INL/CON-24-76392-Revision-0

Evaluation of proposed Section III Division 5 Class B rules: Piping example problem

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Changing the World's Energy Future

Heramb Prakash Mahajan

Idaho National Laboratory

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Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

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Heramb Mahajan
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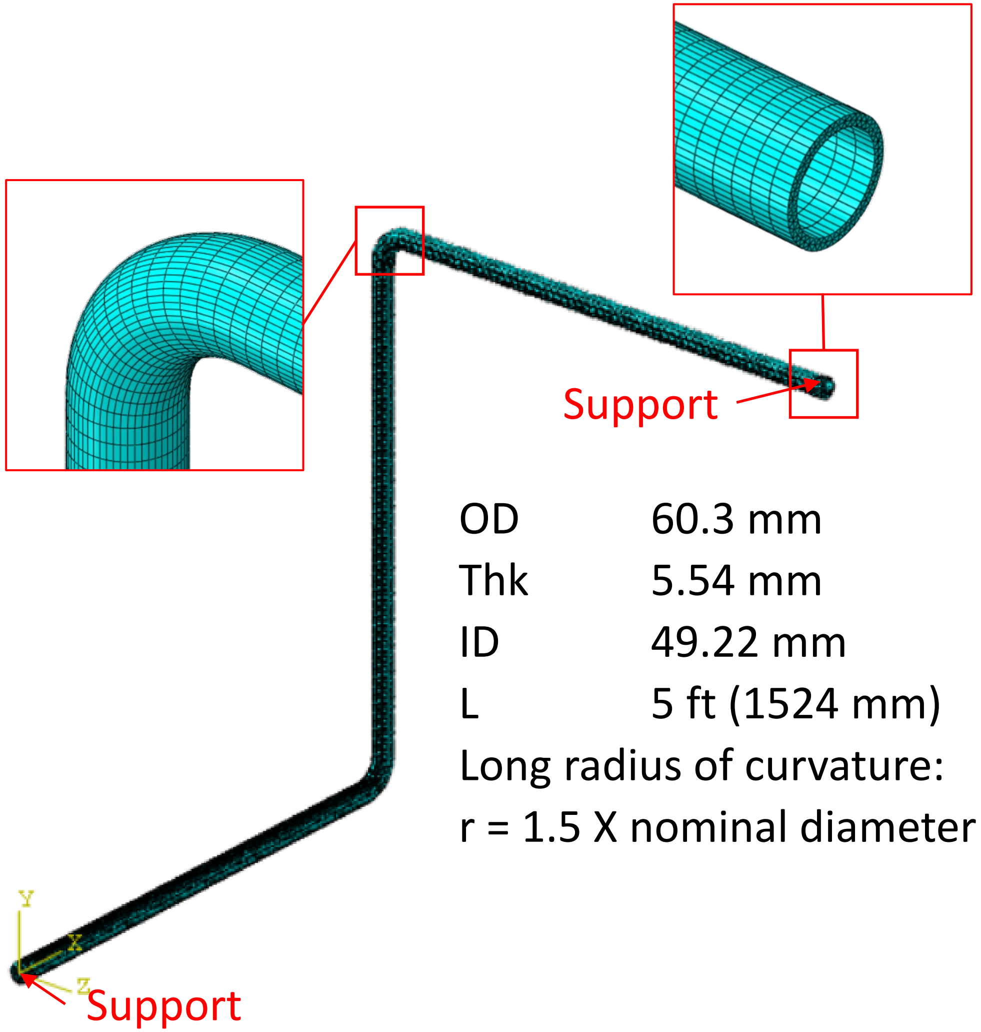
Evaluation of proposed Section III Division 5 Class B rules: Piping example problem

Disclaimer

Results presented in this report are preliminary in nature and shall be used only for understanding purposes. The methodology and procedure discussed here may change in future.

Problem statement – Z pipe Geometry and model

- Piping dimensions (2" Schedule 80 ASTM A312)
- 3D elements quadratic displacements
- Rotation along three axes and out-of-plane motion is restrained on the face of pipe at both supports
- Small deformation assumption: Nonlinear geometry – Off

