ANALYSIS OF CONTINUOUS AND SEGMENTED PIPELINE IN LIQUEFIABLE SOIL

by

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ANALYSIS OF CONTINUOUS AND SEGMENTED PIPELINE IN LIQUEFIABLE SOIL

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ABSTRACT

Pipelines are the important mode of transportation for liquid and gas over competing modes for several reasons as they are less damaging to the environment, less susceptible to theft, and more economical, safe, convenient, and reliable than other modes. Pipelines are generally buried below ground for aesthetic, safety, economic and environmental reasons. They require proper designing and safety checks in order to perform well in earthquake shaking as their failure can lead to major hazards. This paper investigates a number of buried pipelines and their interaction with soil under seismic environment. As a part of this, a number of continuous and segmented pipelines of different diameter, length, and thickness have been taken into consideration. The density, internal pressure of pipe, and density of surrounding soil are taken into account. In continuous pipelines, the safety of the pipeline is checked against the force due to bouncy whereas, in segmented pipelines, it is checked against permanent ground deformation (PGD) due to liquefaction. Results are shown based on the study. Strain and displacement curves for the different pipe parameters including pipe diameter and its thickness are plotted so that one can observe its behaviour and can identify the critical point for safety. 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 analysed as per IITK-GSDMA (IIT-Kanpur-Gujarat state Disaster Management Authority) guidelines on seismic design. MATLAB code had been developed and further buried pipeline risk assessment tool GUI (Graphical User Interface) has also been prepared so that user can enter pipe parameters and soil properties and can find the safety of the pipelines

Keywords: continuous pipelines, segmented pipelines, liquefaction, PGD.

INTRODUCTION

Conduits are safe and economical means of transportation of gas, water, sewage and other fluids and they are usually buried under ground to provide safety, protection and support. Pipelines are generally designed by considering the flow, pressure parameters but the performance of buried pipelines systems in areas subjected to the liquefaction is an important consideration and can be a major cause of damage to the utilities. Many of the exciting buried pipeline system including gas, water and sewer are located at shallow depths and these pipes are already near the limit of their current strength and only a small ground deformation could initiate failure. So the earthquake safety of buried pipelines has attracted a great deal of attention in recent years. Many buried pipelines in India run through seismic areas and, therefore, are exposed to considerable seismic risk. Pipelines running through high seismic zones should be designed in such a way that they remain functional even after subjected to high-intensity earthquake shaking. However modern pipelines manufactured with steel, iron, or concrete possess good ductility. It has been observed that the overall performance record of oil, gas and water pipeline systems in past earthquakes was comparatively good but some disastrous failures did occur in many cases, particularly in areas of unsettled soils. These failures have caused mainly due to large permanent soil displacements, faulting and liquefaction.

In India currently, there is huge pipeline network system. Considering high seismic zones of our country, it is important to ensure seismic safety of buried pipelines. And in last few years, many governments owned and private organizations had built up their pipeline networks across the country. Based on these facts the performance of buried pipelines subjected to PGD due to soil liquefaction and other seismic hazards have become an important subject of study.

