ISSN:2231-0711

Parametric Study of buried Pipelines Under Pressure different Loading Effects and it's signal conditioning

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Abstract: Natural gas is one of the important fuel source in the world and the major source of supply for this natural gas is through pipe lines.These pipe lines travel through different terrains and are most o the times undergroung where they have to bear the load on the top of the soil.The kind of load that is appllied and transferred on the soil decides the life of the pipe and in some cases too much load on the soil results in failure of these pipe lines.Adetail study in support to find the critical parameter for buried gas pipelines underground overload. The ground load as well as internal and external pressure has significant effect on the pipeline safe operation result in inducing bending strain that may cause creep as well as dynamic failures. In this paper effect of the increasing external load, increasing depth, effect of operating pressure on the external load and increase internal pressure were monitored through a numerical simulation model. The analysis was done for two domestic gas distribution pipelines of 2-inch and 1-inch Diameter. Soil tests were conducted at the Soil Mechanics and Laboratory for various soil samples and effect of the external load was monitored under different type of soil. Further it was observed during data collection that the under ground sensors experiening a lot of noise or rubbish signal thus a signal conditioing was also included to refine and improve the results.
Keywords: Finite Element Analysis, Safe Depth, Traffic Load, Gas Pipeline, Abaqus 6.14, Filters, sensors

1. Introduction:

A properly designed and well-maintained Pipeline is a very efficient source of transmitting biofuel and other energy resources. Unlike electricity and other resources with thousands of visible connections, Gas pipeline transmits energy with no very impact on the land surface. Therefore, before Installing the gas pipeline effective measure should be taken So that Pipeline should be free from the disastrous effect of the external loading otherwise can result in catastrophic failures Whichincludes bursting

Pipelines employedbeneath the soil undergoes through two different types of load. These loads are termed as Dead load and Live load. Dead load on the underlying pipeline results from the exertion of load of the surrounding soil on the pipe. The parameters that effects the magnitude of the dead load are; Burying depth and diameter of the pipeline.The depth at which the pipeline is to be buried result in the developing of the dead load because of the employment of substantial amount of soil to cover the pipeline. Live load results from the exertion of the traffic induced pressure on the pipeline and its effect decreases as the buried depth increases. The soil exerts load on the buried pipeline through its weight. [1]The weight of the soil on the rigid pipeline in narrow trench can be estimated by Marston load equation:

of pipes due to poor Maintain ace, Pipeline leakage, Corrosion as Pipeline blockage due to unavailability of pigging operation. So, to avoid these failures, safety measures Should be based onexternal and internal loading parameters as well as Mechanical properties of Buried pipeline. Also, the subsoil has great effect on the external load on bearing 4capacity of Underlying soil Between external load and underground being transmitted which directly depend upon bearing capacity of Soil. So for proper operation of buried Pipeline Evaluation of impact of Mechanical Properties as well as Critical parameters Should be predicted for Smooth operation of Pipeline. A part from that signals coming from DAQ should also be noise free for safe operation of pipe lines analysis.Different Scientist work on the safe integrity of buried Pipeline but their focus were on the large transmission Pipe. Meanwhile, very little attention was paid to distribution pipelines that run through the Urban and Household. So, our focus is on two Standard X70 distributions Pipeline of different diameters.Jie Zhang [1]investigated the effect of Mechanical properties of X65 Transmission Pipeline with different Soil and pipe parameter taken into consideration. M.Mokhtari[2] studied the effect of subsurface detonation on the mechanical properties of X65 pipeline.Jose L. Otegui [3]and other described the failure integrity of buried pipeline with preventive measures . Himan Hojat[4] investigated soil and pipe deformation for reverse faulting effect. Xiao Tian [5]described the failure pressure for buried pipeline subjected to scratch and dent effect. JY Zheng [6]investigated Effect of surrounding soil, Pipeline properties as well as load bearing capacity of buried pipeline subject to deflection loading.