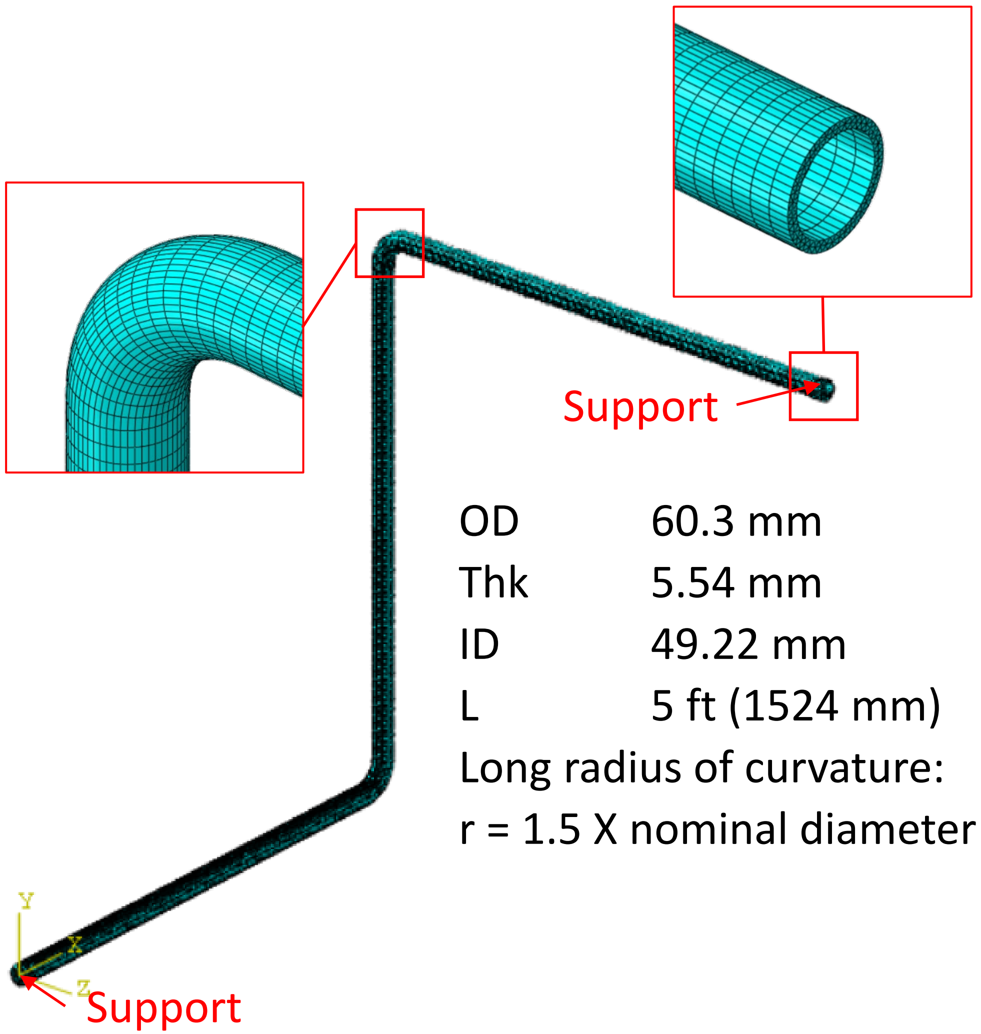


OD	60.3 mm
Thk	5.54 mm
ID	49.22 mm
L	5 ft (1524 mm)

Long radius of curvature:
r = 1.5 X nominal diameter

Problem statement – Z pipe
Loads and design inputs

- Design temperature: 1200F (648.89℃)
- Design pressure: 150 psi (1.03 Mpa)
- No self weight.
- No fluid weight.
- Design time t_{design}: 101,200 hours



OD	60.3 mm
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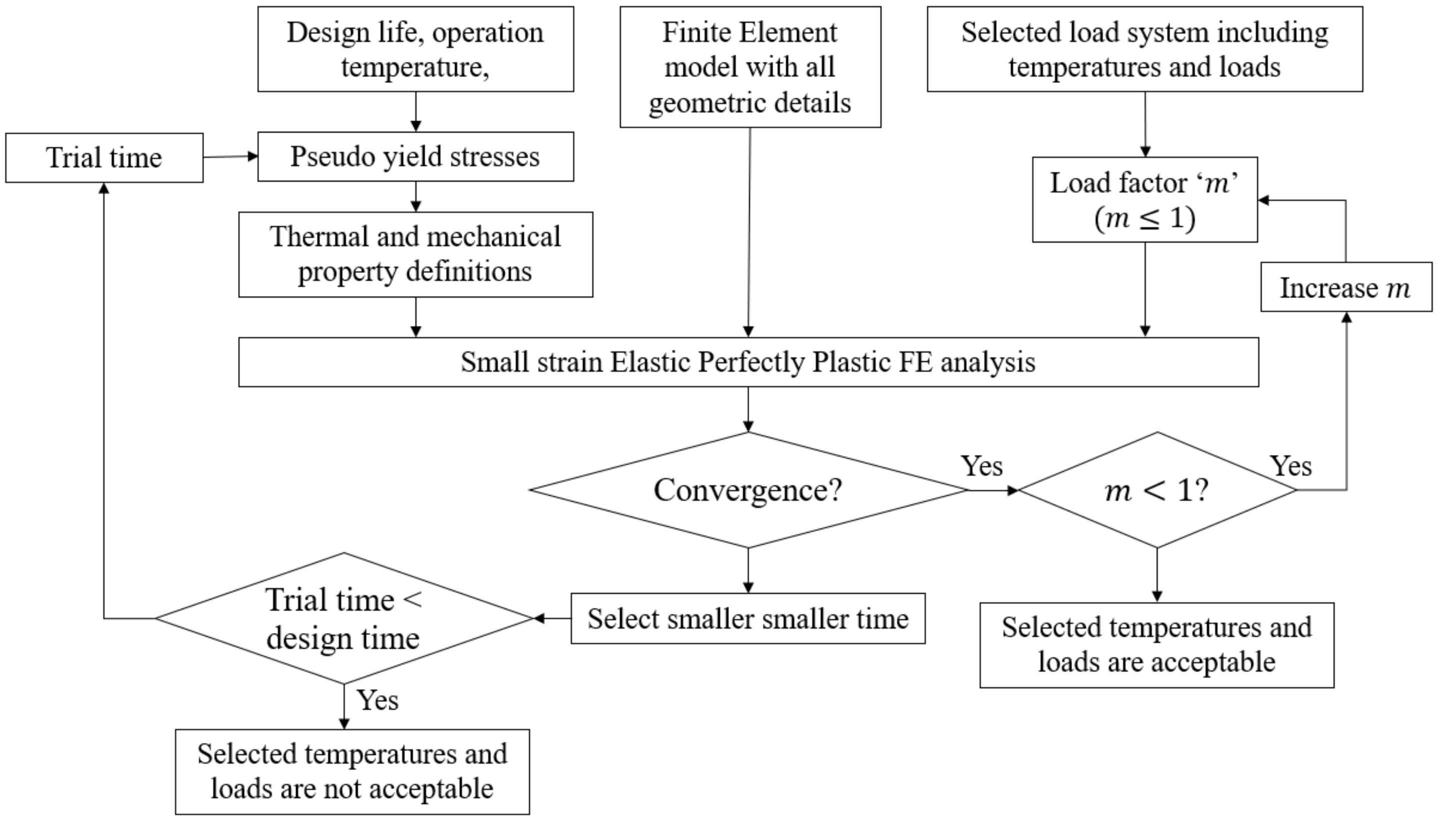
L	5 ft (1524 mm)