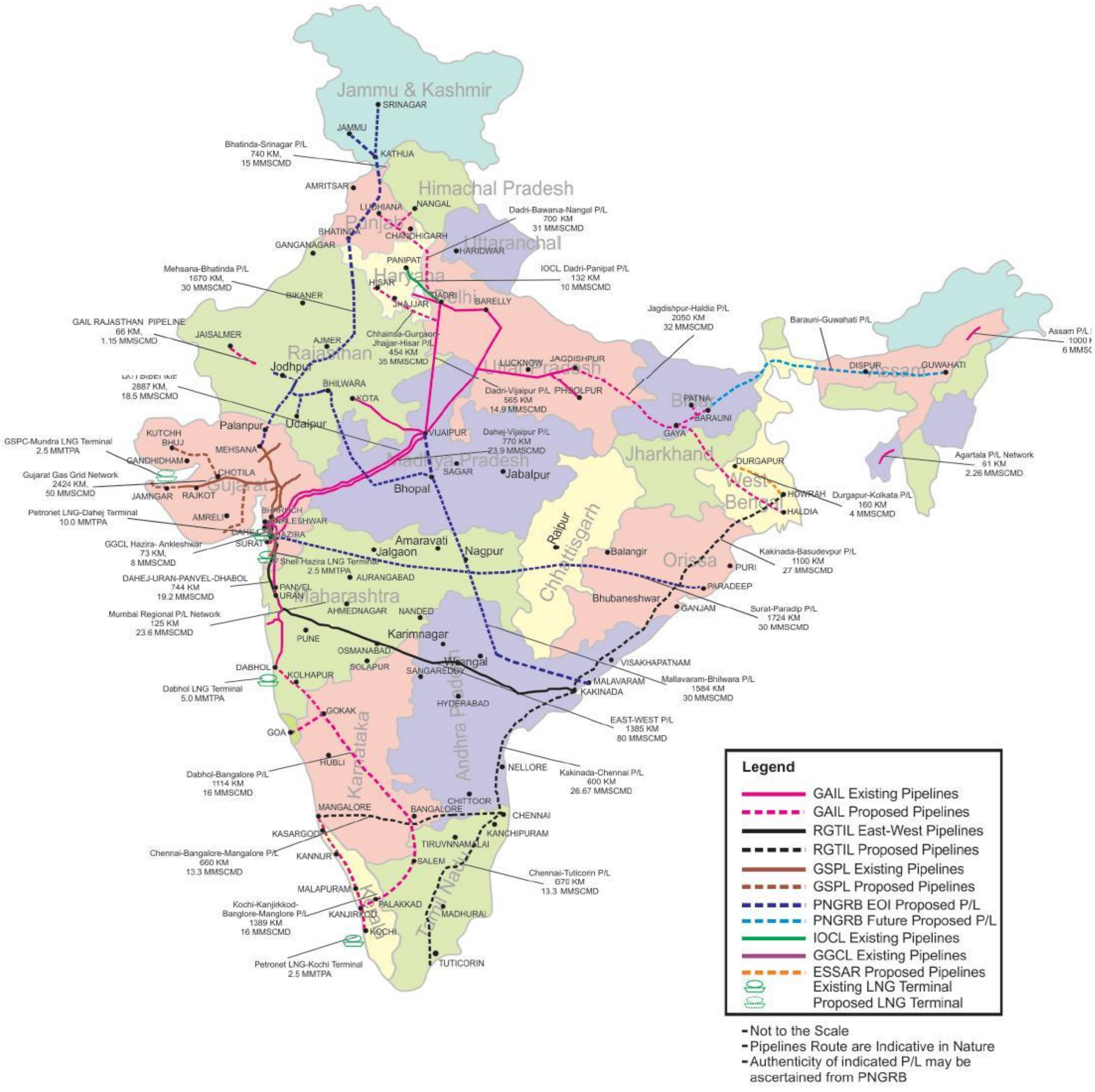


Figure 1. Pipelines network in India (Petroleum and Natural Gas Regulatory Board)

So in this study a number of continuous and segmented pipelines of different diameter, length, and thickness have been taken into consideration. The density, internal pressure of pipe, and density of surrounding soil are taken into account. In continuous pipelines, the safety of the pipeline is checked against the force due to bouncy whereas, in segmented pipelines, it is checked against PGD. Results are shown based on the study. Strain and displacement curves for the different pipe parameters including pipe diameter and its thickness are plotted so that one can observe its behaviour and can identify the critical point for safety. 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 analysed as per IITK-GSDMA (2007) guidelines on seismic design. MATLAB code had been developed and further buried pipeline risk assessment tool GUI (Graphical User Interface) has also been prepared as shown in figure 3, 4, 5 so that user can enter pipe parameters and soil properties and can find the safety of the pipelines

