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Calculation Methodologies for One Dimensional Process Piping Systems

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***Abstract*—Piping systems are constantly present in industrial facilities, being in some cases associated with the transport of fuels and steam at very high temperatures. Due to the nature of those fluids, the design of the piping system that transports them is a task of great responsibility, which must follow codes and standards to guarantee the system's structural integrity.**

Many times the piping systems operate at a temperature higher than the temperature at which they are assembled, leading to the thermal expansion of the system's pipes and since no piping system is free to expand, the thermal expansion will lead to stresses. Besides the stresses caused by thermal expansion, the studied systems are also subjected to constant loads, caused by their weight.

In this perspective, will be developed calculation methodologies in order to do quick analysis of the most common configurations, according to the codes ASME B31.1 and B31.3 (2012), allowing that way improvements on the flexibility of the projected systems.

Although the methodology developed may only be used in simple systems (1D system) and gives very conservative results, in practical cases it can be used to analyze complex systems, by dividing them in simpler cases. Besides that, the method developed, may also be used to analyze simple cases that are frequently present, without having to use commercial software, such as CAESAR II, being helpful to define the system's layout.

***Index Terms*— ASME B31.1, ASME B31.3, Piping Systems, Stress Analysis, Thermal Expansion.**

I. INTRODUCTION

The pipes are important and very sensitive component in the process plant and piping system. The pipes are subjected to various types of load, in different cases and application. These loads are responsible for increase in the stresses and decrease the life span of pipes.

Piping System is a network of Pipes by using Pipe Fittings and other special components to perform the required mode of transferring fluids (Liquids/ Gas/ Slurry) from one location to another location. It is the effective method for transferring fluids without considerable or about zero losses in properties and quality of fluid. Industrially, all piping activities are performed with the compliance and guidelines of International and Industrial Codes & Standards as well as the laws and regulations of respective local authority. Generally, Piping Engineering is applied among the following Industrial systems;

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1) Power Piping System
2) Process Piping System
3) Liquid transportation and distribution piping (Pipelines) System
4) Refrigeration and Heat Transfer Piping System
5) Gas Transmission and Distribution Piping System
6) Building Services Piping System
7) Slurry Transportation Piping Systems

The Process Piping system is a form of pipework used to transport materials used in industrial processes and manufacturing. It is specially designed for particular applications to ensure that it will meet health and safety standards, in addition to suiting the needs of a given manufacturing process. Process piping can be installed by plumbers, as well as contractors who specialize in installing factory components, and like other fixed elements of a manufacturing facility, it is subject to inspection and approval by government regulators. This type of piping can be used in a wide variety of ways. Chemical manufacturing facilities use process piping to transport components of their products along with materials like natural gas used in manufacturing. Refineries and similar facilities also utilize process piping to move chemical compounds.

II. TYPES OF LOAD

1. **Sustained Load:** internal pressure, external pressure, dead weight pipe and content, weight of valves, fittings etc.
2. **Operating Load:** Effects of Temperature, Pressure, and other sustained loadings
3. **Occasional Load:** live loads like wind load, earth quake, waves load, etc.
4. **Expansion Load:** Difference between operating temperature & ambient condition.

In this paper we discussed about the methodology to calculate the various stresses for Process Piping system.

III. CALCULATION METHODOLOGY FOR 1D SUSTAIN LOAD CASE IN PROCESS PIPING

A. Weight Calculation

1. Calculation of the Pipe Weight (in N)

$$W_p\,(N) = \rho_p.V.g = \rho.A.L.g = \rho_p.(\pi/4).(D_o^2 - D_i^2).L.g \quad \ldots.(1)$$

Where,

ρ_p = Density of the fluid in Kg/m^3
V = Volume of pipe in m^3
g = Accerelation due to gravity in m/s^2
A = Cross-sectional area in m^2
L = Length of the pipe in m
D_o = Outer diameter of the pipe in m
D_i = Inner diameter of the pipe in m

