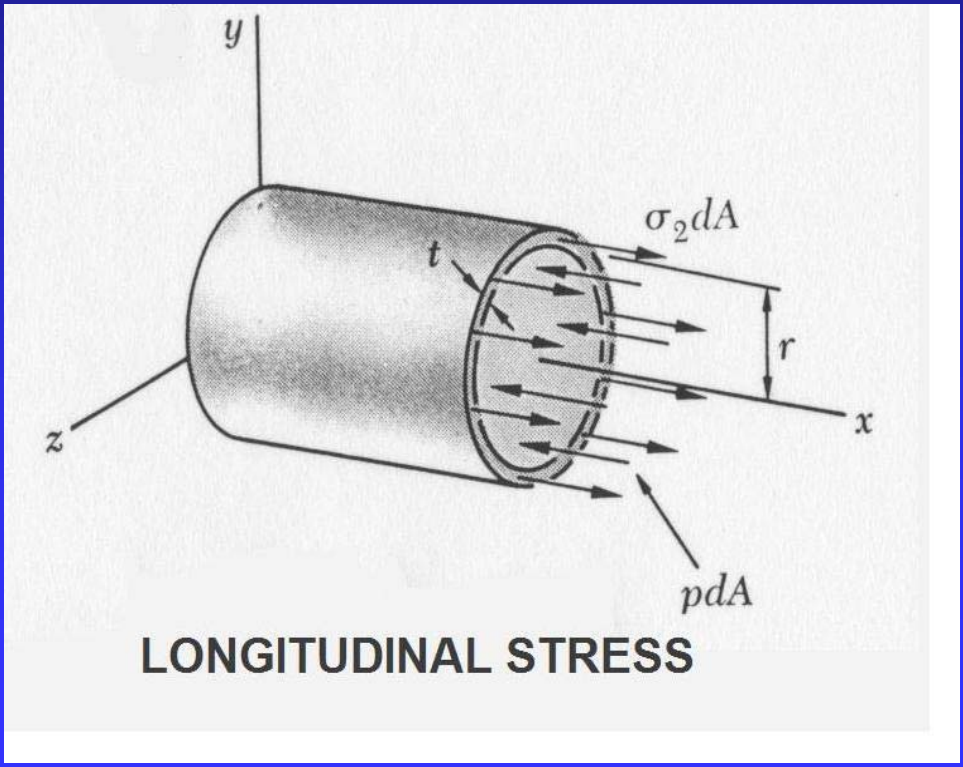
Thermomechanical Considerations and Calculations

- $\Delta L = \alpha_l \times \Delta Temp \times L_i$, where α_l is the linear coefficient of thermal expansion.
- Strain ε (Restrained Growth) = Δ L/L.
- Stress σ = Strain ε x E (Modulus of Elasticity).
- Keeping a line cooler will reduce stress on a line that is fixed at both ends.
- Maximum stress is located where the maximum strain is experienced.
- The relieving locations in the refractory lined system is in the flanges or the cold joints.