Effects of earthquake on buried pipelines

In most of the cases buried pipelines are affected either by wave propagation or permanent ground deformation. There have been some events where buried pipes are affected only due to wave propagation or sometimes only by permanent ground deformation due to liquefaction. Some examples to show an impact of earthquakes on buried pipes 1971, San Fernando Earthquake caused a wide damage to the pipeline system damaging about 1.24 m diameter water pipeline at eight bends. In this effect the behaviour of ductile, steel pipelines against ground shaking is relatively good compared to ground deformation associated with faulting and lateral spread. Pipelines were also damaged by liquefaction-induced due to lateral spread and landslides. This failure was caused by compressive forces wrinkling in the pipes. 1983 Coalinga Earthquake caused numerous damages in the natural gas pipeline. Several pipeline failures occurred in oil drilling and processing facilities and it was observed that most of the damage has occurred at pipe connections. During 1987 Whittier Narrows earthquake a number of pipelines were affected due to the large lateral relative displacement of ground .most of the pipelines affected by this earthquake were corroded or anchored. Southern California Gas reported that 1411 gas pipelines leaked due to this earthquake. The 1989 Loma Prieta Earthquake with a M_W of 7.1 caused a great damage to water lines. This was due liquefaction and excessive pressure of soil. The1992 Big Bear Earthquakes i.e. two earthquakes occurred in San Bernadino County, California, with a M_W of 7.5 and 6.6. These two earthquakes were followed by numerous aftershocks. Horizontal fault rupture displacement associated with this event was from 5 to 9.5 feet. Most of the pipelines damaged in this effect were associated with the rupture zone. 1994 Northridge Earthquake caused 1,400 pipeline breaks in the San Fernando Valley area. Outside the zone of high liquefaction potential, the dispersed pattern of breaks is attributed to old brittle pipes damaged by ground movement. In the On Balboa Boulevard, pipelines were affected in tensile failure and compressive failure. Pipe failures located more where ground rupture zone is perpendicular to the pipeline. In the 1995 Hyogoken-Nanbu Earthquake Takarazuka City was heavily damaged. The damage was more on the water supply system and about 203 pipelines were damaged, 50% of damages occurred in the unliquefied ground. The 1999 Chichi Earthquake also affected buried water and gas pipelines at many sites. It was reported that pipelines went bending deformation due to ground displacement at a reverse fault. The bending deformation in a 100A-size pipeline was V -shaped, with the pipeline being bent at three points.

The deformation of a 200A-sizepipeline was Z-shaped, with the pipeline being bent at two points. There is no substantial deformation in gas pipelines comprised of welded steel pipes. From the past studies, the factors which govern the pipeline failure are Seismic wave propagation, abrupt permanent ground displacement (faulting), Permanent ground deformation (PGD) related to soil failures, Longitudinal PGD, Transverse PGD, and Buoyancy due to liquefaction.

(a).Failure of a steel pipeline
(Mexico City earthquake, 1985)

(b).Joint failure of a concrete pipeline
(Mexico City earthquake, 1985)

(c).buried water pipeline damage due to 2004 Niigata-chuetsu Earthquake

(d).buried pipeline damage due to 2003 Tokachi-oki Earthquakes in Urakawa city

Figure 2. Damages in pipelines during past earthquakes.

Continuous pipelines

Pipelines having high strength and stiffness of joints compared to pipe barrel are generally referred to as continuous pipelines. The tensile failure in continuous pipelines is caused due to soil liquefaction, landslide, and ground motion at the pipe. Local bulking or wrinkling occurs due to the forces induced by the pipe at underground together with tensile strains and compressive on the pipe wall. When the compressive strains in pipe exceed a certain limit, the pipeline wall exhibits instability causing local buckling or wrinkling. Beam buckling generally occurs in pipelines buried at shallow depths. In beam buckling, the pipe undergoes an upward displacement. As the compressive strains in the pipelines are not capable of bearing the load coming due to relative movement over a large distance the potential for tearing the walls of pipes is less. For this sake beam buckling of a pipeline for compression, zone is considered more than the local buckling.

