

Design of buried flexible pipelines during liquefaction

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Abstract

Pipelines are important facilities over the huge area to encounter a seismic hazards and conditions of soil. In India pipe lines run through high seismic areas and exposed to considerable risk. The pipelines have advanced in India compare through the world scenario there is no uniform guideline available for seismic design. Therefore we need to establish at least degree of safety for standard seismic design of pipelines. As a part of this, a number of flexible pipelines of different diameter, length, and thickness have been taken into consideration. The density, internal pressure and density of surrounding soil are taken into account and is checked against permanent ground deformation (PGD) due to liquefaction. Using ABAQUS SOFTWARE we will analyse the soil pipeline interaction and based on the results obtained some consideration are given for the design of pipeline in the Liquefied zone, which improve the capability of the pipeline to withstand buoyancy force due to soil liquefaction. The safety of buried pipelines is analyzed as per IITK-GSDMA (IIT-Kanpur-Gujarat state Disaster Management Authority) guidelines on seismic design.

1. Introduction

Where the saturated soil is substantially loses strength and stiffness due to an applied stress such as earthquake shaking or sudden change in stress condition. The purpose of this study is to understand the failure aspects of buried flexible pipeline caused by earthquake. However, it is necessary to execute static analysis initially without considering seismic effects before computing dynamic analysis with the seismic effects because it is possible to understand seismic effects more easily by comparing static and seismic analysis. Therefore, in this study, seismic analysis for buried pipeline caused by earthquakes will be reported simultaneously.

Buried pipeline

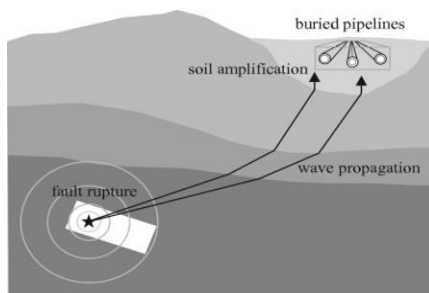


Fig.1: Wave propagation during earthquake affecting buried pipelines

Ground conditions

When considering the design of the structure to study the ground properties for interaction between soil and a buried structure, because there is considerable difference in the failure aspects of a buried formation and the interaction between buried structure and soil depending on the ground properties.

Material properties of soil

| Type of soil | Mechanical properties | Term | Value |
|--------------|-----------------------|--------------------------------|----------|
| SANDY SOIL | Elastic property | Density (kg/m ³) | 1850 |
| | | Young's modulus (MPa) | 24 |
| | | Poisson's ratio | 0.2 |
| | Plastic property | Cohesive strength (C - kPa) | 0 to 17 |
| | | Friction angle (ϕ - deg) | 35 to 40 |
| | | Dilation angle (ψ - deg) | 2 |

Finite Element Analysis (FEM) – ABAQUS

The finite elements are regarded as interconnected at specified joints called nodes or nodal points. These nodes are usually placed on the boundaries. Assume that the variation of field variable inside a finite element can be identified by a simple approximation function because the actual variation of displacement, pressure and stress, etc., is not known inside a continuum. These functions, also called interpolation models. The field equilibrium equations are created of the whole continuum. The nodal values of the field variables can be calculated by solving the field equations, which are generally composed of matrix forms. Once these are known, the field variable throughout the assemblage of elements is clarified by the approximated functions. In this study, the buried pipeline failure caused by static and seismic loads using FEM established by ABAQUS package. It is necessary to accept three basic assumptions are as follows.

(a) The welding in the pipeline is not considered.

- (b) The pipeline is isotropic, perfectly elastic and the soil is characterized by Mohr Coulomb theory.
 (c) Pipeline and soil are perfect without defects and fully bonded each other.

3D-Finite Element (FE) modeling

The reasonable and practical 3D-FE models were established using the platform of ABAQUS. Whereas the pipeline model was created as a 3D deformable shell model due to the thin thickness of the pipeline, the soil model was defined as a 3D deformable solid body



Fig.2: 4-A 3D pipe model (L=100m, dia=1.524m)

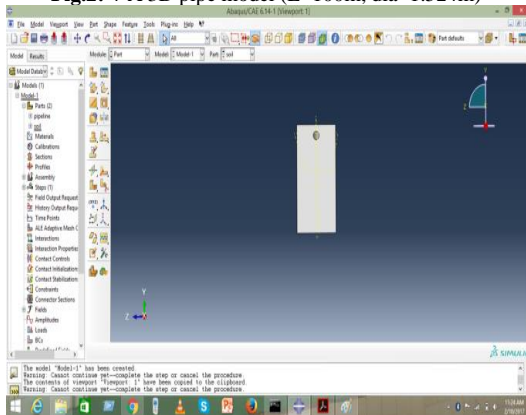


Fig.3: 5- A 3D soil model (100X20X20m)

2. Determination of stress models

First of all, for the static analysis in this study, the choice of a general static stress model controls the simulation results of pipeline failure. In ABAQUS, the stress model can be controlled as constitutive equations of the material. The following assumptions are needed.