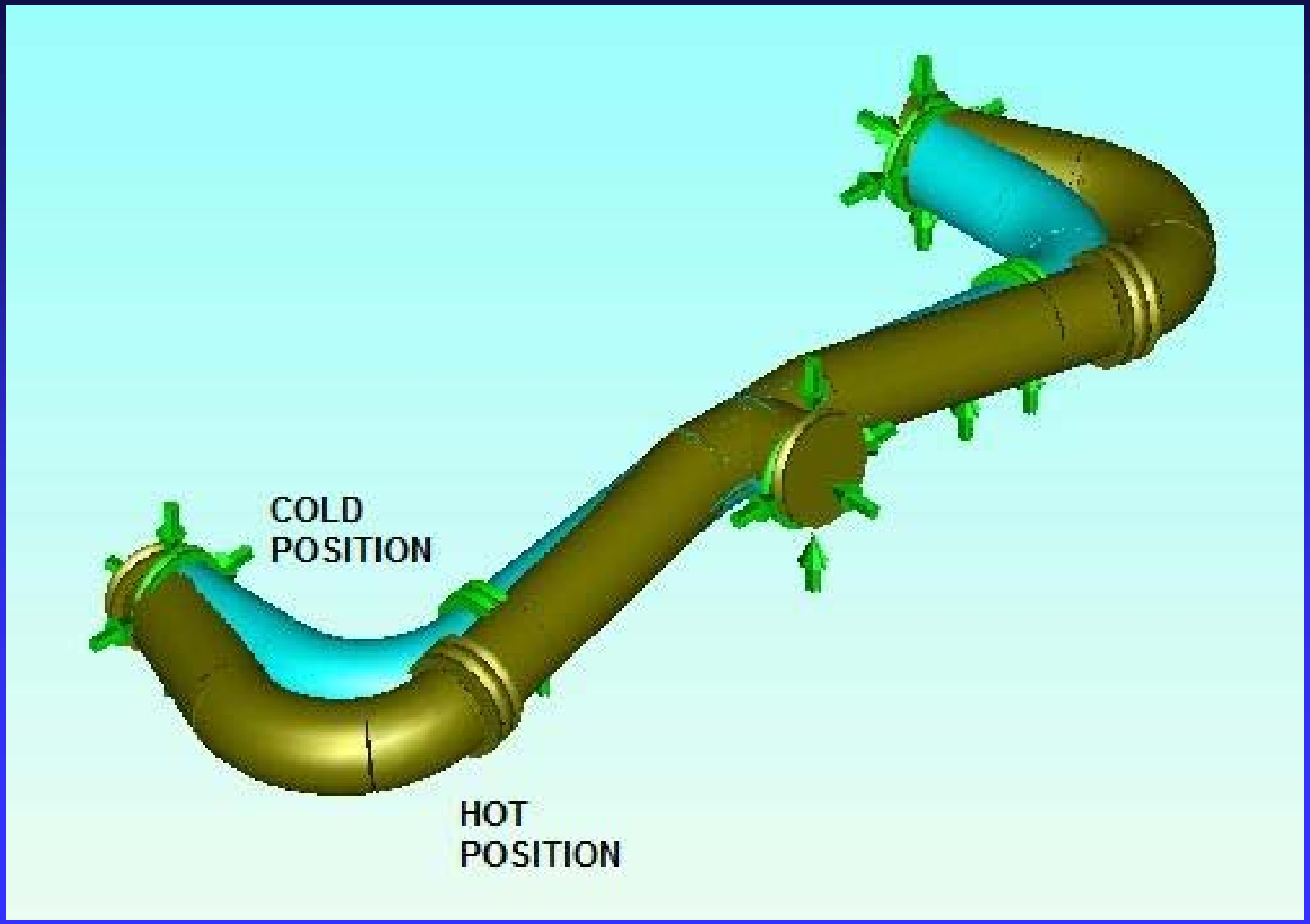
Longitudinal Stresses

- As a reminder, the purpose of the steel support/pipe is to provide the necessary tensile strength to constrain the lining in the heated condition. To accomplish this, the lining must insulate the steel structure from excessive temperatures in order to not have excessive longitudinal & radial stresses.