2. Load on Buried Pipeline

$$\Upsilon B \qquad (1)$$

Where "ϒ"is volume weight of the soil, B is width of trench and C_v is the trench coefficient

$$\underline{\left[1-\exp\left(-\frac{}{}\right)\right]} \qquad (2)$$

Whereas in equation (2),μ is the friction of coefficient between the emerged pipeline surface and the soil, H shows the depth of backfill soil,K is known as the concentration factor for lateral soil pressure, The numerical value of K can be estimated by utilizing the Jacky(1948) [7]and Mayne & Kulhawy (1982)[8]equationfor normally consolidated and over consolidated soils respectively. The equations (3) gives:

(3)

)(4)

Where in equation (4), Φ_c is critical state friction angle and OCR is over consolidated ratio. The friction coefficient μ between the emerged pipeline surface and the soil can be calculated by the experiment that is performed on the coated steel pipelines at Louisiana Tech University[9].The necessary parameters require for pipeline calculation are enlisted in the Table 1:

The traffic load on the emerged pipelines under the soil can be estimated through Boussinesq Equation. Estimation of the load through Boussinesq equation involves the assumption of some soil properties that is linear, isotropic and homogenous behavior of the soil but the scenario is converse of the ideal situation i.e.no soil is perfectly elastic or plastic and homogenous in nature. In addition to that the Boussinesq equation does not take the effect of moisture content, texture and young modulus of the soil into the account. So, Froehlich modified concentration factor of soil based on elastoplastic soil properties and is given byequation (5) and shown in Fig. (1)

$$\sigma_z = \frac{\nu P * z^{\nu}}{2\pi r^{\nu+2}} (5)$$

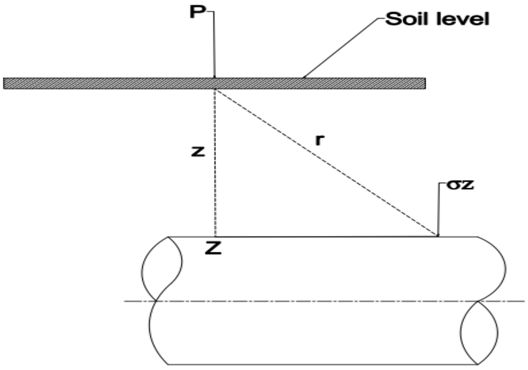

Fig1 : Point load on pipeline

where

ν= Froehlich concentration factor

P=Point load applied

z= vertical distance between load and pipeline

r=radial distance between load and pipeline

Boussinesq used the concentration factor of 3 that was based on the elastic model. The compactness of the soil increases with the tyre loads because of which the value of concentration factor gets effected. To incorporate these effects in the value of concentration factor Soane in 1981 relates the soil pressure, density and porosity of the soil at a given moisture content and assigned the values of 4 for hard soil, 5 for medium soil and 6 for soft soil. if we want to estimate stress at the middle of the pipeline, The condition becomes z=r,the equation shrinks and take the form of equation (6):

$$\sigma_z = \frac{\nu P}{2\pi z^2} (6)$$

By Analyzing the above equation, it is concluded that the stress varies inversely to the square of the depth of underground pipeline. Increase in the depth will affect in the decrease of the Stress

By utilizingBoussinesq equation we have to used different analytical methods for finding these loads.On the Contrary in the Froehlich approach, the equation is integrated and the stress in sand or the silt volume for point load or any distributive load can be easily estimated for a give contact area [10]. For uniform stress over circular area the vertical stress at the depth of z can be calculated by using the equation (7) :

$$\sigma_z = \sigma o\left[1 - \left(\left[\frac{z}{R^2 + r^2}\right]^{0.2}\right)\right] (7)$$

$\sigma_o = W/\pi r^2$ is mean stress on soil surface and W is total weight

z = depth of pipeline

R = radius of assumed circular loaded area;

ν = Froehlich concentration factor

Pipeline get deformed under the action of the applied load there is the certain ratio of deformation between the pipeline x and y axis under applied load.in 1948 the Spangler develop the original Iowa formula to measure the horizontal deflection of the buried pipeline under applied load but the formula was too lengthy and complicated so it was modified by Watkin and Spangler in 1958 by the title of revised Iowa formula in equation (8) and shown in Fig.(2) :

$$\frac{\Delta x}{d}\% = \frac{100 D_L K P}{0.149 PS + 0.061 E'} (8)$$

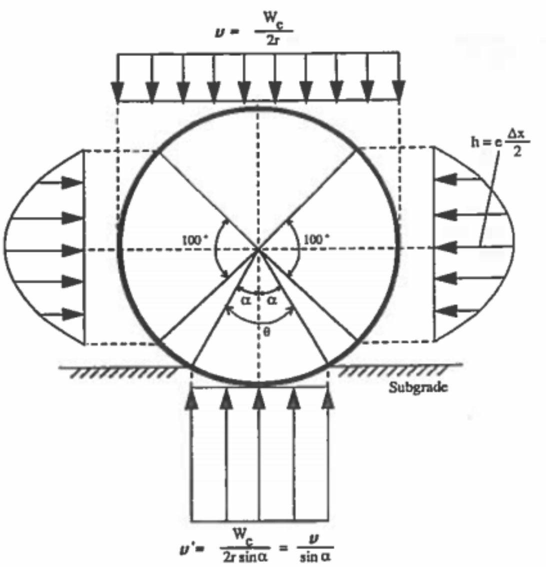

Figure 2 : Stress Distribution by Spangler (Courtesy: Teruhisa Masada)

