \cdot \frac{({D_o}^4 - {d_i}^4)}{D_o}$$

$d_i = D_o - 2 \cdot t_n$ Independent of any Result Model Option

Notes:

1. AutoPIPE calculates three values for Longitudinal stress S_L around the pipe taking in to account maximum tensile and maximum compressive bending stresses i.e. Maximum longitudinal stress (bending stresses causing normal stress in the same direction as axial stresses), Longitudinal stress at neutral axis (no bending stress), and Minimum Longitudinal stress (bending stresses causing normal stress in the opposite direction to axial stresses). This results in a set of three principal stresses, which are then evaluated for maximum stress.

τ = Shear stress due to torsional moment and direct shear stresses, psi

$$\tau = \frac{M_t}{2 \cdot Z} + 2 \cdot \frac{\sqrt{F_i^2 + F_o^2}}{A_s}$$

Where:

M_t = Torsional moment due to gravity and expansion, lbf-in

Z = Section modulus, in^3

$$Z = \frac{\pi}{32} \cdot \frac{({D_o}^4 - {d_i}^4)}{D_o}$$

$d_i = D_o - 2 \cdot t_n$ Independent of any Result Model Option

F_i = In-plane shear forces due to gravity and expansion, lbf

F_o = Out-plane shear forces due to gravity and expansion, lbf

A_s = Cross sectional area of pipe, in^2

$$A_s = \frac{\pi}{4} \cdot (D_o{}^2 - d_i{}^2)$$

$d_i = D_o - 2 \cdot t_n$ When Result Model Option “Use nominal thickness” is checked

$d_i = D_o - 2 \cdot t_r$ When Result Model Option “Use nominal thickness” is unchecked

Notes:

1. Torsional moment is constant around the pipe cross section, whereas the shear forces vary around the cross section. The variance of shear force is taken in to account in AutoPIPE calculations.
2. Torsional stress is only included in the calculations when the Result Model Option “Include torsion” is checked
3. Shear stresses from in-plane and out-plane forces are dependent on the Result Model Option “Direct shear (N/R/A)” option.

σ_2 = Minimum principle stress, psi

$$\sigma_2 = \frac{S_H + S_L}{2} - \sqrt{\left(\frac{S_H - S_L}{2}\right)^2 + \tau^2}$$

Where all the terms remains the same as defined in the section above.

The allowable value for Equivalent Tensile 2 stress is calculated as below:

$$A_{eq2} = 0.9 \cdot S_{ym}$$

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Where:

A_{eq2} = Allowable equivalent tensile stress, psi

S_{ym} = Specified minimum yield strength (Pipe Properties dialog “Minimum yield” field), psi

<u>AutoPIPE default code combination:</u>

Combination name: Max Equiv.: GRTn{m}

Where Tn represents the nth thermal case for the analysis set. {m} in the combination name represents the analysis set number i.e. for first analysis set and thermal load T1, the combination name will be Max Equiv.: GRT1{1}

Category: Eq Tensile

Output report column “Type”: EQTN

Notes:

1. Longitudinal pressure calculations always use $P*A_P/A_S$ formula for Equivalent Tensile stress calculation