Long radius of curvature:
r = 1.5 X nominal diameter

Primary Stress Limit
Service level limit – Overview

1. FEA model + Elastic Perfectly Plastic material with pseudo yield stresses
2. Define loads during steady state operation
3. Conduct EPP analysis through factored load system to check against acceptance criteria



Primary Stress Limit
Pseudo yield stress calculation

1. Select trial time. $t_{trial} = 300{,}000$ hr (> t_{design}).
2. Calculate temperature dependent PSY = $\sqrt{3/4}\, S_{mt}(T(x), t_{trial})$

Table HBB-I-14.3B
S_{mt} — Allowable Stress Intensity Values, 1,000 psi, Type 316 SS — 30-YS, 75-UTS (30-YS, 70-UTS)
S_{mt} — Allowable Stress Intensity Values, MPa, Type 316 SS — 207-YS, 518-UTS (207-YS, 483-UTS)

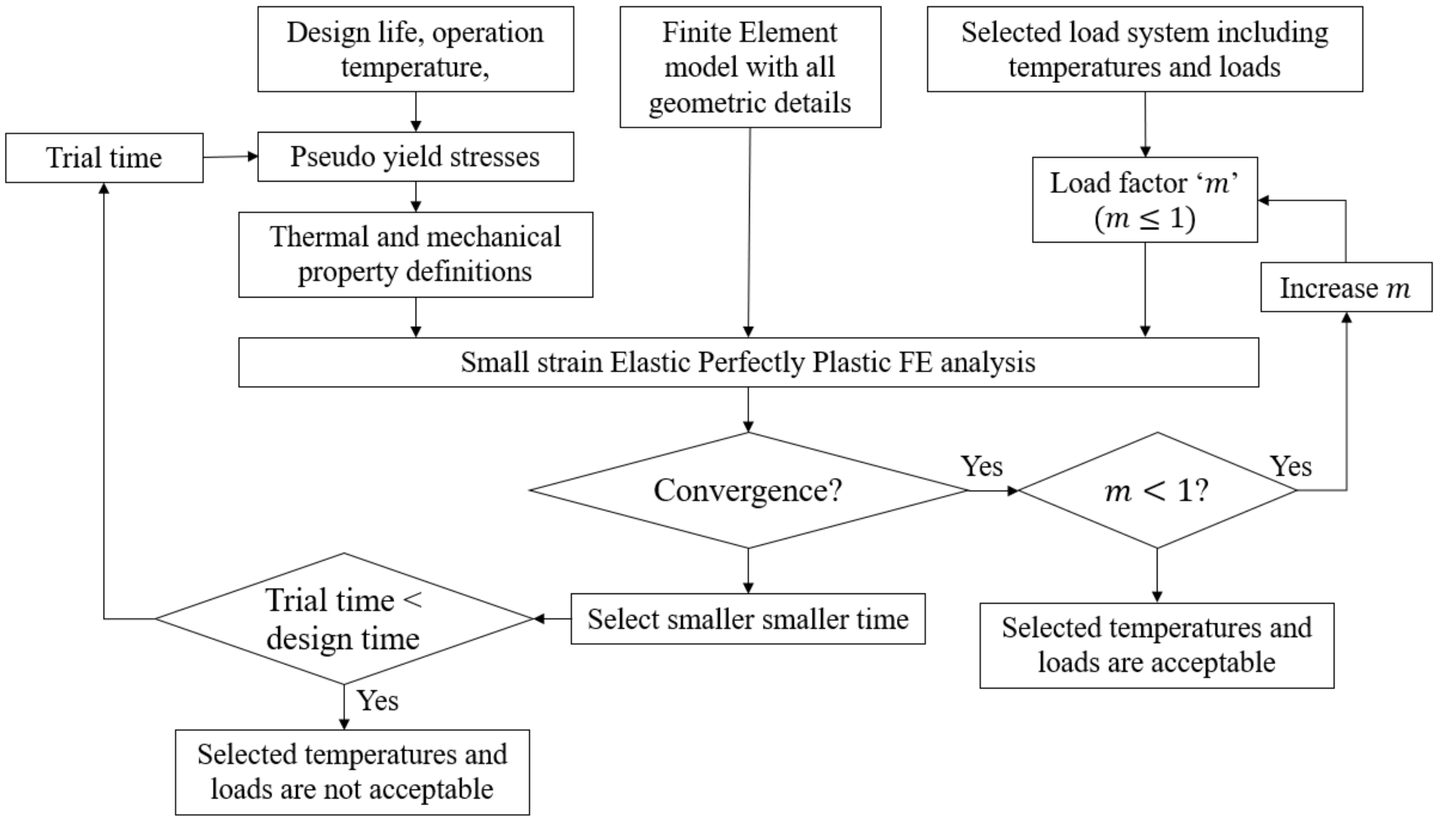
U.S. Customary Units

Temp., °F	1 hr	10 hr	30 hr	10^2 hr	3×10^2 hr	10^3 hr	3×10^3 hr	10^4 hr	3×10^4 hr	10^5 hr	3×10^5 hr
800	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
850	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7	15.7
900	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6
950	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
1,000	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4	14.0
1,050	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	14.9	12.5	10.7
1,100	14.8	14.8	14.8	14.8	14.8	14.8	14.8	13.9	11.5	9.5	7.8
1,150	14.7	14.7	14.7	14.7	14.7	14.2	13.0	10.9	8.9	7.2	5.9
1,200	14.6	14.6	14.6	14.2	12.4	10.6	9.4	8.3	6.9	5.5	4.5