2. Calculation of the Insulation weight (in N)

$$W_{ins}\,(N) = \rho_{ins}.V.g = \rho_{ins}.A.L.g = \rho_{ins}.(\pi/4).(D_{ins}^2 - D_o^2).L.g \quad ....(2)$$

Where,

ρ_{ins} = Density of insulation material in Kg/m^3
V = Volume of pipe in m^3
g = Accerelation due to gravity in m/s^2
A = Cross-sectional area in m^2
L = Length of the pipe in m
$D_{ins} = D_o + t_{ins}$ = Outer diameter of the insulated pipe in m
D_o = Outer diameter of the pipe in m

3. Calculation of the Fluid weight (in N)

$$W_f\,(N) = \rho_f.V.g = \rho_f.A.L.g = \rho_f.(\pi/4).D_i^2.L.g \quad ….(3)$$

Where,

ρ_f = Density of fluid flow in the pipe in Kg/m^3

4. Total Weight

$$W_t = (W_p + W_{ins} + W_f) \quad ….(4)$$

B. Stress Calculation

1. Hoop/ Circumferential Stress (in Pa/Kpa)

$$\sigma_h = P_i D_i'/(2t_{min}) \quad ….(5)$$

Where,

P_i = Inner fluid pressure in Pa/Kpa
$D_i' = (D_i + 2c)$ = New diameter (inner dia + 2*corrosion allowance)
t_{min} = Minimum pipe thickness = (t-c)

2. Axial / Longitudinal Stress (in Pa/KPa)

$$\sigma_a = P_i\, D_o^2/(D_o^2 - D_i'^2) \quad ….(6)$$

3. Bending Stress

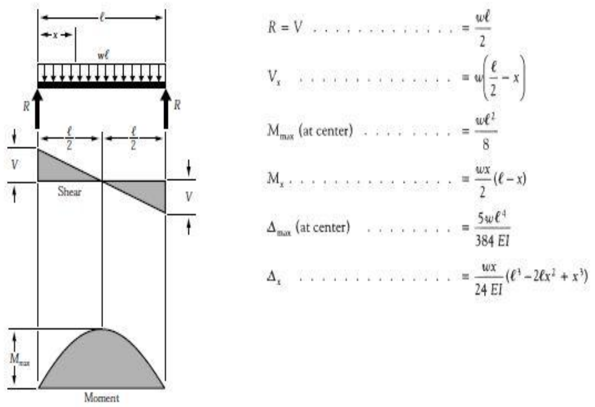
Bending stress in the pipe is given by

$$\sigma_b = \frac{\text{Maximum Bending Moment (M)}}{\text{Section Modulus (Z)}}$$

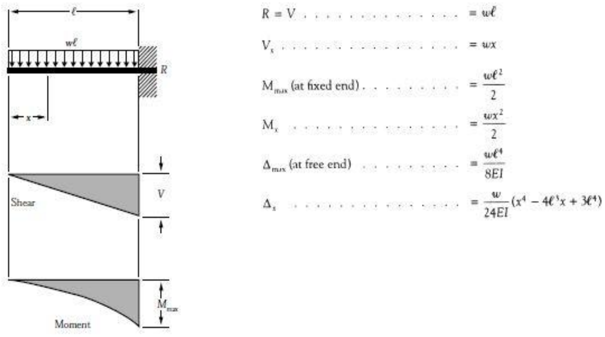
$$\sigma_b = M/Z \quad ….(7)$$

The maximum bending moment, slope and maximum deflection formula for different sections as shown below cases. For 1D Beams,

