STRESS ANALYSIS FOR PROCESS PIPING

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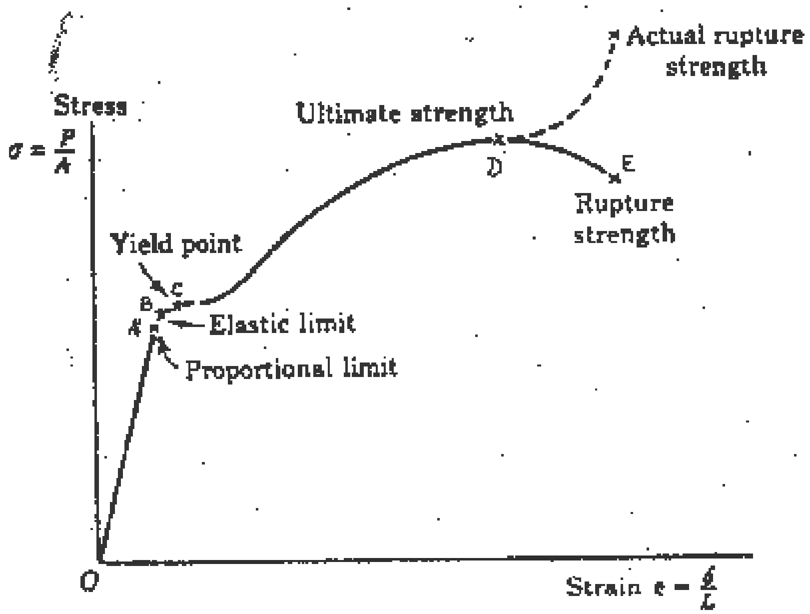
INTRODUCTION TO STRESS - STRAIN RELATIONSHIP

STRESS: Stress of a material is the internal resistance per unit area to the deformation caused by applied load.
STRAIN: Strain is unit deformation under applied load.



STRESS –STRAIN CURVE: It is a curve in which unit load or stress is plotted against unit elongation, technically known as strain.

- O– A represents the stress is directly proportional to strain, and point A is known ***proportional limit***.
- Point B represents ***elastic limit*** beyond which the material will not return to its original shape when unloaded but will retain a permanent deformation called permanent set.
- Point C is called ***yield point*** and is the point at which there is an appreciable elongation or yielding of the material without any corresponding increases of load.
- Point D is ultimate stress or ***ultimate strength*** of material.
- Point E is the stress at failure known as ***rupture strength***.

WHAT IS STRESS ANALYSIS?

Piping Stress analysis is a term applied to calculations, which address the static and dynamic loading resulting from the effects of gravity, temperature changes, internal and external pressures, changes in fluid flow rate and seismic activity. Codes and standards establish the minimum requirements of stress analysis.

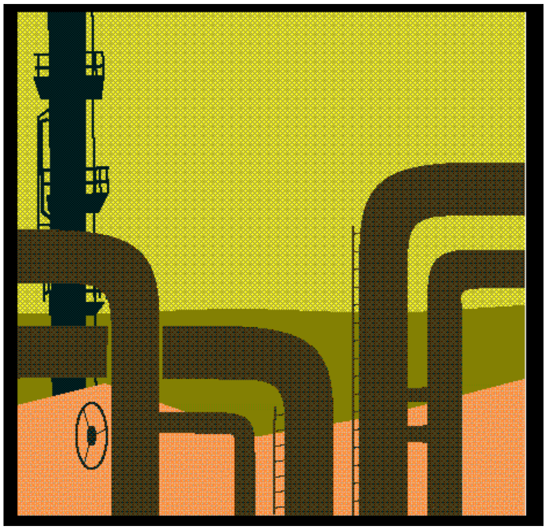
PURPOSE OF PIPING STRESS ANALYSIS

Purpose of piping stress analysis is to ensure:

✈Safety of piping and piping components.

✈Safety of connected equipment and supporting structure.

✈Piping deflections are within the limits.



HOW PIPING AND COMPONENTS FAIL (MODES OF FAILURES)

There are various failure modes, which could affect a piping system. The piping engineers can provide protection against some of these failure modes by performing stress analysis according to piping codes.

- ***FAILURE BY GERNRAL YIELDING:*** Failure is due to excessive plastic deformation.

- **Yielding at Sub Elevated temperature:** Body undergoes plastic deformation under slip action of grains.

- **Yielding at Elevated temperature:** After slippage, material re-crystallizes and hence yielding continues without increasing load. This phenomenon is known as creep.

- ***FAILURE BY FRACTURE:*** Body fails without undergoing yielding.

- **Brittle fracture:** Occurs in brittle materials.

- **Fatigue:** Due to cyclic loading initially a small crack is developed which grows after each cycle and results in sudden failure.