- Selected material of pipeline is perfectly elastic-plastic and chosen material of soil is elastoplastic material according to Mohr-Coulomb theory.
- The Von Mises yield criteria is computed within the program for stress in pipeline and soil.
- In the strain-hardening material, the reloading yield stress after load off is more than initial yield stress.

Thus the general static stress model performs the strain-hardening during application of static loads and determines the calculated figure, area and position of the resulting yield surface. Additionally, the choice of FE dynamic arithmetic and implicit algorithm in simulation of earthquake exciting was selected. The choice can accept dynamic stress model caused by dynamic load with the characteristic of constringency which dynamic explicit algorithm does not make the model allow but dynamic implicit makes the model allow (Huang et al., 2008). By the evaluation of the variations of the dynamic force, stress field and strain are investigated using the 3D-FE model field.

Boundary conditions

In 3D-FE models related to soil and pipeline, two boundary conditions of bottom surface and four beside surfaces of 3D-FE soil model and it is also necessary to consider two boundary conditions of 3D-FE pipeline model.

The pipelines are affected by the soil due to displacement and stress. The types of soil, such as sandy soil and cohesive soil, make the act of pipeline different (Liu et al., 2010). The buried pipeline is moved relatively with soil. Therefore, the pipeline of the circumferential surface is assumed to be bonded with soil in order to simulate this behaviour of pipeline.

The infinite length of pipeline, ends are consider as roller because the buried pipeline may be moved with soil relatively. consider, if finite length of buried pipeline is defined due to the existence of buildings at the ends of buried pipeline, it is suitable to consider hinge as the boundary ends. Thus, the restrained ends of pipeline may be completely fixed in all directions (i.e. $u = v = w = 0$). To be honest, built-in infinite elements can simulate infinite boundary condition in ABAQUS. But, unknown errors occurred when the models were made in ABAQUS for this research. Therefore, considering roller boundary condition was presented in this research as an alternative method for considering infinite boundary condition.

Adaptive Meshing for Finite Element Analysis (FEA)

FEA is very important to determine the type, shape and the number of elements required for entire continuum.

The type of element

In ABAQUS packages is related to the 3D-FE modeling process, elements exist not only with appreciable anti-distorting ability and also with appreciable flexibility. Under the comprehensive consideration of the pipeline, whereas the 3D reduced integration continuum element with eight nodes as a linear interpolation and with twenty nodes as a quadratic interpolation, the 3D reduced shell continuum element with four nodes as a first-order (or linear) interpolation, S4R, and with eight nodes as a second-order (or quadratic) interpolation, S8R were chosen.

Size of the element

Increasing the density of the meshed elements also provides the accuracy of analysis because the number of elements in 3D-FE models is one of the most important factors for the quality of analysis as well as the selection of the adaptive element type. Mesh refinement for selecting the optimal number of elements is a difficult issue. This is because there is no regulation which number of meshed elements is an optimum number for the accuracy of analysis. Thus, in order to examine the best adaptable number of elements, it is necessary to investigate all the cases of each number of elements from a coarse mesh to a fine mesh within the range based on available computational capacity.

Static analysis

Static analysis was executed by using the 100m model under static loads as outlined on section. The self-weight of pipeline and soil are considered as static loads, traffic load onto ground and internal pressure of pipeline. Among these loads, traffic load onto ground and internal pressure of pipeline were considered as maximum magnitude load in order to examine the critical statement of pipeline in the moment of the most danger. In the ABAQUS model adding gravity value as 9.81 N for self-weight of both pipeline and soil. The traffic load onto ground was considered as a uniform contact pressure, 1100 kPa, on the top surface of soil

model. The internal surface of pipeline model applied the internal pressure as 414 kPa.

Displacement of soil

The calculated soil subsidence was considered as a short-term serviceability issue because the present soil model created by ABAQUS considered only immediate settlement under static loads without considering drainage of water situated in the soil and the soil's consolidation depending on passage of time. Even though the magnitude of „soil settlement“ in the vertical varied in accordance with different soil types such as sandy soil and cohesive soil, the soil settlement affected by static loads typically behaved vertically. ABAQUS yield results of calculated scenarios were shown by each buried depth of pipeline and soil type.