In this paper, performance of continuous pipelines in liquefiable soil is carried out as explained below.

- The Net upward force per unit length of the pipeline is calculated as

$$F_b = \frac{\pi D^2}{4}(\gamma_{sat} - \gamma_{content}) - \pi D t \gamma_{sat} \qquad (1)$$

- Bending stress in the pipeline due to uplift force is calculated by

$$\sigma_{bf} = \pm \frac{F_b {L_b}^2}{10Z} \qquad (2)$$

- Maximum strain in pipe to the corresponding bending stress is been evaluated as

$$\varepsilon = \frac{\sigma_{bf}}{E}\left[1 + \frac{1}{1+r}\left(\frac{\sigma_{bf}}{\sigma_s}\right)^r\right] \qquad (3)$$

- The longitudinal stress induced in the pipe due to internal pressure is calculated as

$$S_p = \pm \frac{PD\mu}{2t} \qquad (4)$$

- The longitudinal strain in the pipe due to internal pressure is calculated as

$$\varepsilon_p = \frac{S_p}{E}\left[1 + \frac{n}{1+r}\left(\frac{S_p}{\sigma_y}\right)^r\right] \tag{5}$$

- The longitudinal stress induced in the pipe due to change in temperature is evaluated by

$$S_T = E\alpha(T_2 - T_1) \tag{6}$$

- The longitudinal strain in the pipe due to change in temperature is measured by

$$\varepsilon_t = \frac{S_t}{E}\left[1 + \frac{1}{1+r}\left(\frac{S_t}{\sigma_y}\right)^r\right] \tag{7}$$

- Operational strain is calculated by adding the strains caused due to internal pressure and temperature changes.
- Design strain in Tension = Maximum strain + Operational Strain
- Design strain in Compression = Maximum strain - Operational Strain

By considering the above equations (1-7) the behaviour of continuous pipelines for different grades of pipes i.e. X42, X52, X60, X65, and X70 is checked and relative graphs are plotted in figure (6-7).

Segmented pipelines

The common type of failure that occurs in the segmented pipe is axial pull-out at the joints this is due to the shear strength of joint covering material is much less than the pipe. The crushing of bell-and-spigot joints is a very common failure mechanism in areas of compressive strain. In the areas of tensile ground strain, a flanged joint pipeline may fail at joint due to the breaking of the flange connection. When a segmented pipeline is subjected to lateral permanent ground movements, the ground is accommodated by some combination of rotation and flexure in the pipe segments. The relative Contribution of these two mechanisms depends on the joint rotation and pipe segment flexural stiffness.

In this paper the segmented pipe behaviour against liquefaction is carried out as explained below

- The longitudinal stress induced in the pipe due to internal pressure is been calculated by

$$S_p = \frac{PD\mu}{2t} \tag{8}$$

- The longitudinal strain in the pipe due to internal pressure is been evaluated by

$$\varepsilon_p = \frac{S_p}{E}\left[1 + \frac{n}{1+r}\left(\frac{S_p}{\sigma_y}\right)^r\right] \tag{9}$$

- The longitudinal stress induced in the pipe due to change in temperature is measured by

$$S_T = E\alpha(T_2 - T_1) \tag{10}$$

- The longitudinal strain in the pipe due to change in temperature is calculated by

$$\varepsilon_t = \frac{S_t}{E}\left[1 + \frac{1}{1+r}\left(\frac{S_t}{\sigma_y}\right)^r\right] \tag{11}$$

- Operational strain has been calculated by adding the strains caused due to internal pressure and temperature changes.
- Operational Joint displacement can is determined by Multiplying the Length of the segmented pipeline and the operational strain.