Where d=diameter of unreformed pipe pipe(=2r), K=beddingConstant, D_L=time lag factor, P=vertical pressure on pipeline(=$0.5W_c/r$),PS=pipe stiffness,E'=modulus of soil reaction. Vertical deflection was formulated by Teruhisa Masada [11]

$$\frac{\Delta y}{d}\% = \frac{100 D_L K P}{0.149 PS}\left[0.0595E'\left(\left[\frac{\Delta x}{d}\right]\right) - k(P)\right] (9)$$

By further simplification

$$\frac{\Delta y}{\Delta x} \approx 1 + \left[\frac{0.0094E'}{(PS)}\right] (10)$$

3. Numerical simulation model

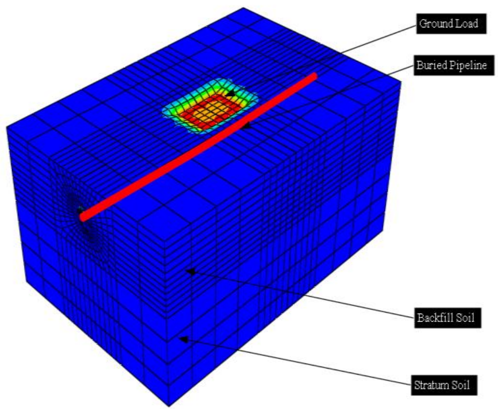

Figure 3:Full model Schematic view

A 3D numerical simulation model was developed using the Abaqus. Full schematic of the model is shown in Fig (3). A linear isotropic model of steel and surrounding soil is developed with suitable interaction between these two to achieve the high level of accuracy. To save computational time the ¼ model was developed as shown in Fig (4) . The pipeline is embeded in to the soil Stratum in the Z direction as shown in Fig (3). To model the steel four nodes reduced integration shell elements were used and Eight node reduced integration elements were used to model the soil. The length of the full is 2m*1.5m*3m for 1 feet soil. The size of the loading area is 0.4m*0.6m .TO model the soil Mohr coulomb theory is used which characterize the elasto-plastic properties of the soil including cohesion, Friction angle, elastic modulus and poison ratio. The poison ratio was taken to be 0.3 [1]The dilation angle in our case was assumed to be zero[12].To find remaining soil properties experimentally soil test were conducted at Soil Mechanics Laboratory UET Peshawar which including Direct shear test and Gradation test was done to find the soil properties at each depth in order to achieve high level of accuracy. The results are shown in Table (1)

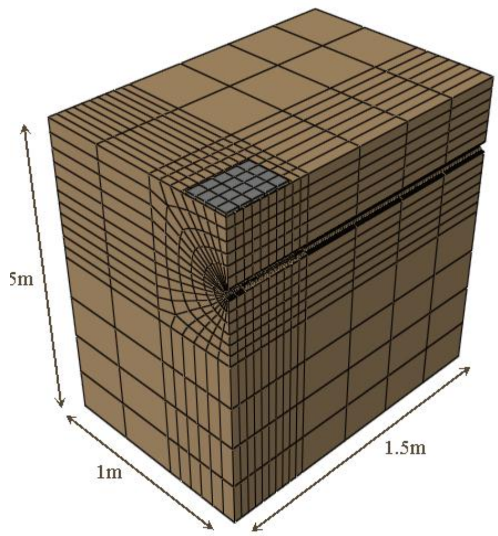

Figure 4:Numerical simulation 1/4 model

Pipeline properties	Pipe 1	Pipe 2
Diameter	0.0508m	0.0254m
Wall thickness	0.007m	0.007m
Yield strength	482.63Mpa	482.63Mpa
Poison ratio	0.3	0.3
API grade	X70	X70
Elastic Modulus	200e9 pa	200e9 pa
Yield to tensile ratio	0.93	0.93

Table 1:Soil properties

USCS Soil classification	Low Plasticity silt	Low Plasticity clay
USCS Soil classification	Low Plasticity silt	Low Plasticity clay
Cohesion(pa)	34473.8	35383.5
Angle of internal friction	20.6	25.4
Mass density (kg/m)	1574.61	1859.74
Elastic modulus	3949959	5363628
Bearing Capacity (Ton)	0.95	1.29