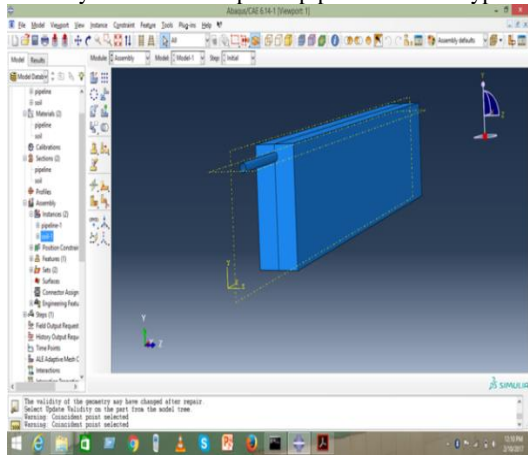


Fig.4: Assembly of pipeline

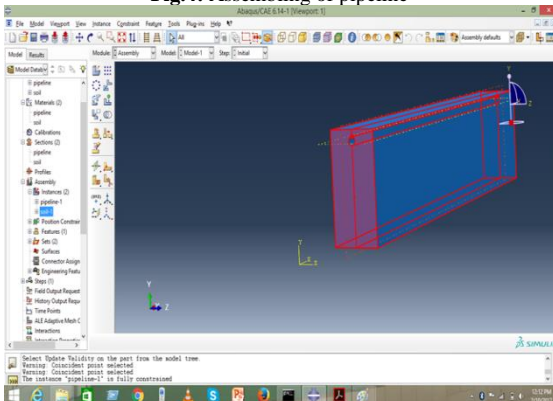


Fig.5: Assembly of soil and pipeline (burial depth =2m)

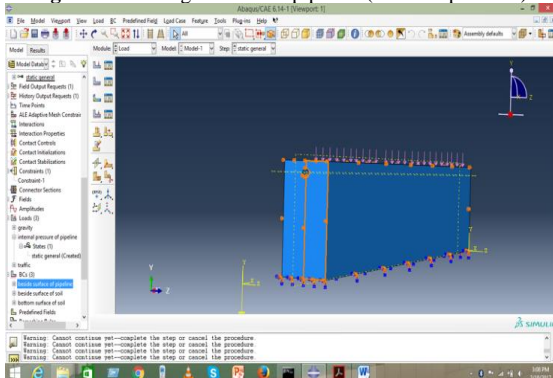


Fig. 6: Loadings on the entire soil-pipeline model

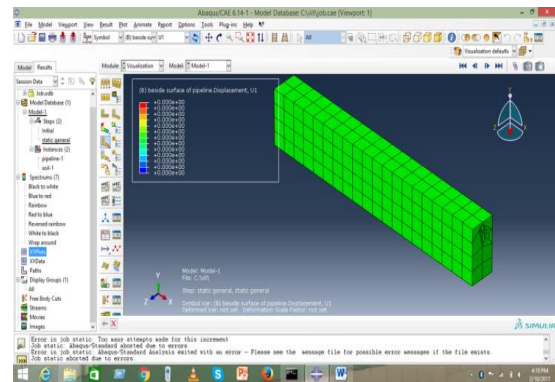


Fig. 7: Meshing on the entire soil-pipeline model

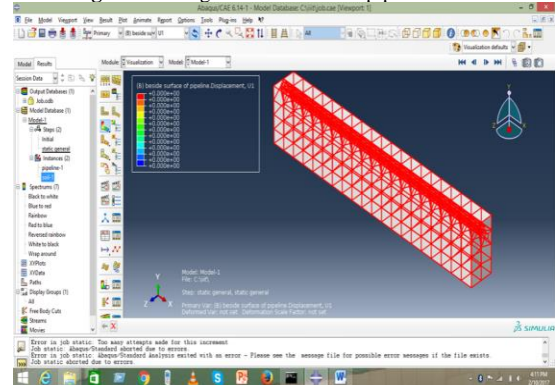


Fig 8: Results (static analysis)

3. Dynamic analysis

Seismic analysis was executed by using the 100m model under seismic load described as ElCentro Earthquake as outlined on section 1.3.2 and Appendix A. The El-Centro Earthquake has about 0.3g of vertical ground acceleration with 7.1 magnitude on the Richter Scale and 31.18sec duration time history. In this section, seismic pipeline displacement and stress affected by a quasi-state 0.31882g of downward vertical ground acceleration at 2.02 sec are analysed in order to examine critical statement of the moment behaviour of pipeline is the most danger.