- Design ground movement due to seismic action is determined by the Multiplying the PGD and Importance factor of Pipe and by considering the allowable joint displacement of the Pipe as 6mm.
- From the above equations we will be carrying out the Design displacement in compression and tension

By considering the above equations (8-10) the behaviour of segmented pipes in liquefiable soil is checked and the relative graphs are shown in figure 5, 8

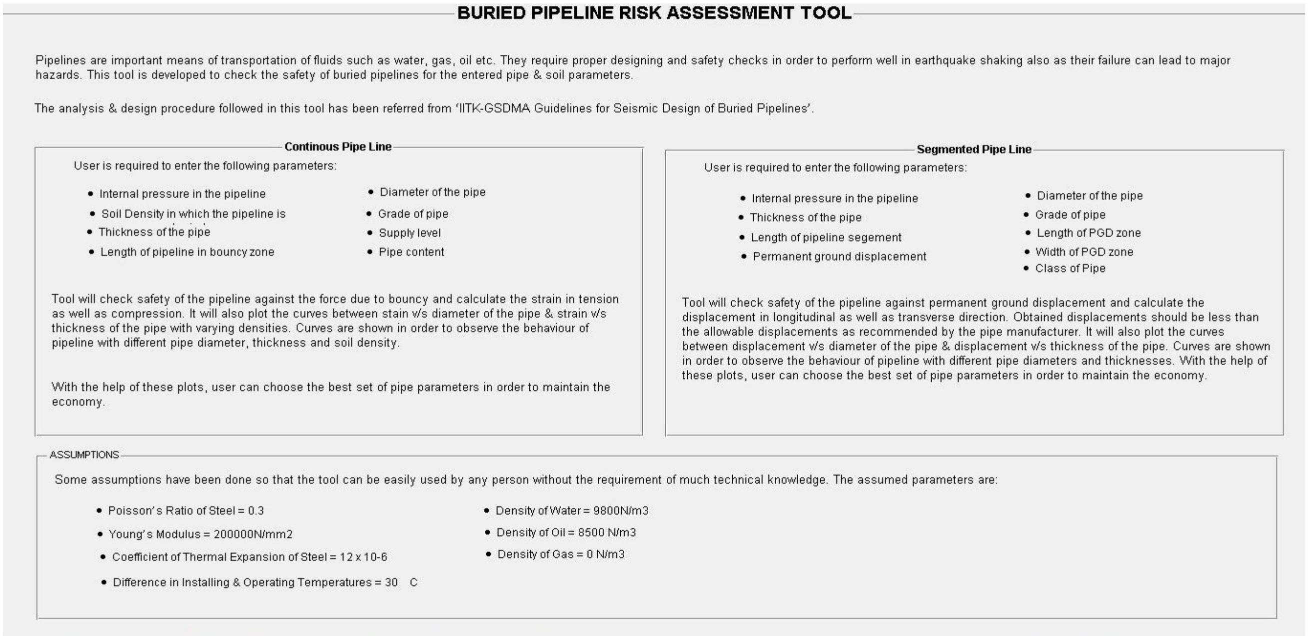


Figure 3. Graphical user interface (GUI)