PSY = $\sqrt{3/4} \times 4.5$ = 3.89 ksi = 26.87 MPa

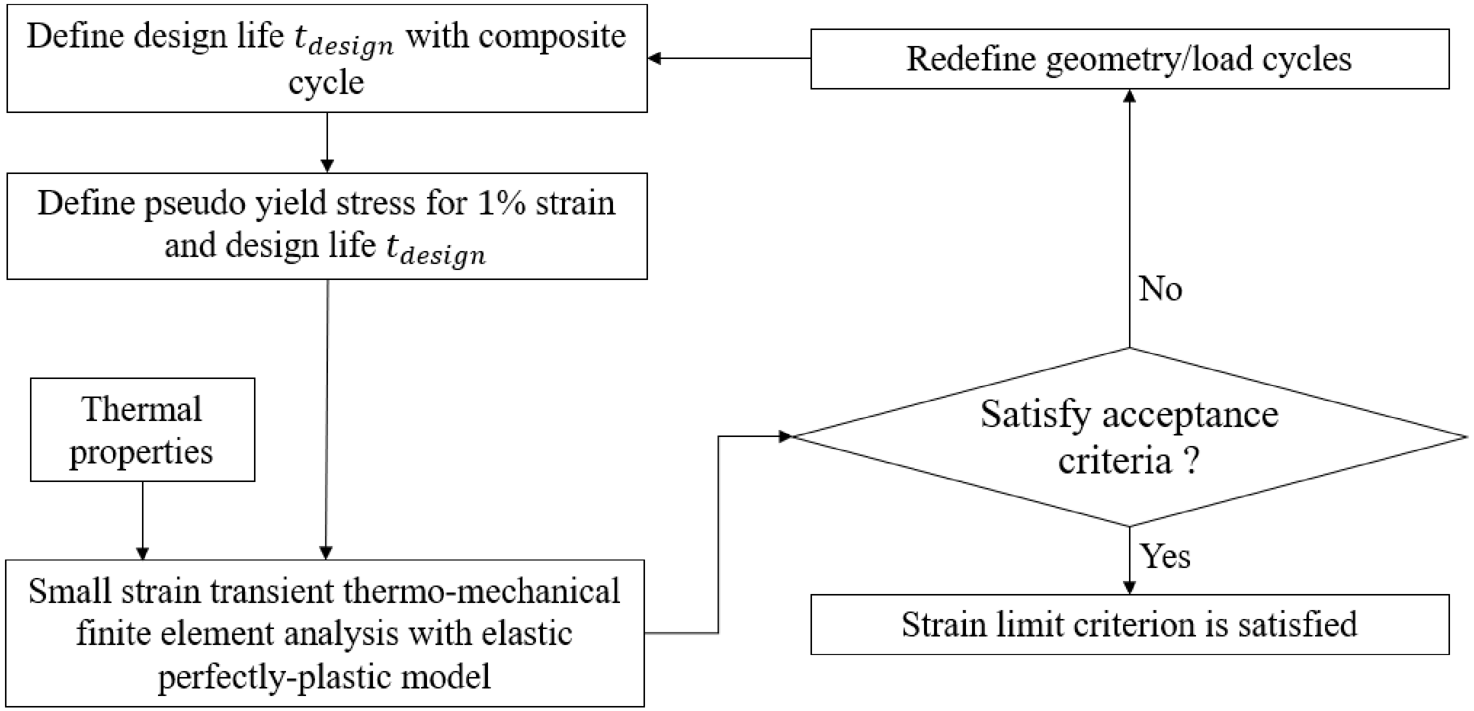
Primary Stress Limit
Factored load procedure

- Used factored load application procedure
- Solution converged for $m = 1$. (Primary stresses are low).



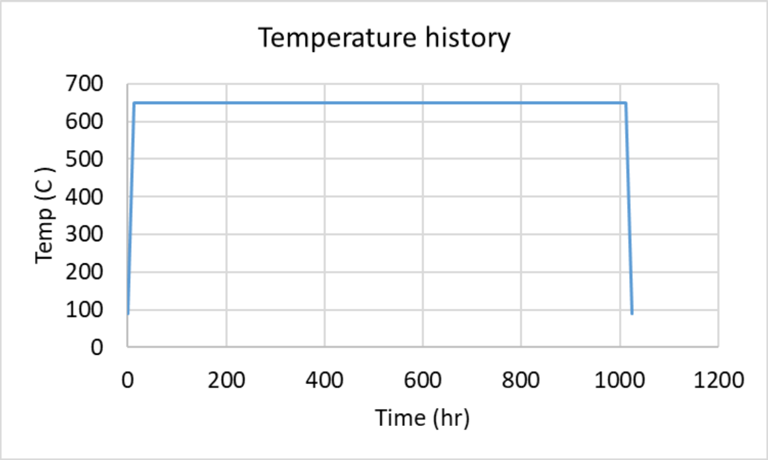
Strain limit evaluation Overview

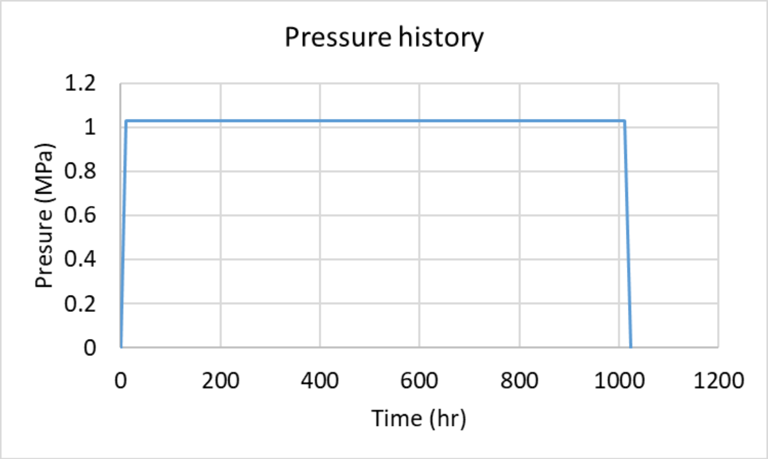
1. FEA model + EPP material with temperature dependent pseudo yield stresses.
2. Define composite load cycle
3. Conduct EPP analysis and check for ratcheting



Strain limit evaluation
Composite load cycle

- Composite load cycle shall include cycles from level A and B type loads.
- For this component, a simple cycle is selected as a composite cycle.
- Pressure and Temperature ramps to peak values in 12 hours, hold for 1000 hr at peak load, followed by ramp down of load.





