Process Piping - Stress Analysis

An Online Continuing Education Course for Engineers

Course Number: M-6025

Credit: 6 Hours / 6 PDH / 6 CPD

Process Piping – Stress Analysis

A. Bhatia, Mechanical Engineer

The piping systems are subjected to combined effects of fluid internal pressure and temperature, its own weight and restrained thermal expansion. The piping engineer has to design the systems to ensure reliability and safety throughout design plant life. The task of piping stress engineer is:

- To ensure an adequate wall thickness to sustain the internal pressure with safety.
- To select piping layout with an adequate flexibility between points of anchorage to absorb its thermal expansion without exceeding allowable material stress levels, also reacting thrusts and moments at the points of anchorage must be kept below certain limits.
- To limit the additional stresses due to the dead weight of the piping by providing suitable supporting system – effective for cold as well as hot conditions.

All these objectives are achieved by:

- Assuming adequate support to prevent excessive sag and stresses in piping system.
- Incorporating sufficient flexibility to accommodate stress resulting from changes in pipe length due to thermal effects and movement of the connection at the end of pipe.
- Designing the piping system to prevent its exerting excessive forces and movements on equipment such as pumps and tanks or on other connection and support points.

Various computer packages such as CEASAR II, CEAPIPE, PIPEPLUS etc. has improved pipe stress analysis job productivity immensely. However, this has also led to a decline in the knowledge about the basics of pipe stress analysis especially in situation where the stress analysis engineer after acquiring some sort of skill in the use of analysis package does not make effort to learn about the basis of pipe stress.

This 6-hr course will cover the fundamental principles and concepts used in pipe stress analysis. The course is written in a simple format without stretching too much on the mathematical equations.

This course is the 8th of the 9 modules in series that cover the entire gamut of piping engineering in in quick reference. All topics are introduced to readers with no or limited background on the subject. The course is divided into four (4) chapters:

CHAPTER -1: FAILURE ANALYSIS

This chapter discusses the material characteristics, strength, stress-strain curve, yield point, modulus of elasticity and relationship of elastic properties. It discusses various types of pipe failures and common causes of failures. It also provides information on the specifications of steel pipes, pipe grades, and ASTM material designation.

CHAPTER -2: THERMAL EXPANSION AND FLEXIBILITY

This chapter discusses the pipe failures due to stress caused due to temperature variations and material expansion and contraction. It provides methods of increasing flexibility in design by use of expansion loops, expansion joints, anchors & guides and directional changes.

CHAPTER -3: PIPE STRESS ANALYSIS

This chapter discusses the fundamental concepts and factors responsible for pipe stress. It discusses theories of failure, hoop stresses and longitudinal stresses, acceptability conditions for allowable stress as prescribed by ASME B31.1 and B31.3 codes. It provides information on analyzing equipment nozzle loads, various prerequisites, tools and checklists for Stress Analysis.

CHAPTER -4: PIPE SUPPORTS SPACING

This chapter discusses the allowable pipe spans based on stress and deflection criteria. It includes examples to calculate the support spans and provide recommended spacing table and thumb rules.

CHAPTER 1

1. FAILURE ANALYSIS

A piping system in particular or a structural part in general is deemed to fail when a stipulated function of various stresses and strains in the system or structural part crosses a certain threshold value. There are various failure modes, which could affect a piping system.

1. **Failure by general yielding:** Failure is due to excessive plastic deformation.
2. **Yielding at Sub-elevated temperature**: Body undergoes plastic deformation under slip action of grains.
3. **Yielding at elevated temperature:** After slippage, material re-crystallizes and hence yielding continues without increasing load. This phenomenon is known as creep.
4. **Failure by fracture:** Body fails without undergoing yielding.
5. **Brittle fracture:** Occurs in brittle materials.
6. **Fatigue:** Due to cyclic loading initially a small crack is developed which grows after each cycle and results in sudden failure.

The piping engineers can provide protection against some of these failure modes by performing stress analysis according to piping codes.

1.1. Purpose of Piping Stress Analysis

The primary purpose of the pipe stress analysis is to ensure that the applied stresses do not exceed the piping allowable stresses. The pipe stress analysis can serve other functions as well including determination of loads on supports, determination of loads on connected equipment, and assessment of piping movements to help avoid potential clashes with other equipment and structures.

The objective is to:

- Limit piping deflections are within the allowable parameters.
- Ensure safety of piping, components, connected equipment and supporting structure.

ASME B31 Codes and standards establish the minimum requirements of stress analysis.

Important

The most basic and important requirement of pipe stress analysis is to ensure that each piping component is strong enough to contain the service pressure. In a very high percentage of the time it is not the pipe that is the weakest link. Remember, the pipe is normally stronger and/or less vulnerable to damage than what the pipe is connected to.

1.2. Tools for Stress Analysis

1. PIPSYS – An integrated pipe stress analysis module of PLADES 2000
2. CEASER – Computer Aided Engineering Stress Analyzing Reporter sold by COADE Engineering Software
3. CAEPIPE
4. AUTOPLANT
5. PIPE PACK
6. PDMS

1.3. Inputs for Stress Analysis

To carry out any pipe stress analysis, there are number of properties that must be known in advance. Some of these properties, such as fluid pressure, temperature, and density, are dictated by the process and would be the same regardless of what piping material was used.