WHEN PIPING AND COMPONENTS FAIL (THEORIES OF FAILURE)

Various theories of failure have been proposed, their purpose being to establish the point at which failure will occur under any type of combined loading.

The failure theories most commonly used in describing the strength of piping systems are:

- ***Maximum principal stress theory***

This theory states that yielding in a piping component occurs when the magnitude of any of the three mutually perpendicular principle stresses exceeds the yield point strength of the material.

- ***Maximum shear stress theory***

This theory states that failure of a piping component occurs when the maximum shear stress exceeds the shear stress at the yield point in a tensile test.
In the tensile test, at yield, S_1=Sy (yield stress), S_2=S_3=0.So yielding in the components occurs when

$$\text{Maximum Shear stress} = \tau_{max} = S_1 - S_2 / 2 = Sy / 2$$

The maximum principal stress theory forms the basis for piping systems governed by ASME B31.3.

Note: maximum or minimum normal stress is called principal stress.

STRESS CATEGORIES

The major stress categories are primary, Secondary and peak.

PRIMARY STRESSES:

These are developed by the imposed loading and are necessary to satisfy the equilibrium between external and internal forces and moments of the piping system. **Primary stresses are not self-limiting.**

SECONDARY STRESSES:

These are developed by the constraint of displacements of a structure. These displacements can be caused either by thermal expansion or by outwardly imposed restraint and anchor point movements. **Secondary stresses are self-limiting**.

PEAK STRESSES:

Unlike loading condition of secondary stress which cause distortion, peak stresses cause no significant distortion. Peak stresses are the highest stresses in the region under consideration and are responsible for causing fatigue failure.

CLASSCIFICATION OF LOADS

- **Primary loads:**

These can be divided into two categories based on the duration of loading.

- **Sustained loads**

  These loads are expected to be present through out the plant operation. e,g. pressure and weight.

- **Occasional loads**.

  These loads are present at infrequent intervals during plant operation. e,g. earthquake, wind, etc.

- **Expansion loads:**

These are loads due to displacements of piping. e,g .thermal expansion, seismic anchor movements, and building settlement.

REQUIRMENTS OF ASME B31.3 (PROCESS PIPING CODE)

This code governs all piping within the property limits of facilities engaged in the processing or handling of chemical, petroleum or related products. Examples are a chemical plant, petroleum refinery, loading terminal, natural gas processing plant, bulk plant, compounding plant and tank farm.
The loadings required to be considered are pressure, weight (live and dead loads), impact, wind, earthquake-induced horizontal forces, vibration discharge reactions, thermal expansion and contraction, temperature gradients, anchor movements.

The governing equations are as follows:

1.Stresses due to sustained loads.

$$S_L \leq S_h$$

$S_L = (PD/4t) + S_b$
S_h = Basic allowable stress at maximum metal temperature.
The thickness of the pipe used in calculating S_L shall be the nominal thickness minus mechanical, corrosion, and erosion allowance.

2.Stresses due to occasional loads.

The sum of the longitudinal loads due pressure, weight and other sustained loads and of stresses produced by occasional loads such as earthquake or wind shall not exceed 1.33Sh.

3.Stress range due to expansion loads.

The displacement stress range S_E shall not exceed S_A:

$$S_E \leq S_A$$

WHERE

$$\mathbf{S_E = (S_b^2 + 4S_t^2)^{1/2}}$$

S_b = resultant bending stress,psi
= [(IiMi)2 + (IoMo)2] / Z

Mi = in-plane bending moment, in.lb
Mo = out-plane bending moment, in.lb
Ii = in- plane stress intensification factor obtained from appendix of B31.3
Io = out- plane stress intensification factor obtained from appendix of B31.3
St = Torsional stress ,psi
= Mt / (2Z)
Mt = Torsional moment, in.lb

S_A = Allowable displacement stress range:

(Allowable stress)$_{cold}$ = $S_c = (2/3)\, Sy_c \Rightarrow Sy_c = (3/2)S_c$
(Allowable stress)$_{hot}$ = $S_h = (2/3)\, Sy_h \Rightarrow Sy_h = (3/2)\, S_h$

Sy_c = yield point stress at cold temperature
Sy_h = yield point stress at hot temperature

Allowable stress $= Sy_c + Sy_h$

$= 3/2\ (S_c + S_h)$

$= 1.5\ (S_c + S_h)$

$= 1.25(S_c + S_h)$---- after dividing with F.O.S

Final allowable stress $= [(1.25(S_c + S_h) - S_L]$

$$\mathbf{S_A = f\ [(1.25(S_c + S_h) - S_L]}$$

S_c = basic allowable stress at minimum metal temperature
f = stress range reduction factor from table 302.2.5 of B31.3

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