Strain limit evaluation
Pseudo Yield Stress

PSY is minimum of following two:

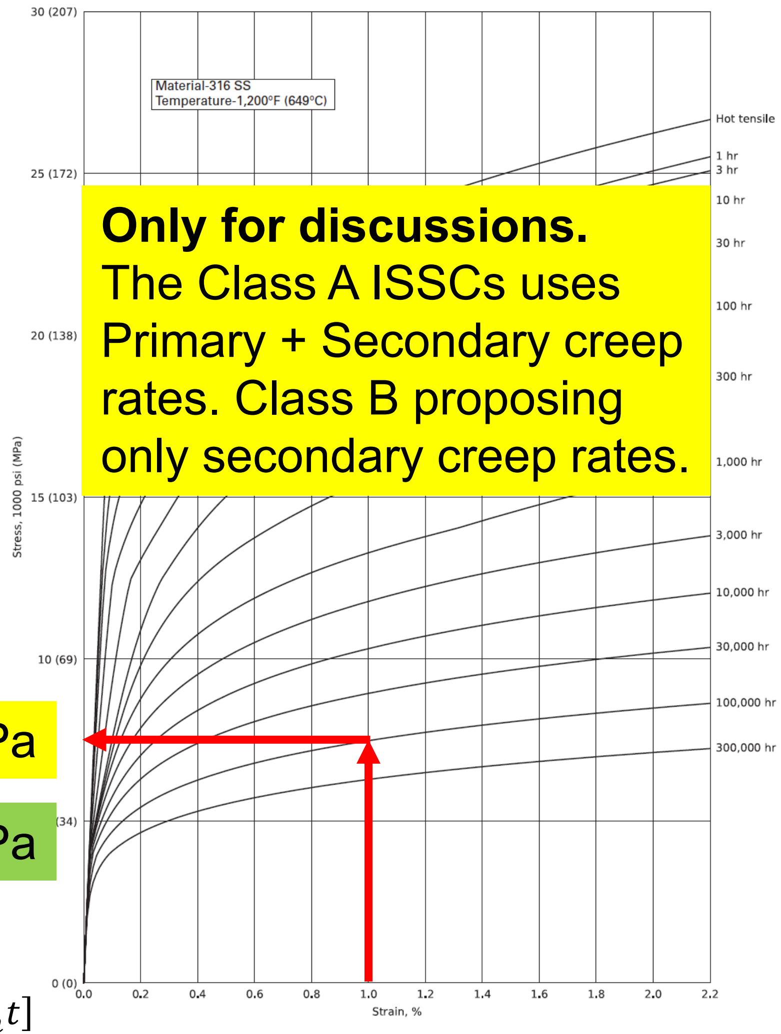
1. S_y (Section III.5 HBB-I-14.5)
2. Select target strain of 0.01 and get stresses from Isochronous Stress Strain Curves for design lifetime.

Table HBB-I-14.5
Yield Strength Values, S_y, Versus Temperature

	U.S. Customary Units					
	Stresses, ksi					
Temp., °F	304 SS	316 SS	Ni-Fe-Cr UNS N08810	$2^1/_4$Cr-1Mo	9Cr-1Mo-1V	Ni-Cr-Fe-Mo-Cb UNS N07718
RT						150.0
100						148.4
200						143.9
300						140.7
400						138.3
500						136.7
600						135.4
700	See Section II, Part D, Subpart 1, Table Y-1 for Values up to 1,000°F					134.3
750						133.7
800						133.1
850						132.4
900						131.5
950						130.5
1,000						129.4
1,050	15.2	16.8	15.5	22.4	36.6	128.0
1,100	14.9	16.6	15.5	20.7	32.7	...
1,150	14.5	16.3	15.5	18.6	28.6	...
1,200	14.1	16.0	15.5	16.1	24.2	...

S_y = 16 ksi = 110 MPa

Figure HBB-T-1832-11
Average Isochronous Stress–Strain Curves



Only for discussions.
The Class A ISSCs uses Primary + Secondary creep rates. Class B proposing only secondary creep rates.

Class A = 51.6 MPa

Class B = 53 MPa

Creep strain equations of 316H comparison

Class A $\varepsilon_c = \frac{1}{100}[\varepsilon_s(1-e^{-st}) + \varepsilon_r(1-e^{-rt}) + \dot{\varepsilon_m}t]$