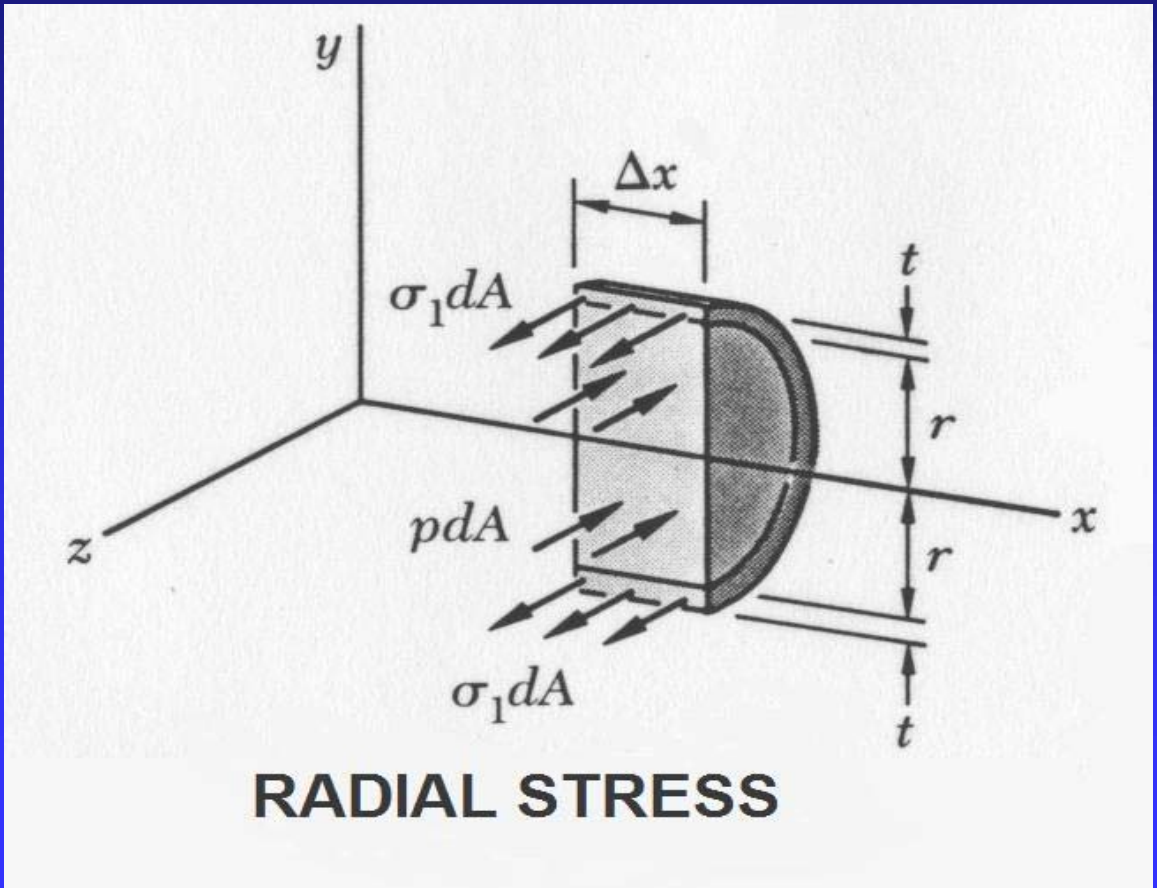
Pipe Stress Analysis (Longitudinal)

Caesar II Analysis



Radial Stresses

- Hoop (circumferential) stress of steel, where ideal case is in compression, i.e. yielding a positive value.



Radial Stress Considerations & Calculations in terms of Thermal Interference

- $\Delta\delta T = (\alpha_l \times R_L \times \Delta T_L) - (\alpha_s \times R_S \times \Delta T_S)$
  - where R_L = Average of inside & outside radius
    $\Delta T_L = [(T_{oper} + T_{steel})/2] - T_{ambient}$
    R_S = Steel Outside Radius
    $\Delta T_S = T_{steel} - T_{ambient}$
- If the result is a negative value then the implication is the lining is in tension and not compression, an undesirable state.
- Therefore, the steel is growing radially more than the lining. As a result the lining will not be constrained by the vessel, resulting in a loose lining, where gaps/voids develop at the interface of steel and lining.
- Gaps/ voids promote hot spots.

Components of Cylindrical Lining Expansion Stress

- The ideal scenario is to have the refractory lining expanding radially more than the steel shell, yielding a positive value signifying compression.