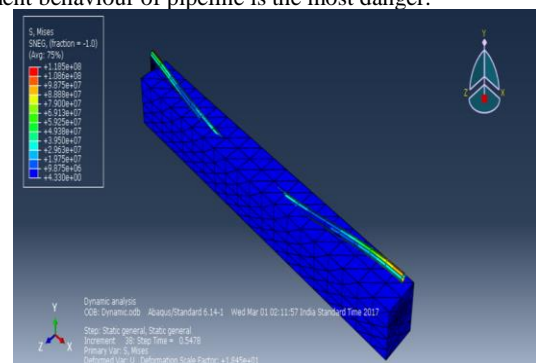


Fig 9: Results (dynamic analysis)

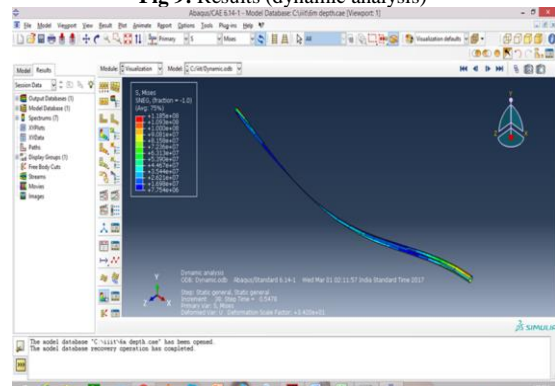


Fig.10: Pipe deflection on amp. of 30sec. (dynamic analysis)

4. Dynamic analysis of continuous pipe with 5 joints

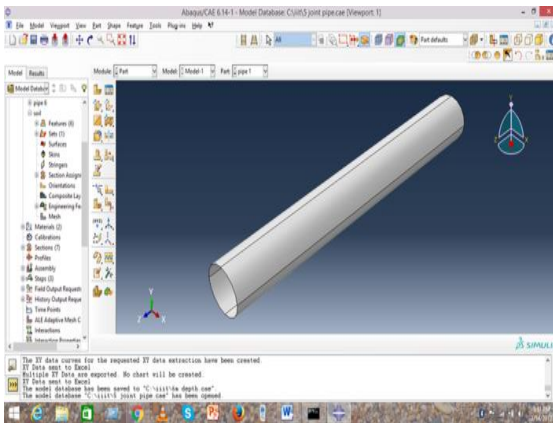


Fig.11: 3D Pipeline model (L=100m, dia=1.524m)

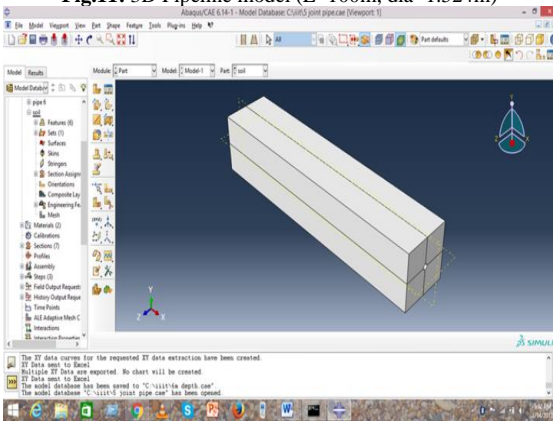


Fig.12: 3D Soil model (L=100X100X20m)

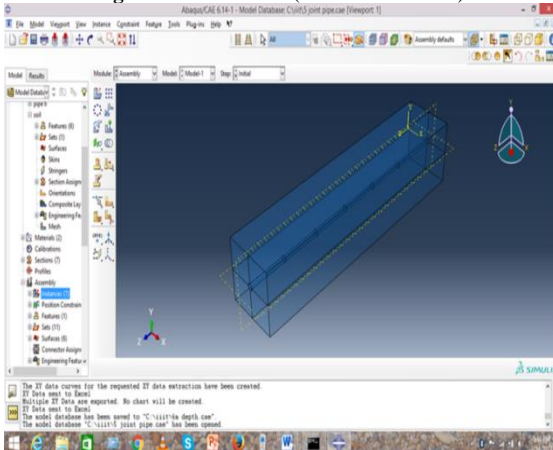


Fig.13: Assembly of soil-pipeline model (burial depth =6m)