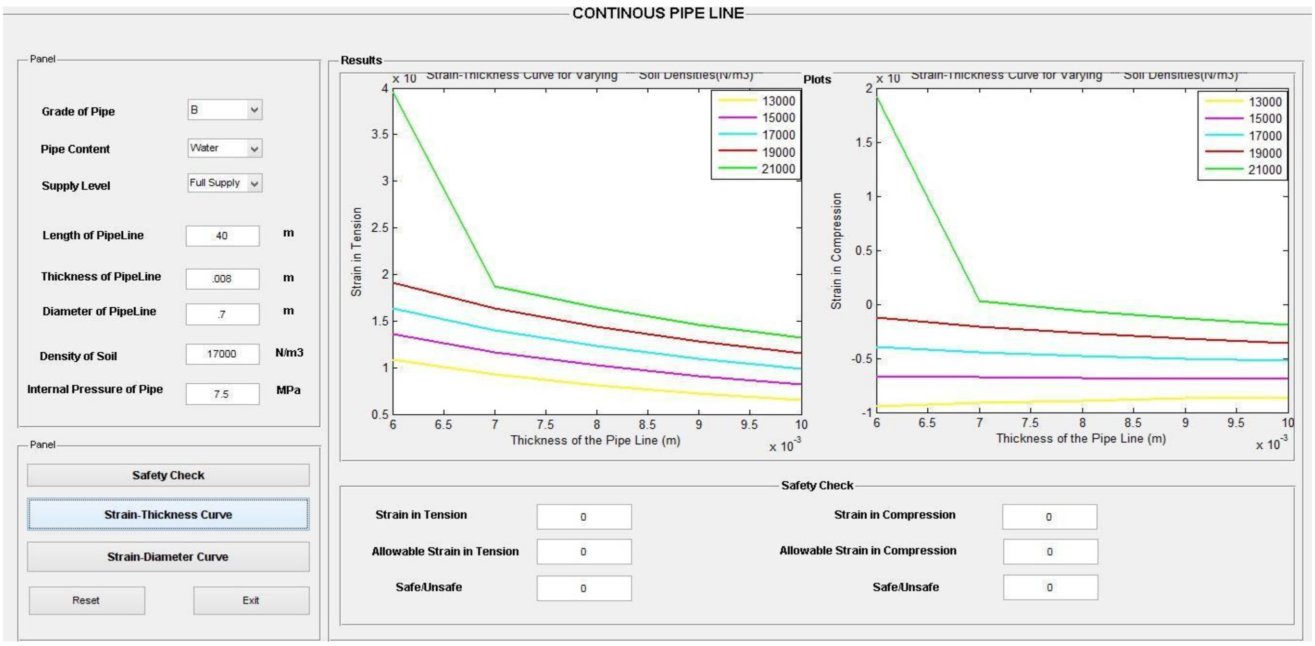


Figure 4. Graphs for continuous pipelines in GUI

