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Static, Dynamic and Flow Analysis of Ship Fuel System by Beam Based Finite Element Analysis

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Abstract

The present work deals with the stability analysis of fuel system used in entire ship, flow distribution inside piping includes pressure and velocity distribution and flow paths and vibration response of piping due to structural and flow excitations. Pipe stress analysis is usually done using beam based finite element analysis. The dynamic analysis deals with determining the natural frequency and mode shapes in order to avoid resonance condition. Using computational fluid dynamic pressure distribution, velocity distributions are visualized in the piping system.

Key words: CAESAR –II, GAMBIT AND FLUENT

1. INTRODUCTION:

Pipes are the most delicate components in any process plant. They are also the busiest entities. They are subjected to almost all kinds of loads, intentional or unintentional. It is very important to take note of all potential loads that a piping system would encounter during operation as well as during other stages in the life cycle of a process plant. Ignoring any such load while designing, erecting, hydro-testing, start-up shut-down, normal operation, maintenance etc. can lead to inadequate design and engineering of a piping system. The system may fail on the first occurrence of this overlooked load. Failure of a piping system may trigger a Domino effect and cause a major disaster.

Stress analysis and safe design normally require appreciation of several related concepts. An approximate list of the steps that would be involved is as follows.

- Identify potential loads that would come on to the pipe or piping system during its entire life.
- Relate each one of these loads to the stresses and strains that would be developed

in the crystals/grains of the Material of Construction (MoC) of the piping system.

- Decide the worst three dimensional stress state that the MoC can withstand without failure
- Get the cumulative effect of all the potential, loads on the 3-D stress scenario in the piping system under consideration.
- Alter piping system design to ensure that the stress pattern is within failure limits.

The goal of quantification and analysis of pipe stresses is to provide safe design through the above steps. There could be several designs that could be safe. A piping engineer would have a lot of scope to choose from such alternatives, the one which is most economical, or most suitable etc.

2. PROBLEM DESCRIPTION:

2.1. Fuel System in a Ship:

The general routing of the fuel system in a ship is as shown below.

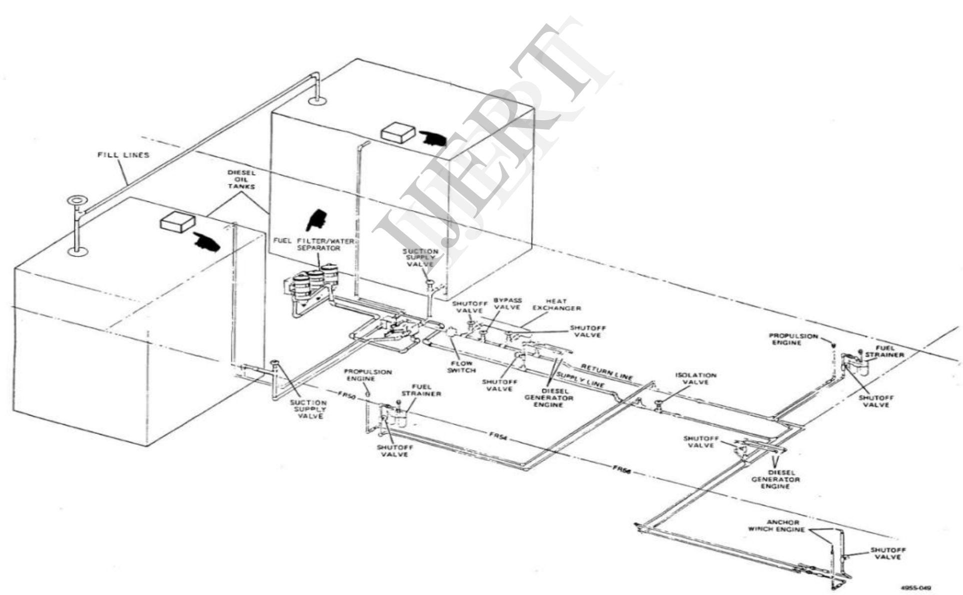

Fig.2.1 Fuel System in a Ship

The geometry of the fuel system is analyzed statically and dynamically using CAESER-II. In case of static analysis the system is made to pass the code stress check by making modifications in the type of supports, altering the routings and even changing the material of the pipes. Passing the code stress check indicates that the stress components in all directions are below the allowable stress. CAESER-II provides detailed information regarding stresses and displacements at every node. In the Flow analysis flow parameters like velocity distribution, pressure distribution and flow paths are to be visualized using CFD.