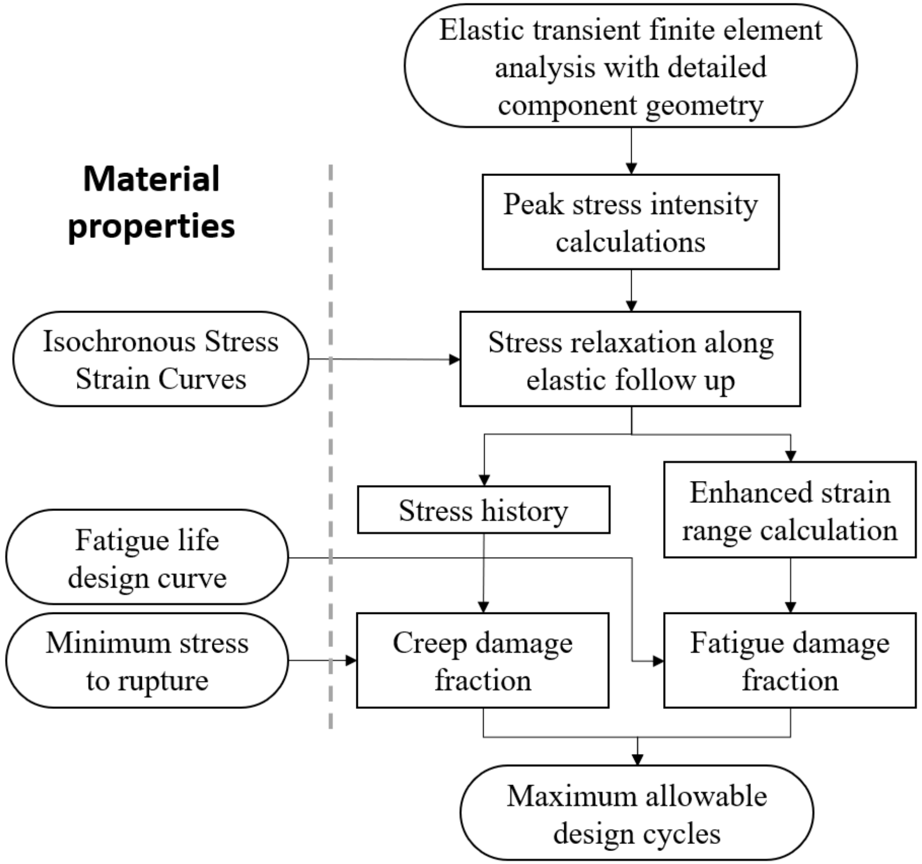
Class B $\varepsilon_c = \frac{1}{100}[\dot{\varepsilon_m}t]$

Strain limit evaluation
Strain limit criteria and ratcheting check

1. If ratcheting detected, the selected composite cycle fails.
2. All integration points showed elastic shakedown and no ratcheting was detected.

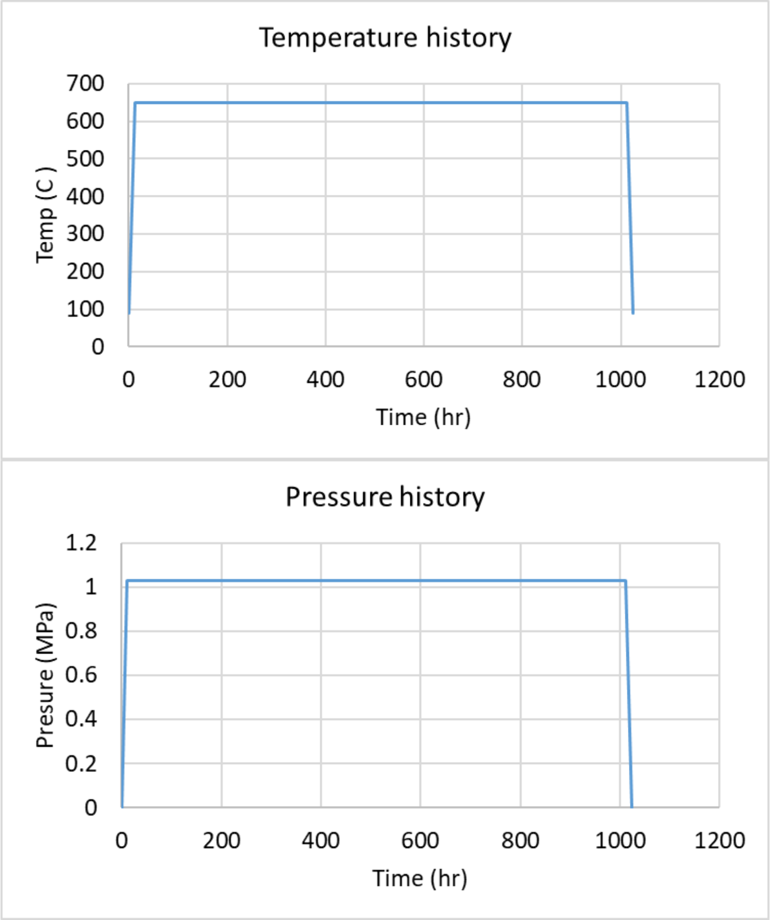
Creep fatigue damage evaluation Overview

1. Elastic FEA with load case
2. Alternating stresses from FEA
3. Stress relaxation calculation
   1. Stress history for creep damage
   2. Enhanced strain range for fatigue damage
4. Creep-fatigue damage evaluation



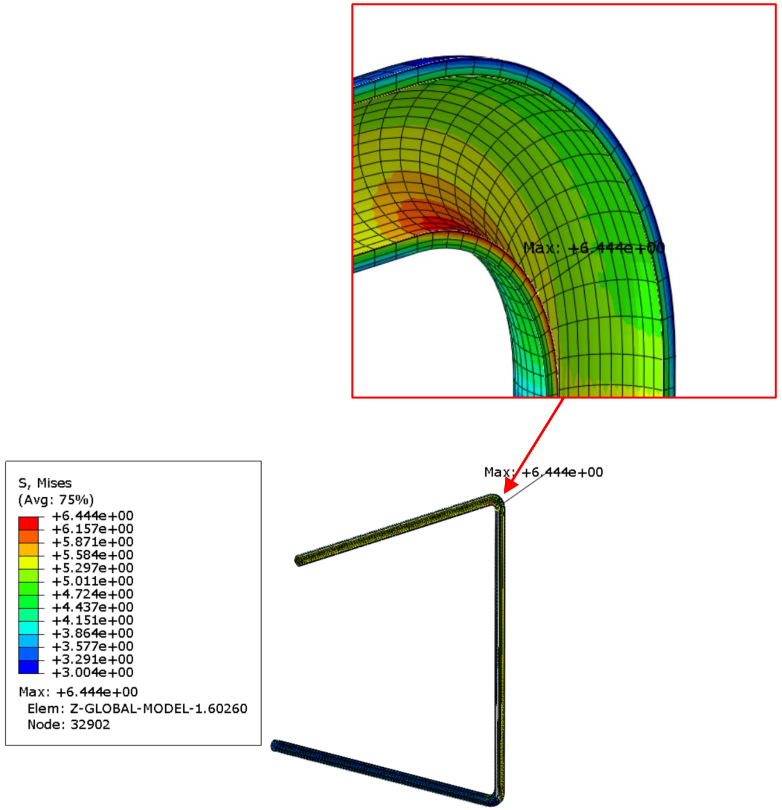
Creep fatigue damage evaluation Elastic FEA