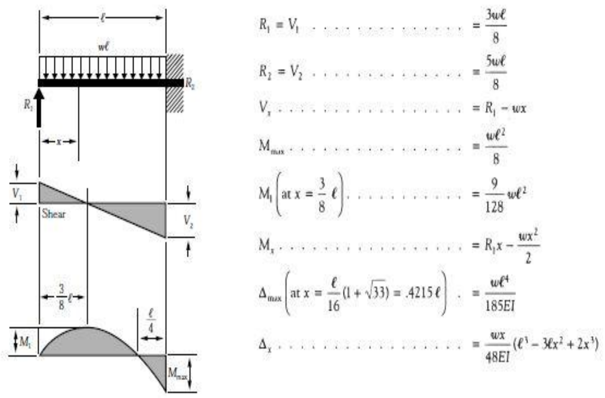
Case 1: Uniformly distributed load over the entire span of simply supported



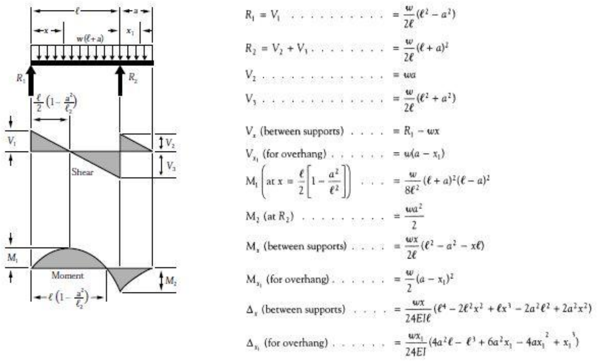
Case 2: Uniformly distributed load over the entire span of cantilever



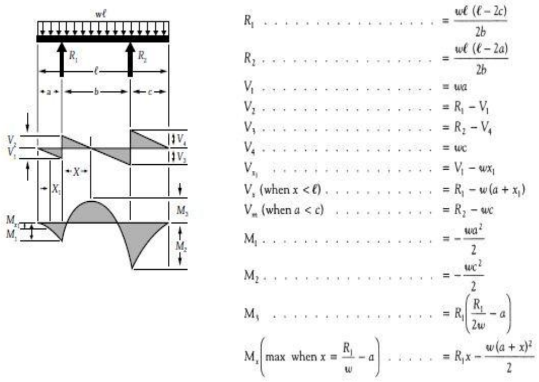
Case 3: Uniformly distributed load over the entire span of cantilever with other side rest



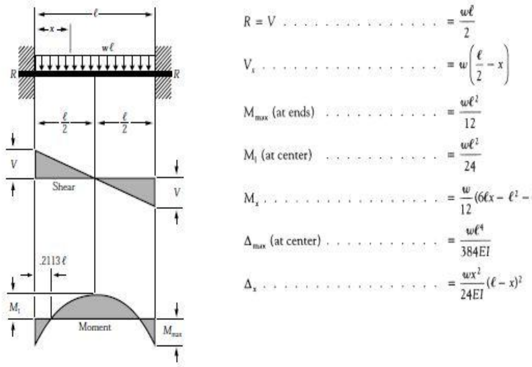
Case 4: Uniformly distributed load over the entire span of one side overhanging



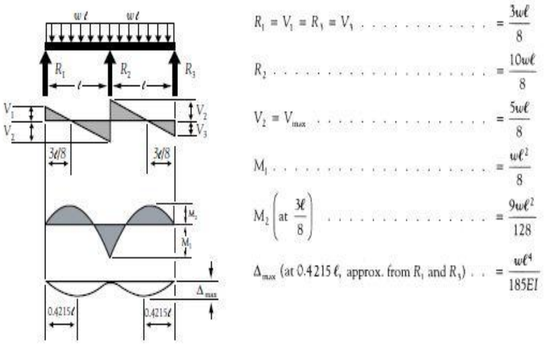
Case 5: Uniformly distributed load over the entire span of both side overhanging



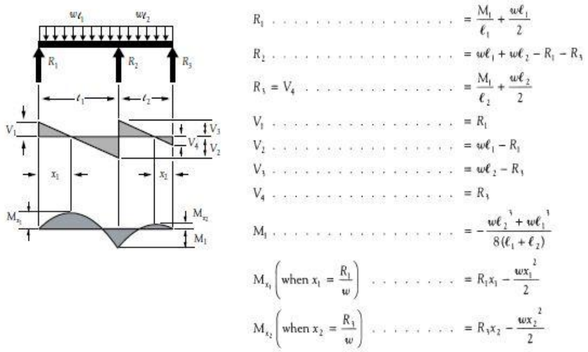
Case 6: Uniformly distributed load over the entire span of both ends fixed