2.2 Work Structure:

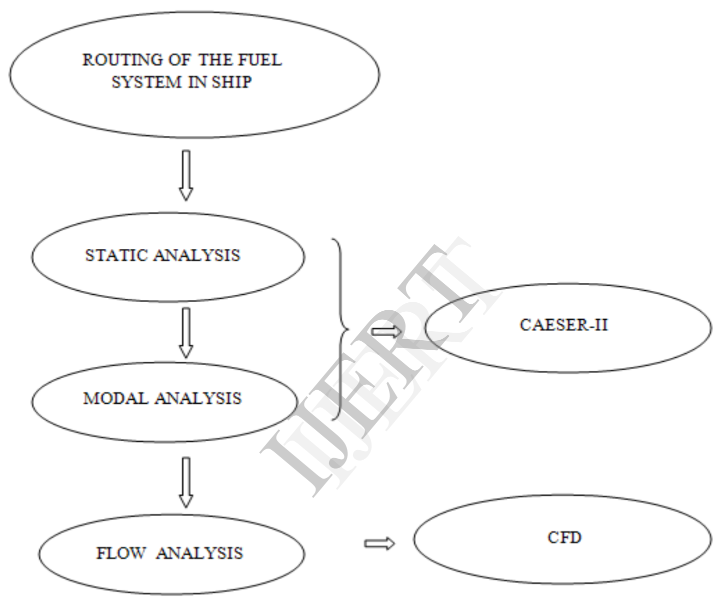

Fig.2.2.Flow chart for total work structure

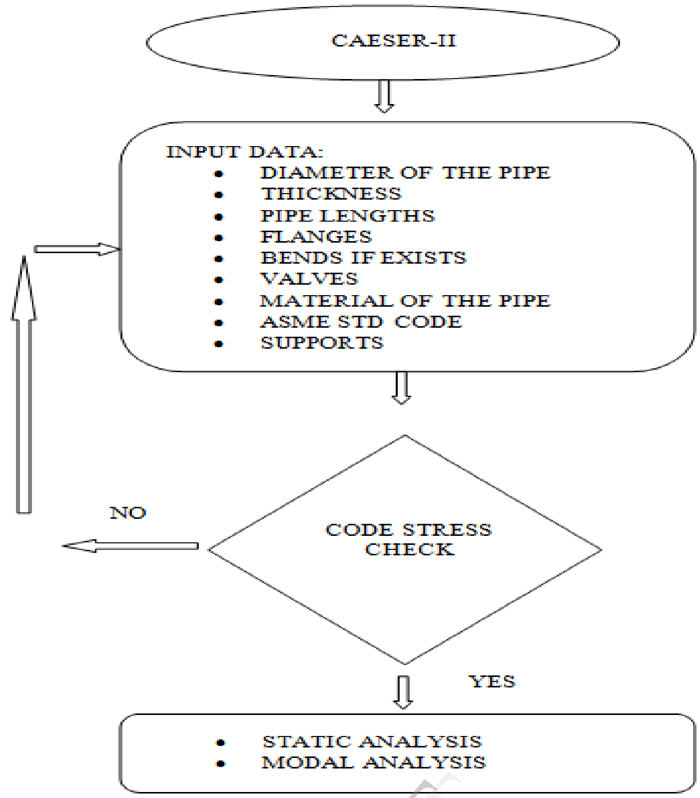

Fig.2.2.1. Flow chart for CAESER-II work

The CAESER-II model generated after above proces is as shown.