Other properties are dependent on the piping material and include physical properties (e.g. density), thermal properties (e.g. coefficient of thermal expansion), and mechanical properties (e.g. modulus of elasticity and strength). Of these properties, we're going to focus on the mechanical properties, which are typically divided into the elastic properties and the strength properties (from which we can determine the allowable stresses).

1.4. Material Characteristics

Pipe materials characteristics are broadly defined by its strength, ductility, toughness, and corrosion resistance.

1.4.1. Strength

The strength of a material is defined by:

1. Modulus of elasticity
2. Yield strength
3. Ultimate tensile strength

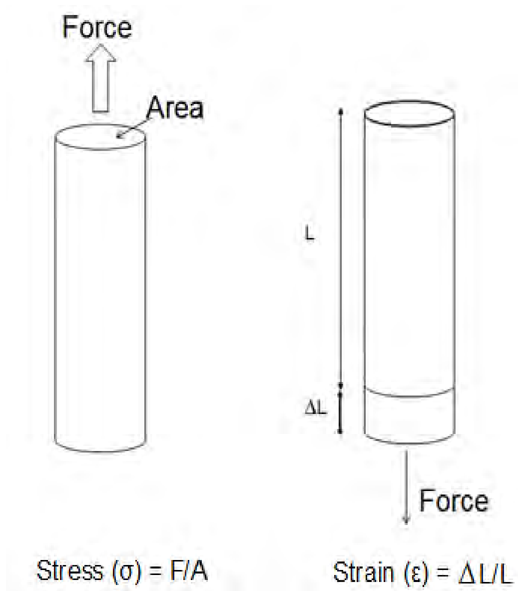
There are two terminologies which need to be understood first.

- **Stress (σ)**
  - Stress (σ) equals to force divided by cross sectional area of the material (F/A).

    Stress (σ) = F/A

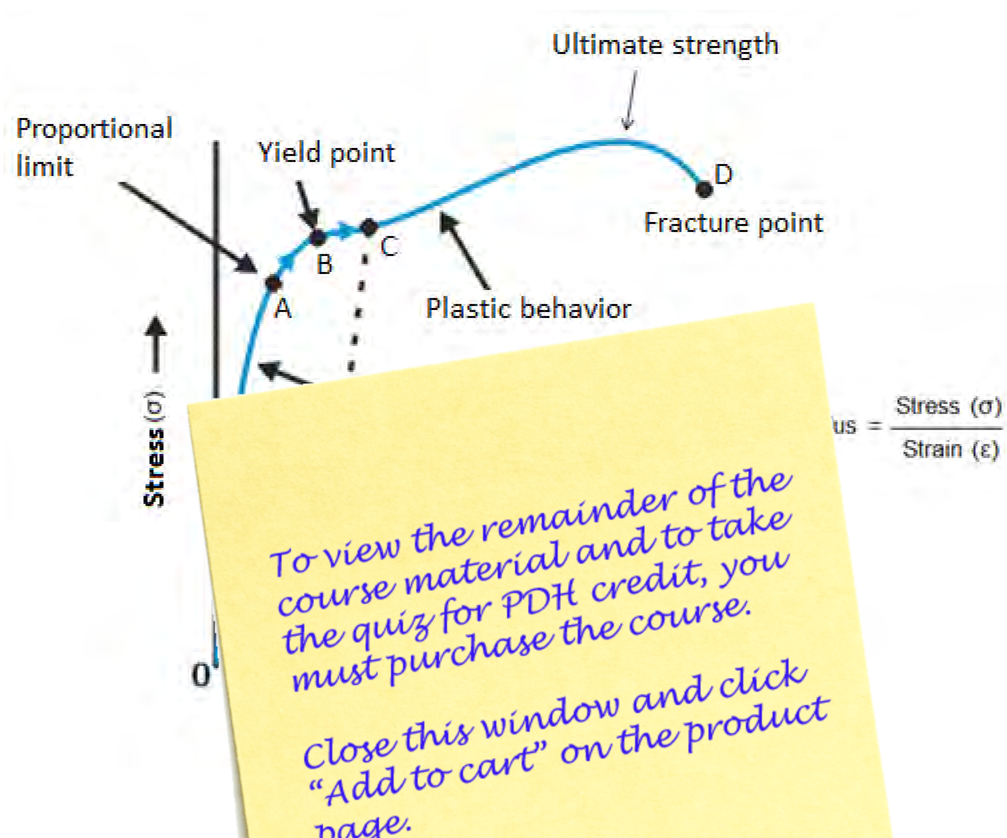
- **Strain (ε)**
  - Strain (ε) is unit deformation under applied load. From the definition, it equals to ΔL/L.

    Strain (ε) = ΔL/L



1.4.2. Stress-Strain Curve

A stress-strain curve is a curve in which unit load or stress (σ) is plotted against unit elongation, technically known as strain (ε). The nature of the curve varies from material to material. A typical stress-strain curve for ductile metal is shown below:



- **O – A:** represents th … ship between stress and strain is b … roportional limit. Beyond the proporti … e the relationship is linear … dulus of elasticity, E, where E = σ/ε this is also kn …
- **Point B:** With an increase in stress beyond the proportional limit the strain increases more rapidly than the stress. At this section there is a considerable elongation of the specimen, and this is known as yielding. 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. The material becomes perfectly plastic; this means that there is deformation without an increase in applied load.
- **Point D**: After undergoing large strains during yielding the material begins to strain harden, which means that the material undergoes changes in its crystalline structure, resulting in increased resistance to further deformation. Point D is ultimate stress or ultimate strength of material.