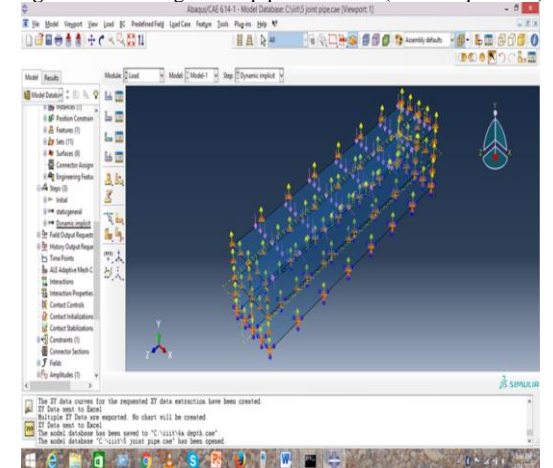


Fig.14: dynamic loading on the entire soil-pipeline model

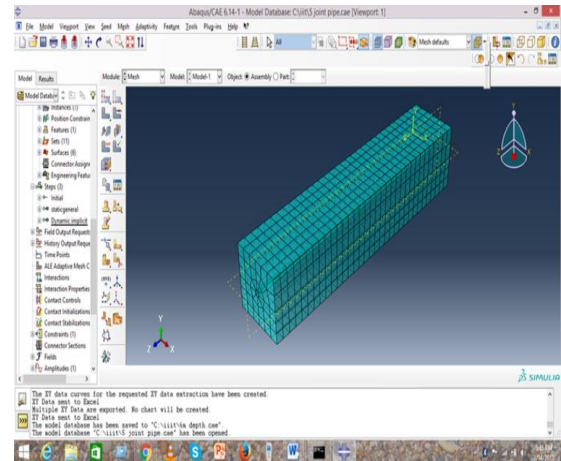


Fig.15: Meshing on the entire soil-pipeline model

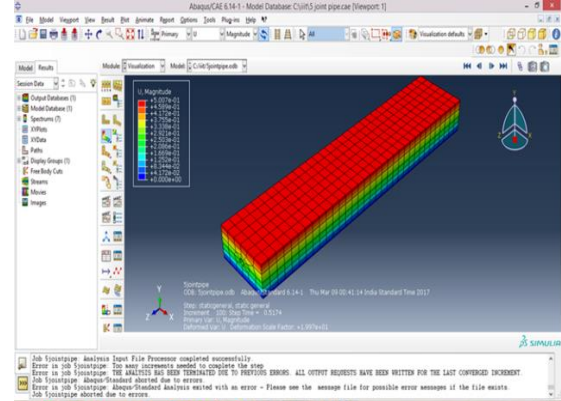


Fig.16: Results (dynamic analysis of soil-pipeline with burial depth 6m)

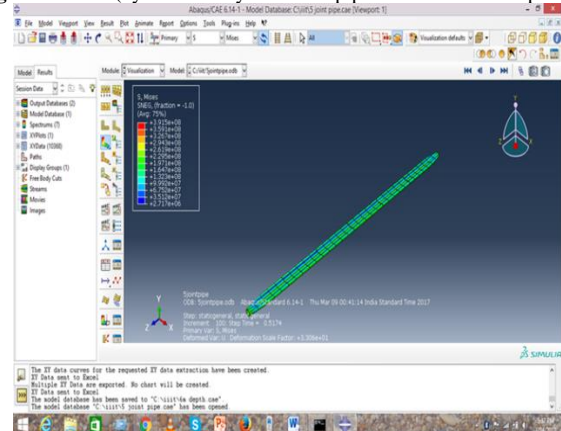


Fig.17: Deflection of pipe (Dynamic analysis)

5. Dynamic analysis of soil-pipeline model by varying density of soil

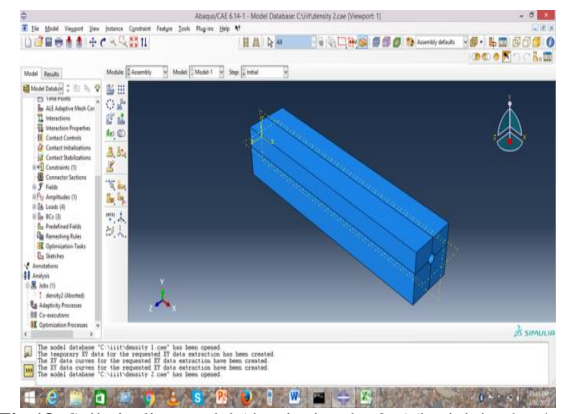


Fig.18: Soil pipeline model (density inc. by 2%)(burial depth =4m)

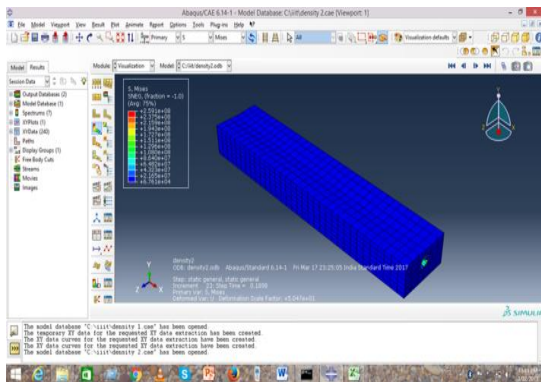


Fig.19: Results on dynamic analysis soil-pipeline (densityinc by 2%)