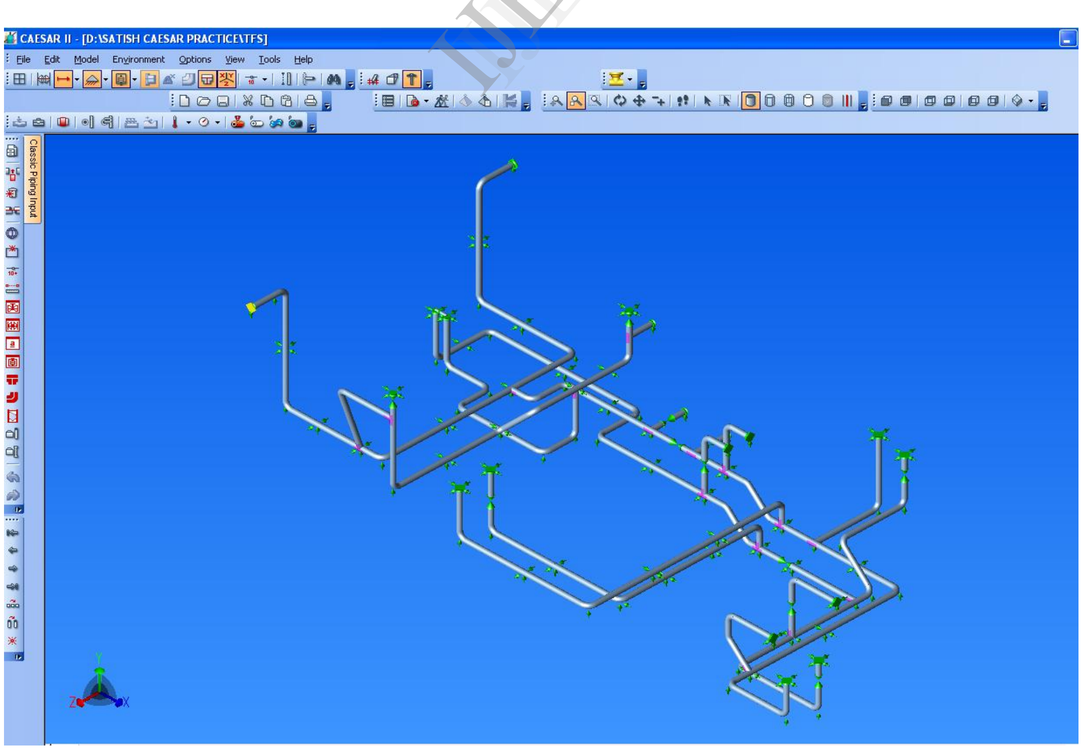

Fig.2.2.2. CAESER-II model of Fuel System in a Ship.

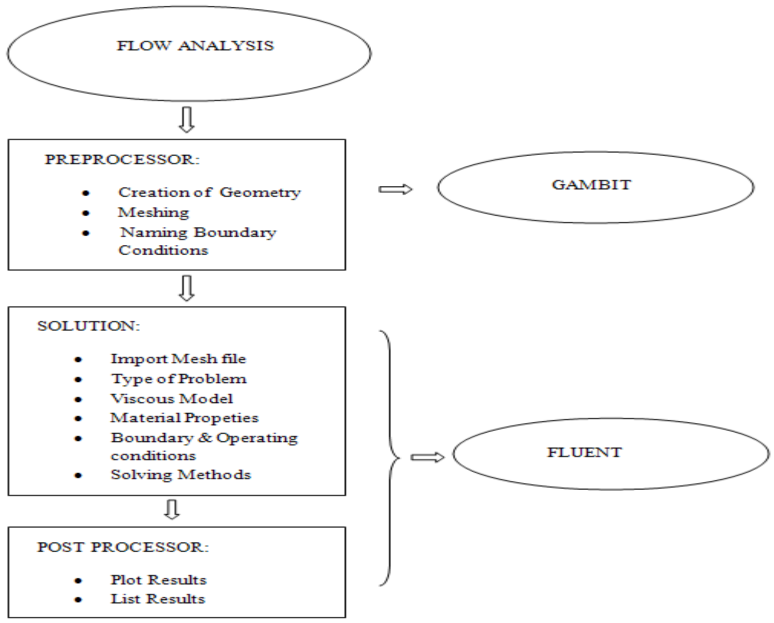

Fig.2.2.3. Flow chart for CFD work

3. METHODOLOGY:

3.1 Classification of Loads on Piping System:

The loads the piping system (or for that matter any structural part) faces are broadly classified as primary loads and secondary loads.

3.1.1 Primary loads : These are typically steady or sustained types of loads such as internal fluid pressure, external pressure, gravitational forces acting on the pipe such as weight of pipe and fluid, forces due to relief or blow down pressure waves generated due to water hammer effects. Primary loads are not self-limiting. It means that the stresses continue to exist as long as the load persists and deformation does not stop because the system has deformed into a no-stress condition but strain hardening has come into play.

3.1.2 Secondary loads: The secondary loads are often cyclic but not always. For example load due to tank settlement is not cyclic. The load due to vessel nozzle movement during operation is cyclic because the displacement is withdrawn during shut-down and resurfaces again after fresh start-up. A pipe subjected to a cycle of hot and cold fluid similarly undergoes cyclic loads and deformation. Failure under such loads is often due to fatigue and not catastrophic in nature.