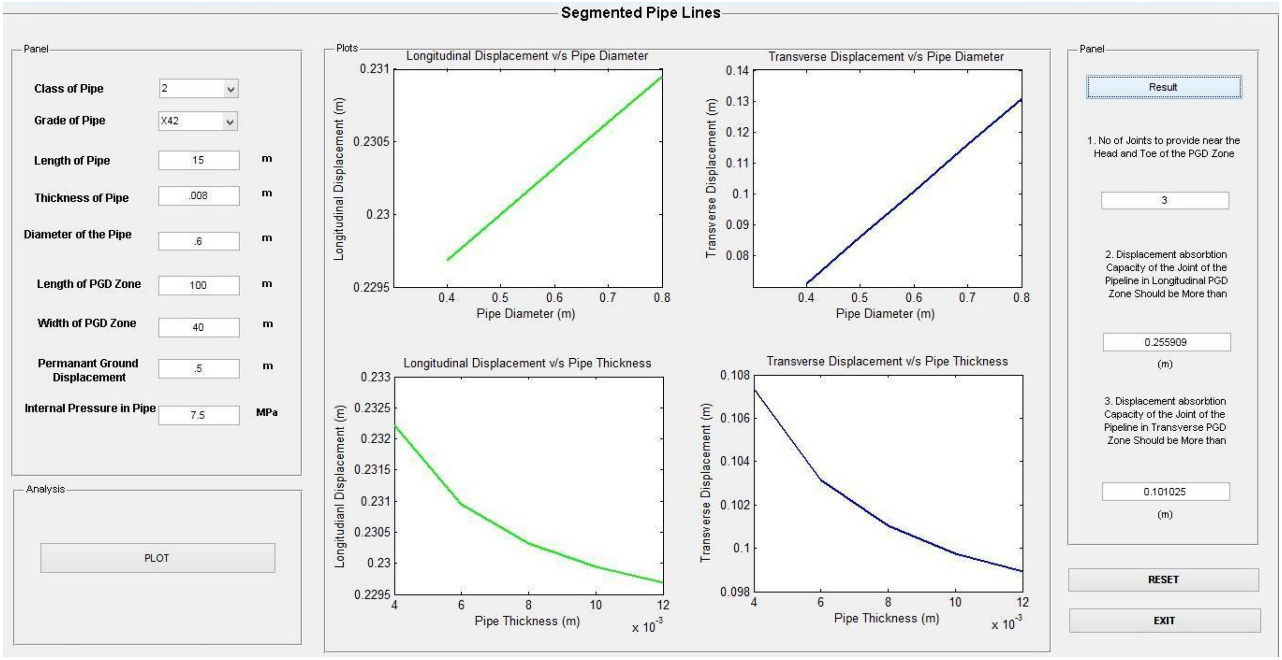
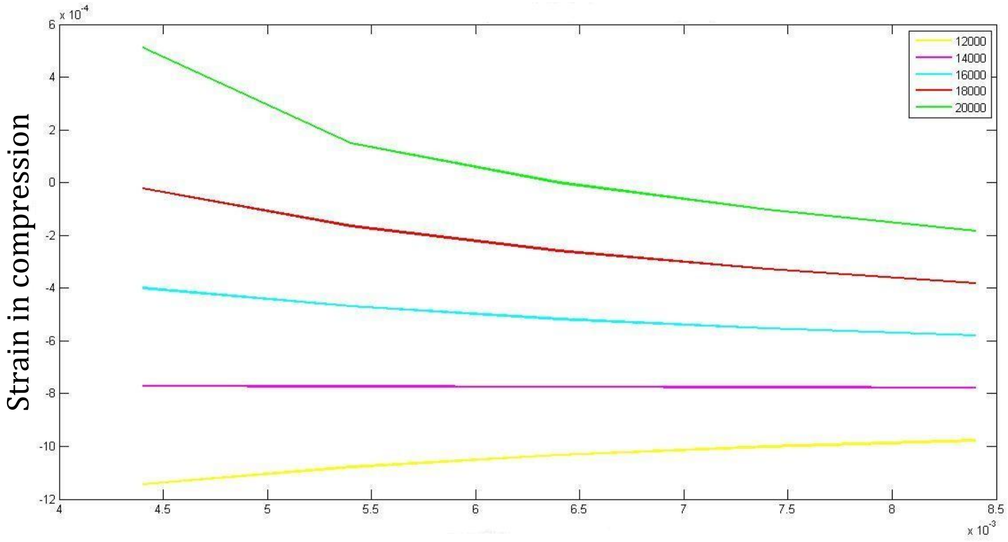