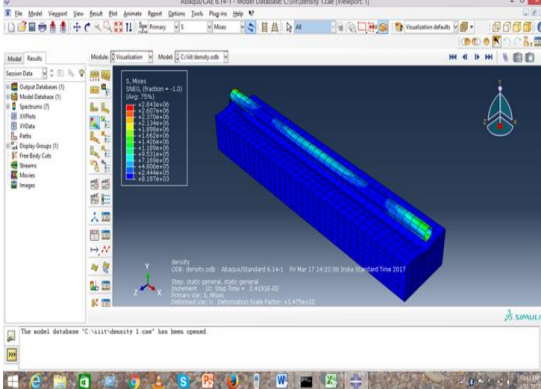


Fig.20: Pipe deflection on inc. density by 2%

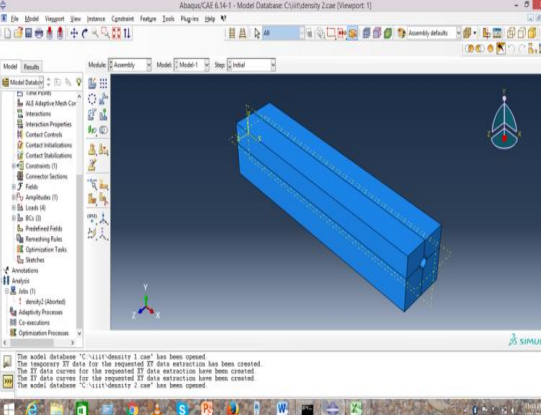


Fig.21: Soil pipeline model (densityinc by 4%, burial depth=8m)

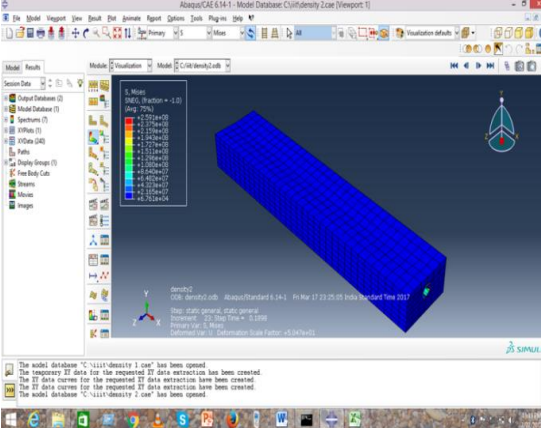


Fig.22: Results for dynamic analysis of soil-pipeline (density inc by 4%)