3.1.3 Stress: When we calculate stresses, we choose a set of orthogonal directions and define the stresses in this co-ordinate system. For example, in a pipe subjected to internal pressure or any other load, the most used choice of co-ordinate system is the one comprising of axial or longitudinal direction (L), circumferential (or Hoope's) direction (H) and radial direction (R) as shown in figure. Stresses in the pipe wall are expressed as axial (S_L), Hoop's (S_H) and radial (S_R). These stresses which stretch or compress a grain/crystal are called normal stresses because they are normal to the surface of the crystal.

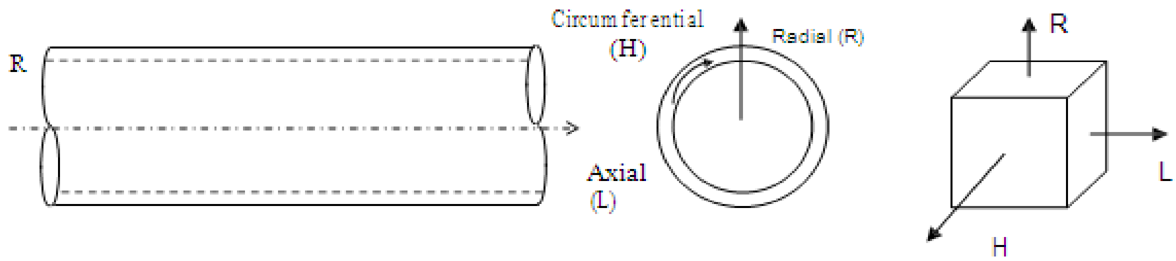

Fig.3.1Coordinate System in pipe

Solid mechanics also states that the sum of the three normal stresses for all orientation is always the same for any given external load. That is

$$S_L + S_H + S_R = S_1 + S_2 + S_3$$

The maximum shear stress in a 3-D state of stress can be shown to be

$$\tau_{max} = (S_1 - S_3)/2$$

Use of Mohr's circle then allows calculating the two principle stresses and maximum shear stress as follows.

$$S_1 = (S_L + S_H)/2 + [\{(S_L - S_H)/2\}^2 + \tau^2]^{0.5}$$

$$S_2 = (S_L + S_H)/2 - [\{(S_L - S_H)/2\}^2 + \tau^2]^{0.5}$$

$$= 0.5\,[(S_L - S_H)^2 + 4\tau^2]^{0.5}$$

4. Normal and Shear Stresses From Applied Load Axial Load:

A pipe may face an axial force (F_L) as shown in Figure. It could be tensile or compressive.

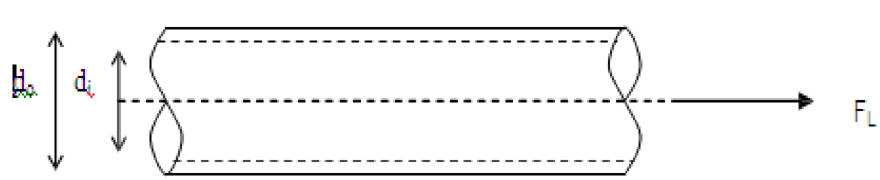

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Fig.4.1.Axial load acting on a pipe

The stress can then be calculated as

$$S_L = F_L \ / \ A_m$$

The load bearing cross-section may be calculated rigorously or approximately as follows.

$$A_m = \pi (d_o^2 - d_i^2)/4 \quad \text{(rigorous)}$$

$$= \pi(d_0 - d_i)t/2 \text{ (based on average diameter)}$$

$$= \pi d_0 t \text{(based on outer diameter)}$$

5. Internal / External Pressure:

The internal pressure exerts an axial force equal to pressure times the internal cross-section of pipe.

$$F_L = P \quad d^2 \pi/4$$

This then induces axial stress calculated as earlier. If outer pipe diameter is used for calculating approximate metal cross-section as well as pipe cross- section, the axial stress can often be approximated as follows.

$$S_L = P \, d_o \ / \ (4t)$$

The internal pressure also induces stresses in the circumferential direction as shown in figure

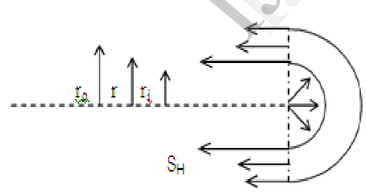


Fig.5.1.Hoop Stress direction

The stresses are maximum for grains situated at the inner radius and minimum for those situated at the outer radius. The Hoop's stress at any in between radial position (r) is given as follows (Lame's equation)

$$S_H \text{ at } r = P\,(r_i^2 + r_i^2 r_o^2/r^2)/\,(r_o^2 - r_i^2)$$

For thin walled pipes, the radial stress variation can be neglected. From membrane theory, S_H may then be approximated as follows.