Figure 5. Graphs for segmented pipelines in GUI

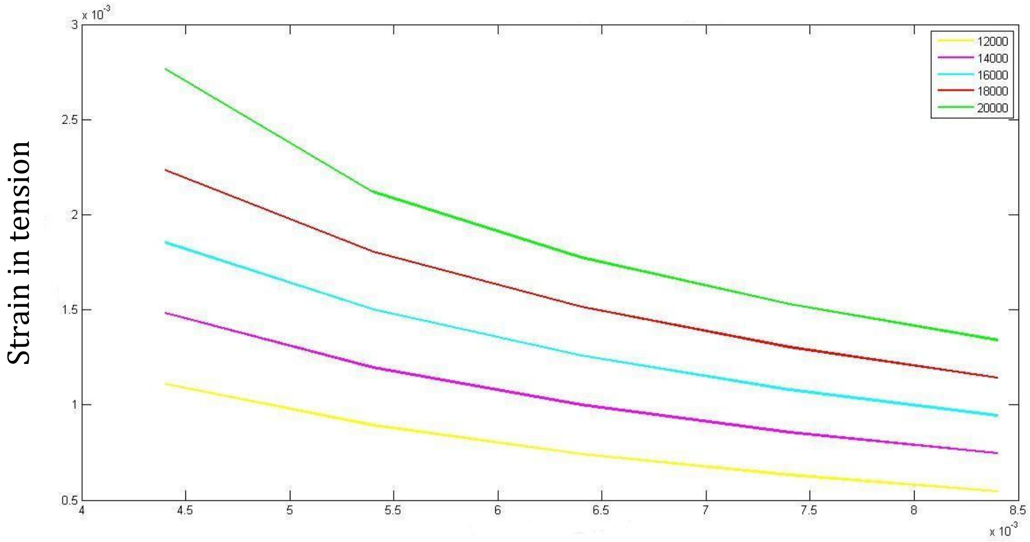
RESULTS AND DISCUSSION

The problem was analyzed by taking set of analytic equations from preceding authors Trautmann and O'Rourke (1985), IITK-GSDMA (2007) and the results are compared in Fig (6-8).The GUI will check safety of pipeline against the force due to bouncy and plot the graphs between strain vs. diameter / thickness of the pipe in compression, tension with varying soil densities. Curves are shown in order to observe the behavior of pipelines with different pipe diameter, thickness and soil density, with the help of these plots, user can choose the best set of pipe parameter in order to maintain the economy, safety.



Thickness of the pipe (m)

Figure6. Strain vs thickness of pipe in compression for varying soil densities.



Thickness of the pipe(m)

Figure7. Strain vs thickness of pipe in tension for varying soil densities

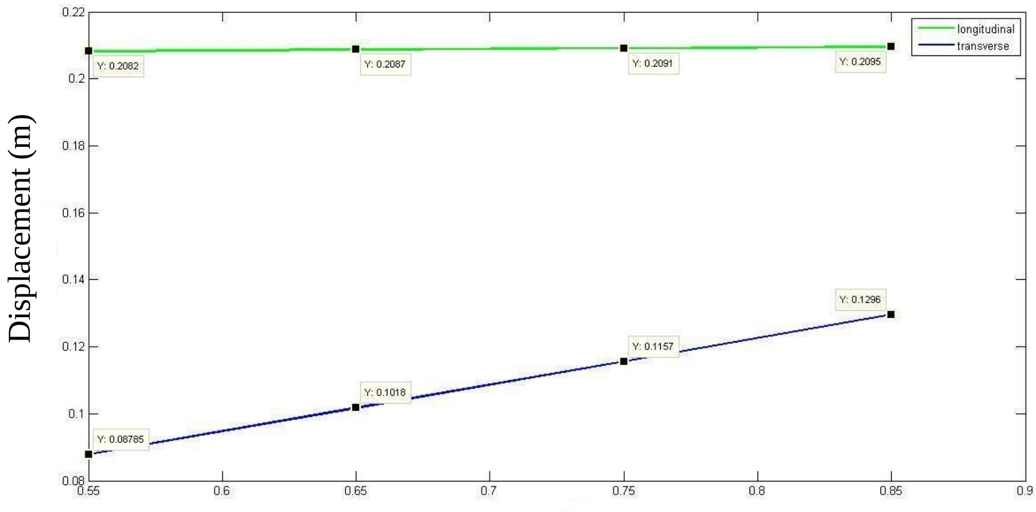


Figure 8 Displacement curve vs diameter of pipe in segmented pipes

From the following graphs I.e. figure (6-8) Continuous pipelines of higher density leads to higher strain and thus create unsafe condition for pipelines. Density of soil is the most critical factor affecting the pipeline safety, loose soil should be preferred as a backfill material and for segmented pipelines strength of soil surrounding the pipeline should be improved to reduce the lateral soil movement and soil flow, special connections are required to accommodate large ground movement in the areas of permanent ground deformation. The pipelines may be supported at large distance on piers to increase the flexibility.

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