6. Results and discussions

Dynamic analysis

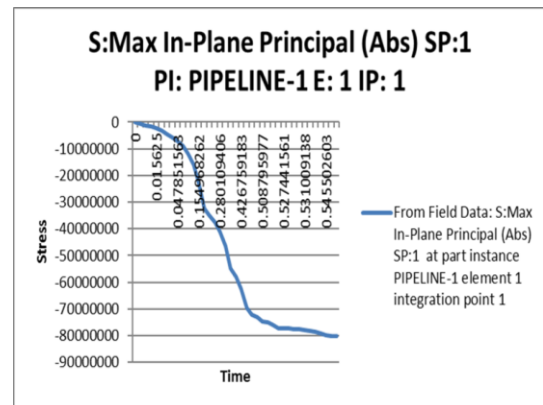


Fig.23: Graph for stress v/s time, element no.1 at node 1

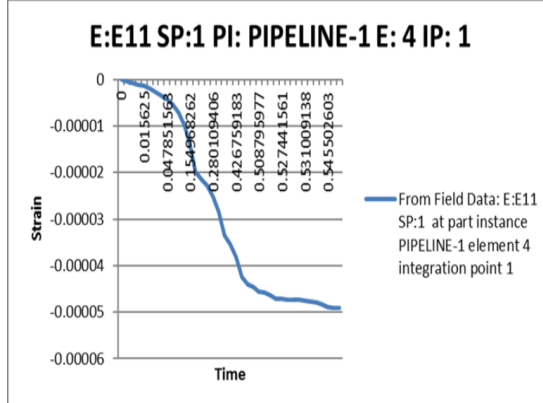


Fig.24: Graph for strain v/s time, element no.4 at node 1

Dynamic analysis of cont. pipe with 5 joints

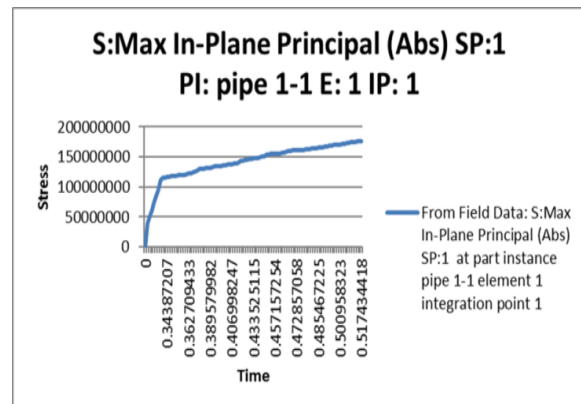


Fig. 25: Graph for stress v/s time at nodal point 1

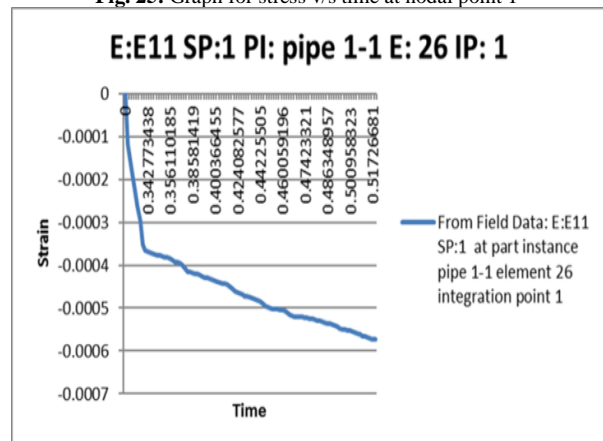


Fig.26: Graph for strain v/s time at nodal point 1

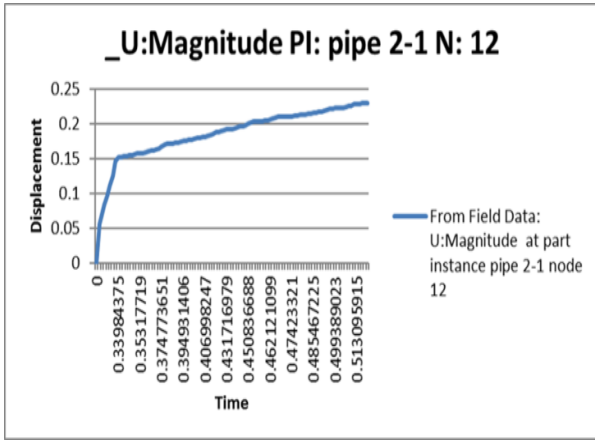


Fig. 27: Graph for displacement v/s time at nodal point 2

Dynamic analysis of soil-pipeline model with varying density of soil

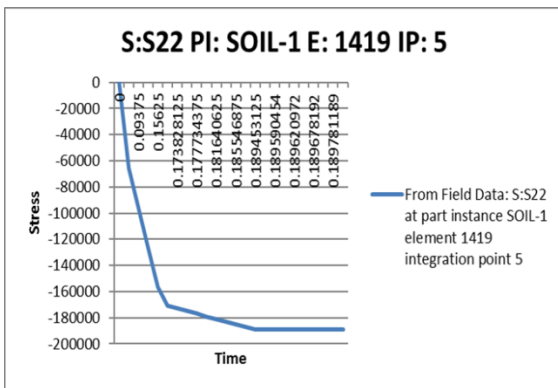


Fig. 28: Graph for stress v/s time at nodal point 5 (densityinc. by 2%)

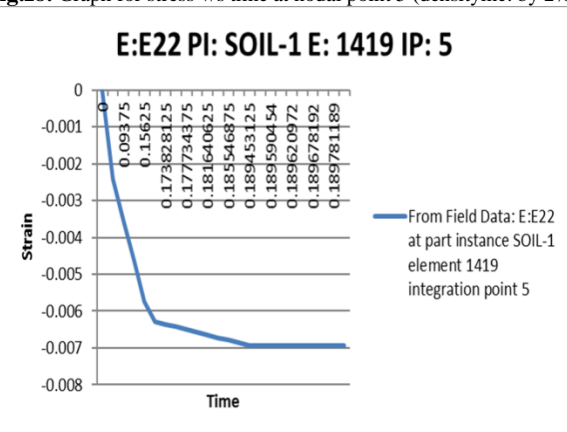


Fig. 29: Graph for strain v/s time at nodal point 5 (densityinc. by 2%)

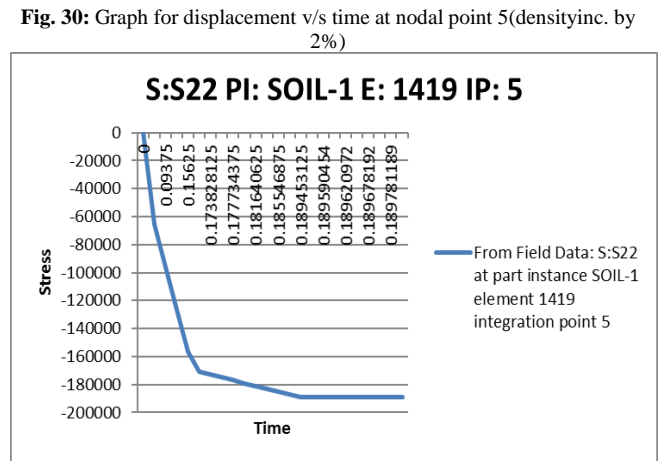
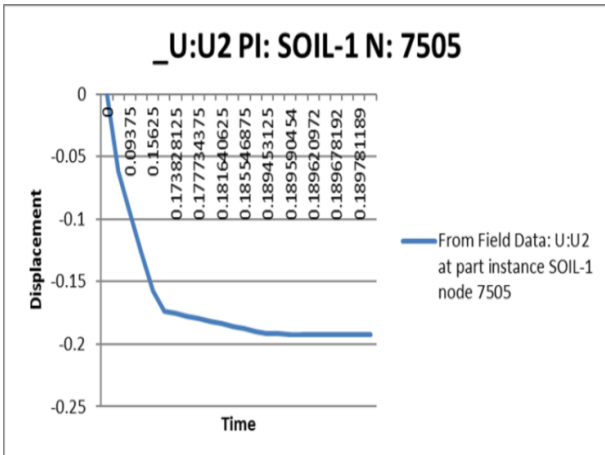