$$S_H = P\, d_o \ / \ 2t \quad \text{or}$$
$$P\, d_i \ / \ 2t$$

Radial stresses are also induced due to internal pressure as can be seen in figure

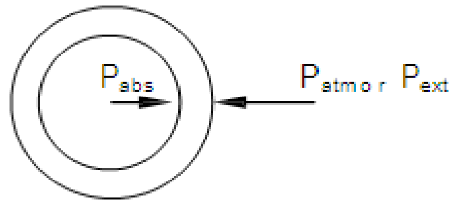


Fig.5.2. Internal Pressure acting in a pipe

6. Bending Load:

Let the total weight of the pipe, insulation and fluid be W and the length of the unsupported span be L (see Figure).

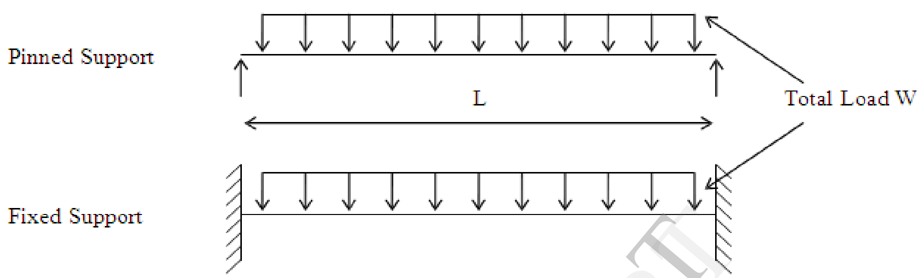


Fig.6.1. Uniform loading

Whenever the pipe bends, the skin of the pipe wall experiences both tensile and compressive stresses in the axial direction as shown in Figure .

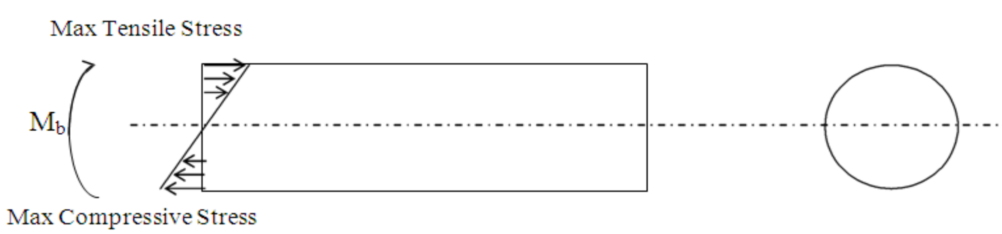


Fig.6.2. Bending Stress Variation

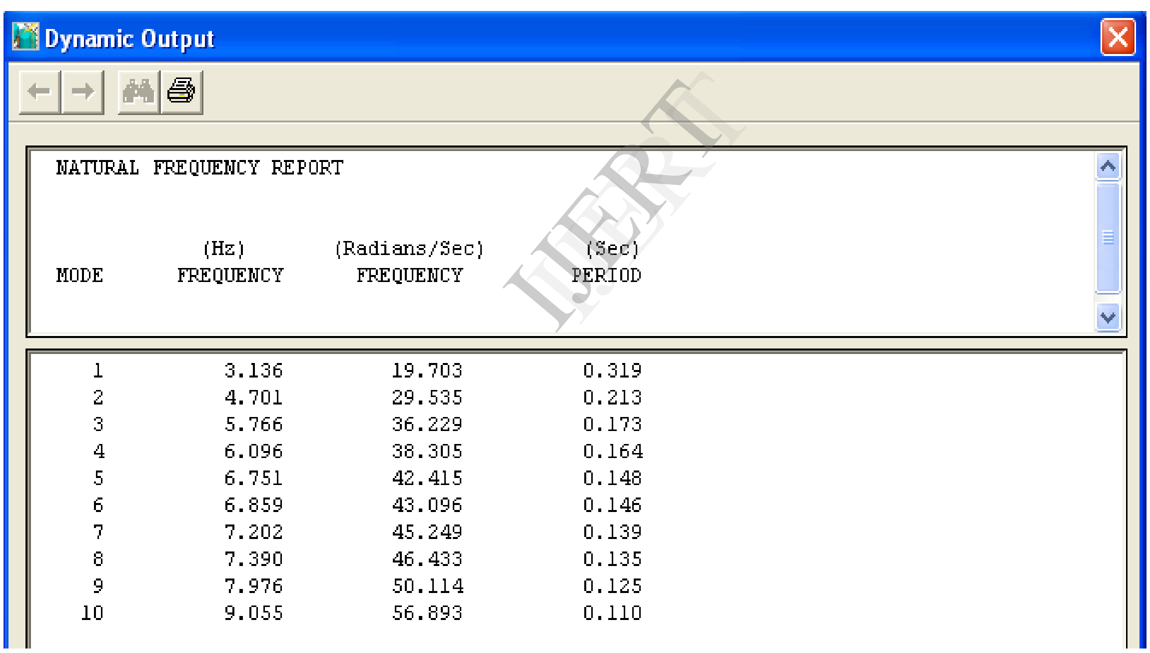
7. RESULTS:

7.1 Displacements, Stresses and Forces:

The fuel system of the ship is designed in CAESER-II as per the basic knowledge of the positions of the accessories like fuel tanks, Engines, Fuel Strainers ,Heat exchanger and valves, the layout obtained is validated by the code stress check by altering the routing or valve positions and supports. The results obtained are :

```
Piping Code: B31.3       = B31.3

 CODE STRESS CHECK PASSED       : LOADCASE 2 (SUS) W+P1

Highest Stresses: (   KPa     )

CodeStress Ratio (%):        15.3  @Node    190

Code Stress:               19299.6  Allowable:   125815.5

Axial Stress:                875.8  @Node    550

Bending Stress:            18677.6  @Node    190

Torsion Stress:             1775.3  @Node     48

Hoop Stress:                1255.7  @Node     17

3D Max Intensity:          19302.1  @Node    190
```

In Modal Analysis the values of natural frequencies obtained are as shown.



Dynamic Output

NATURAL FREQUENCY REPORT

MODE	(Hz) FREQUENCY	(Radians/Sec) FREQUENCY	(Sec) PERIOD
1	3.136	19.703	0.319
2	4.701	29.535	0.213
3	5.766	36.229	0.173
4	6.096	38.305	0.164
5	6.751	42.415	0.148
6	6.859	43.096	0.146
7	7.202	45.249	0.139
8	7.390	46.433	0.135
9	7.976	50.114	0.125
10	9.055	56.893	0.110

Fig. 7.1 Natural Frequency Report

In the flow analysis the plots obtained are as

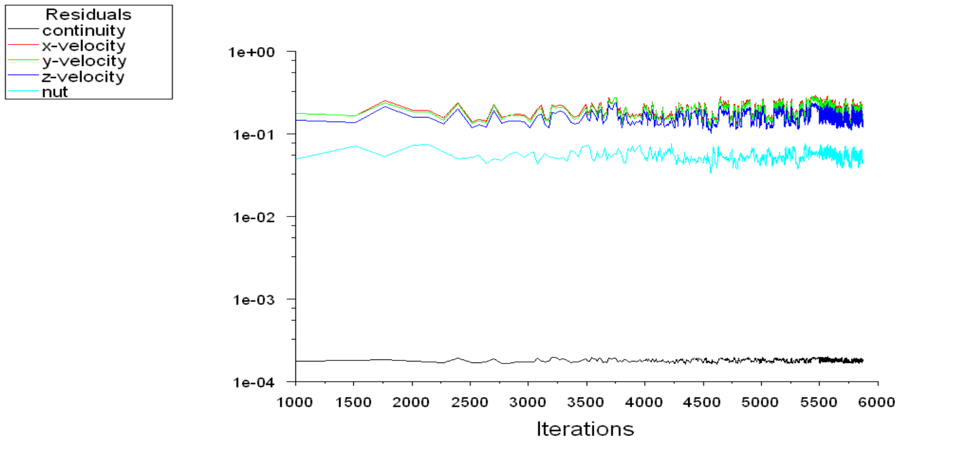


Fig.7.2. Scaled Residuals

8. CONCLUSION:

Here an attempt is made to analyze the piping system statically and dynamically for sustained case, operating case using CAESER-II, which also supports seismic analysis and harmonic analysis. And flow analysis is also carried out using GAMBIT and FLUENT. However the analysis does not consider impact loads, occasional loads, if so the analysis will be much realistic and optimal. Also in the present work analysis is done on a single pipe material i.e. A 105. If different materials of pipe are included then further optimization may be possible.

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