- FEA model + temperature dependent elastic material properties
- Load case with a combination of level A and B cycles. Total number of cycles = 100. Load cycle period is 1024 hr (12 hr ramp up, 1000 hr dwell, and 12 hr ramp down)



Creep fatigue damage evaluation
Alternating stress calculations

1. Principal stress calculation ($\sigma_i(t)$)
2. Stress differences ($S_{ij}(t) = \sigma_i(t) - \sigma_j(t)$)
3. Stress intensity range $S_{r,ij} = \max|S_{ij}(t)| - \min|S_{ij}(t)|$
4. Alternating stress intensity $2S_{alt} = \max(S_{r,ij})$

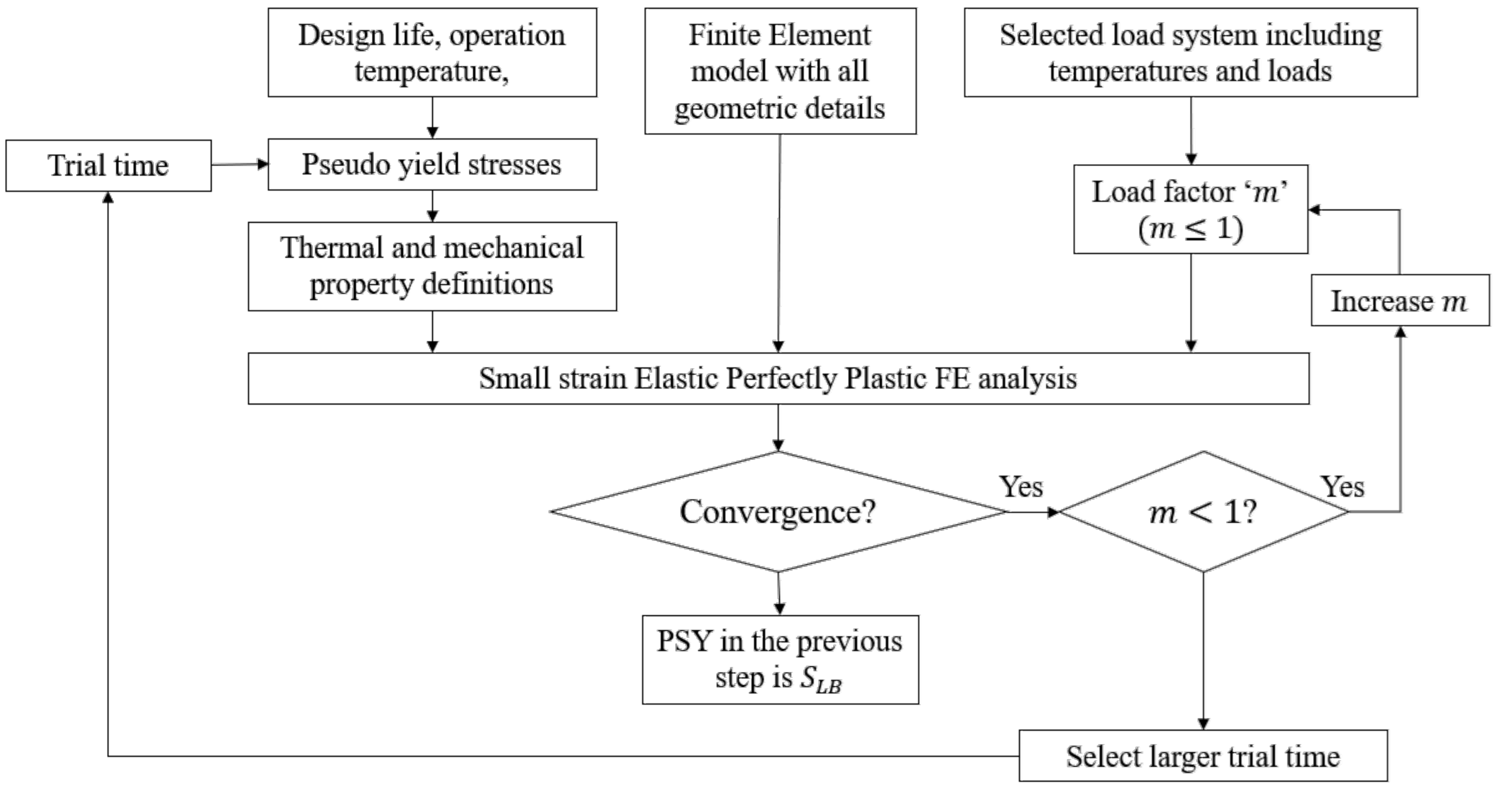


Stresses at critical location

	Principal stresses (Mpa)			Step 2 Sij (Mpa)			Step 3 Sr,ij (Mpa)		
Time (hr)	1	2	3	12	23	31	12	23	31
0	0	0	0	0	0	0	4.61	2.75	7.36
12	6.30	1.69	-1.06	4.61	2.75	-7.36			