Case 7: Uniformly distributed load over the entire span of continuous with equal distant



Case 8: Uniformly distributed load over the entire span of continuous with unequal distant



4. Code Stress

$$\sigma_{code} = (\sigma_b + \sigma_a) \quad \ldots.(8)$$

5. Maximum Stress Intensity

This can be calculating by using Theories of Failures. There are two theories are used for ductile materials,

1. Von-Mises theory
2. 3D Maximum shear stress theory

In these theories 3Dmaximum shear stress theory is used in CAESAR II Software.

$$\sigma_{max} = (\sigma_{max} - \sigma_{min})/2 \quad \ldots.(9)$$

6. Ratio

Ratio (%) = Code Stress / Allowable Stress

$$= (\sigma_{code} / \sigma_{allowable}) \quad \ldots.(10)$$

7. Thermal Stress

$$\sigma_{exp} = \alpha.\ \Delta T.E \quad \ldots.(11)$$

Where,

α = Coefficient of thermal expansion in / °C (ASME B31.3 Appendix C)

ΔT= Change in Temperature in °C

E = Young's modulus in Pa/KPa (See ASME B31.3 Appendix C)

8. Natural Frequency

Natural frequency in cycles per second is given by

$$f_n = \frac{\alpha}{L^2}\sqrt{\frac{EI}{W'}} \quad \ldots.(12)$$

Where,

L = Length of pipe in m

E = Modulus of elasticity in N/m^2

I = Moment of inertia in m^4

W' = Weight of pipe in N/m

α = Constant depends on end condition (See below table)

End Condition	Configuration	Mode	Value of α
Both ends simply supported	1st	Fundamental(1st) Second mode	0.743 2.97
Both ends fixed		First mode Second mode	1.69 4.64
One end fixed; one end simply supported		First mode Second mode	1.16 3.76

Table-1. α Values for different end conditions

IV. CONCLUSION

The objective of this work is to develop calculation methodologies for the design of piping systems of fuels and steam. There are several codes and standards that can be used so assure the integrity of the systems, being the ASME B31.1 and B31.3 (2004) the most used.

According to the ASME B31.1 and B31.3 (2012) Codes, the stresses to which a piping system is subjected may be separate in three main classes, for which the codes establish limits: the stresses caused by sustained loads (pressure and weight), the stresses caused by occasional loads and the stresses caused by thermal expansion. Since the stresses due to occasional loads are only verified in very specific cases, the methodologies developed are only for the sustained loads and thermal expansion. To calculate the stresses according to the ASME B31.1 and B31.3 Codes, it is necessary to know the forces and the moments to which the system is subjected.

Besides the Codes' stress requirements, it is also important to analyze the systems in the operation conditions, namely the loads on the supports and the displacements.

In order to find the forces and the moments caused by the system's weight, the equations of static equilibrium, the beam deflection formulas and the torsion formulas can be used. These methodologies give results very similar to the CAESAR's results, but more conservative, due to the fact of neglecting the curvature of the directions changes. During the development of the methodologies for the calculation of the weight loads, was concluded the pipes torsion cannot be neglected, since it has a great influence in the calculation of the forces, moments and deformations.

The calculation method is good for the beginners to understand the behavior of piping system due self-weight, component weights and nature effects. The manual calculated results are compared with CAESAR II Software results and found variations in the range of 10% to 20% in Bending Moment only. The formulae are used to calculate,

1. Displacement.
2. Restraints.
3. Forces acting on the pipe.
4. Stresses due to self-weight, internal and external pressures, operating temperatures, etc.
5. Natural frequency, etc.

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