Fig. 30: Graph for displacement v/s time at nodal point 5 (densityinc. by 2%)

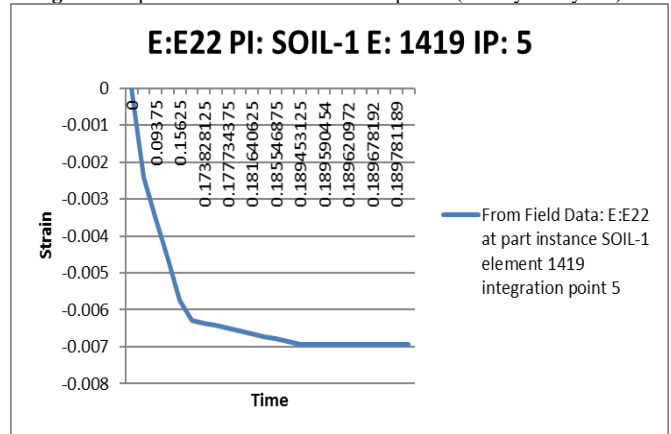


Fig. 31: Graph for stress v/s time at nodal point 1 (densityinc. by 4%)

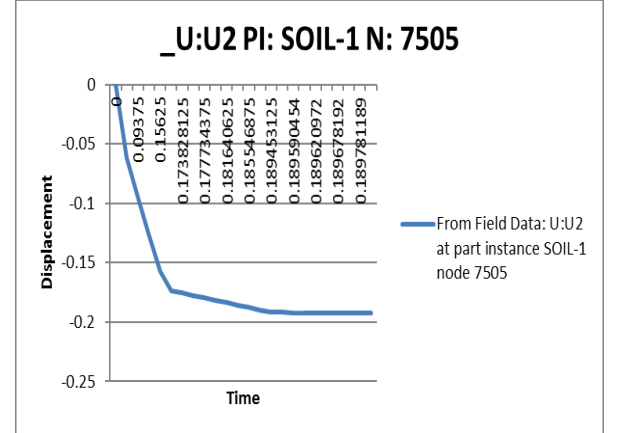


Fig. 32: Graph for strain v/s time at nodal point 1 (densityinc. by 4%)

7. Summary

The Finite Element Analysis for buried pipelines - for static analysis mesh study was carried out initially, the analysis for understanding boundary condition effects of pipeline ends and seismic analysis. Secondly, static loads were applied to the 100m models involving both soil and pipeline; 1100kPa uniform traffic surface load onto the top surface of the soil, 414kPa internal pipeline pressure on internal pipeline surface and self-weight of both pipeline and soil. Static loads generally cause oval shaped pipeline deformation and vertical soil settlement with pipeline. The behaviour of both soil and pipeline caused by static loads was considered in short-term serviceability issues because the permeability of water situated in soil and the consolidation of soil depending on passage of time were not considered. Different magnitudes of settlement comparing soil and pipeline were assessed because the pipeline settlement was relatively smaller than the settlement of the soil burying pipeline. This meant that

even though the pipeline buried in the soil moves vertically under static loads, the pipeline movement is smaller than the movement of the soil.

Thirdly, the pipeline ends, roller and hinge are considered as two boundary conditions were assumed and 100m models involving soil and pipeline were used in order to examine the boundary condition effects on pipeline ends under static loads. Two different boundary conditions considered involve two different meanings; roller boundary condition at pipeline ends are consistent with infinitely long pipelines without any restriction at pipeline ends and hinge boundary condition with a pipeline between two buildings at pipeline ends.

Finally, a seismic load was applied to the 100m models involving soil and pipeline; ElCentro earthquake was about 0.3g of vertical peak ground acceleration with 31.18sec seismic time history. However, in the seismic analysis for buried pipelines, there is something to be desired because the effect of each burial depth of pipeline caused by vertical peak ground acceleration was not examined due to the different step time selection for the analysis.

8. Conclusion

Thus, we have designed buried pipelines by giving dynamic loads with varying burial depths, density of soil to show the pipe deflection in each case. For example- during static loads the pipe behavior is almost negligible as compared to in dynamic loading the pipe behavior changes rapidly. Hence, we can conclude that the decrease of generated pipeline stress should be considered for pipeline design under seismic load when the pipeline is built.

References

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