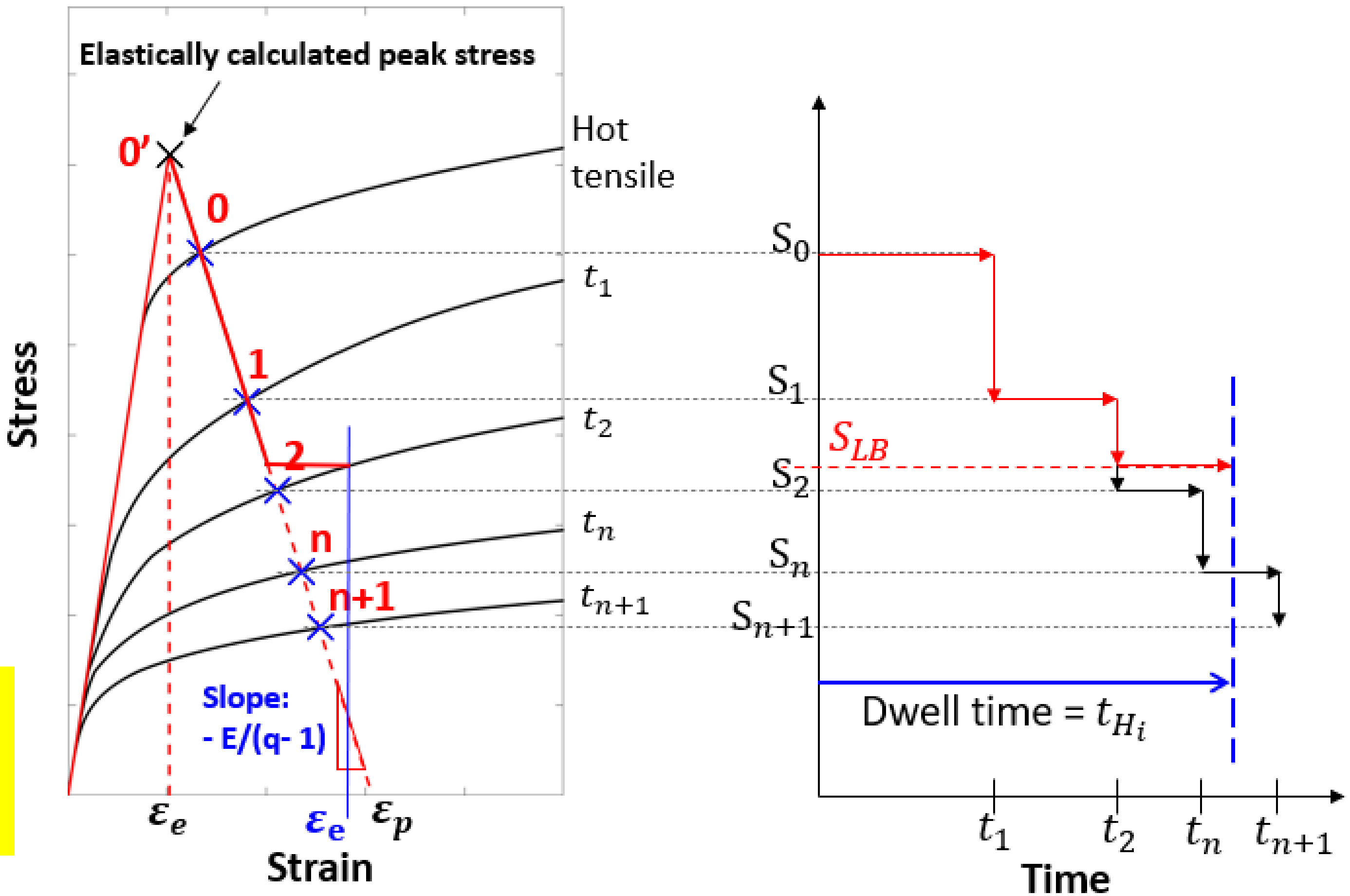
Creep fatigue damage evaluation
Lower bound stress

- Limit load calculations using the Primary stress limit approach
- The goal is to find maximum permissible design life for which PSY for the component results collapse.



Creep fatigue damage evaluation
Stress relaxation history

1. Draw ISSCs with only secondary creep rates.
2. Plot point ‘*o*’.
3. Draw line from point o with slope $-E/(q-1)$.
4. Stress intersection points [1,2, .. N+1] gives stress relaxation profile.



Stresses are too low for stress relaxation in this problem. Hence, no stress relaxation was detected in the selected component.

Creep fatigue damage evaluation
Damage fractions

Creep damage

- For the selected problem, stresses are low and stress relaxation is negligible. The creep damage fraction is calculated as follows:

$$D_c = N_{cyc} \times \frac{t_i}{T_d @ 7.36MPa} = 100 \times \frac{1012}{1.4482 \times 10^7} = 0.0069$$

Fatigue damage

- Strain range at the end of dwell time and corresponding cycles to failure , N_f:

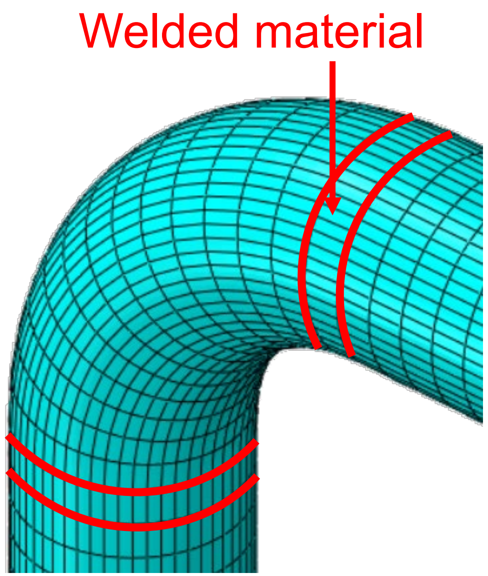
$$\varepsilon_t = 5.1 \times 10^{-5}, \qquad N_f = 7.22 \times 10^8$$

Fatigue damage fraction:

$$D_c = \frac{n}{N_f} = 1.38 \times 10^{-7}$$

Recommendations to consider for Z-pipe problem

- Increase primary stress
- Temperature gradient across thickness
- Consider level A and level B cycle types
- Consider welded material behavior near elbow and pipe joint
- Different support constraints?



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