Table 2:Pipline properties

The pipeline used was standard X70 pipeline. Due to its high Yield strength, it is the most favorable pipeline used all over the world for Oil and Gas transportation. To model the pipeline the required properties are enlisted in Table (1)
Gravity loading as well as external loading were imposed to check the Pipeline behavior under different operating condition. The soil pipe interface has a large effect on the strain induced. Therefore, for accuracy the contact algorithm was used to model soil pipe interface which accounts for Soil Pipe Friction. Further during modelling to reduce penetration behavior surface to surface contact was used[1].Isotropic coulomb friction was used with the approximate value of 0.5[13]

4. Results

4.1 Effect of external pressure under different type of soil for 2" pipeline:

Pipeline periphery get effected under external load. This will affect the pipeline if the external load approach certain value which is termed as critical limit. This critical load mainly depend upon the soil behavior mainly depends on elastic modulus as well as bearing capacity of soil. In thisSection,the 2-inch pipeline was analyzed under two different soil as shown in Table 1. The results are summarized in figure 5 and figure 6. In clay soil with bearing capacity of 1.29 ton the Plastic deformation of pipeline started at stress level of .8 Mpa. This critical stress appeared on both pipeline top and pipeline bottom nodes with same magnitude. The magnitude of this plastic strain result from this stress is 0. 0045 and the magnitude of pipeline vertical deflection at the pipeline upper node is

0. 05m.As compared to this under silt soil with baring capacity of 0.95 tons the critical von Mises stress appeared after the stress level reached .6 Mpa. Plastic strain induced at this stress level is 0.0045 and magnitude of pipeline vertical displacement is 0.05m at upper nodes. This means that critical stress in silt soil reduced to 25% than clay soil. So, for pipeline backfilling the area having clay should be best for pipeline burying as clay can bear high stress than silt soil. Also further analysis in this paper were done using clay as back fil soil for more accurate and reasonable results

4.1.1 INCHPIPELINE:

4.1.1.1 CLAY SOIL:

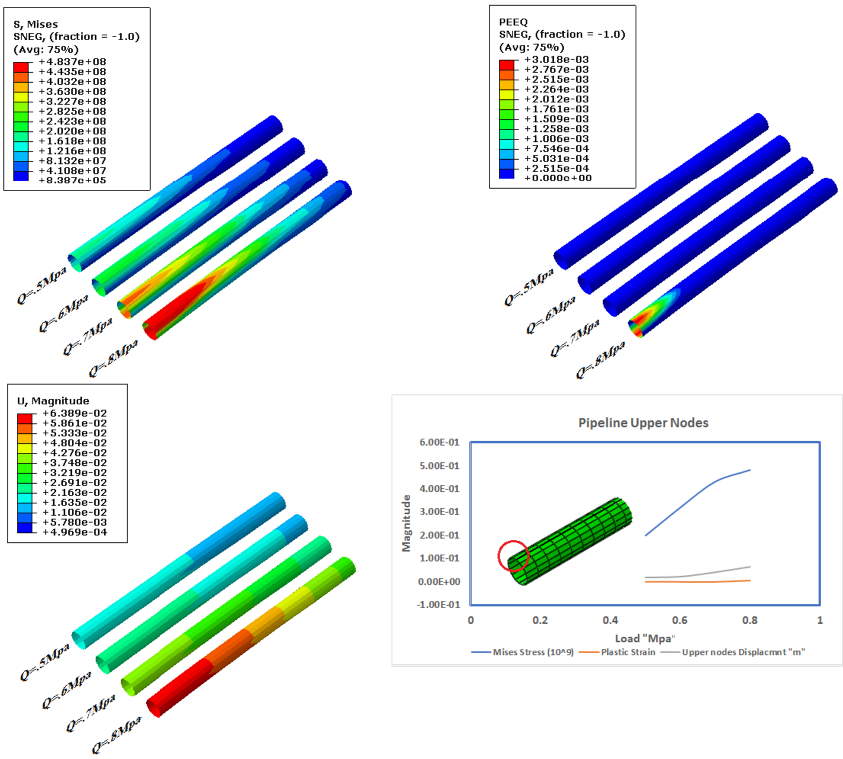

Figure 5:Mises , Strain and Displacement effect under various load for 2" Pipeline under clay soil

4.1.1.2 SILT SOIL

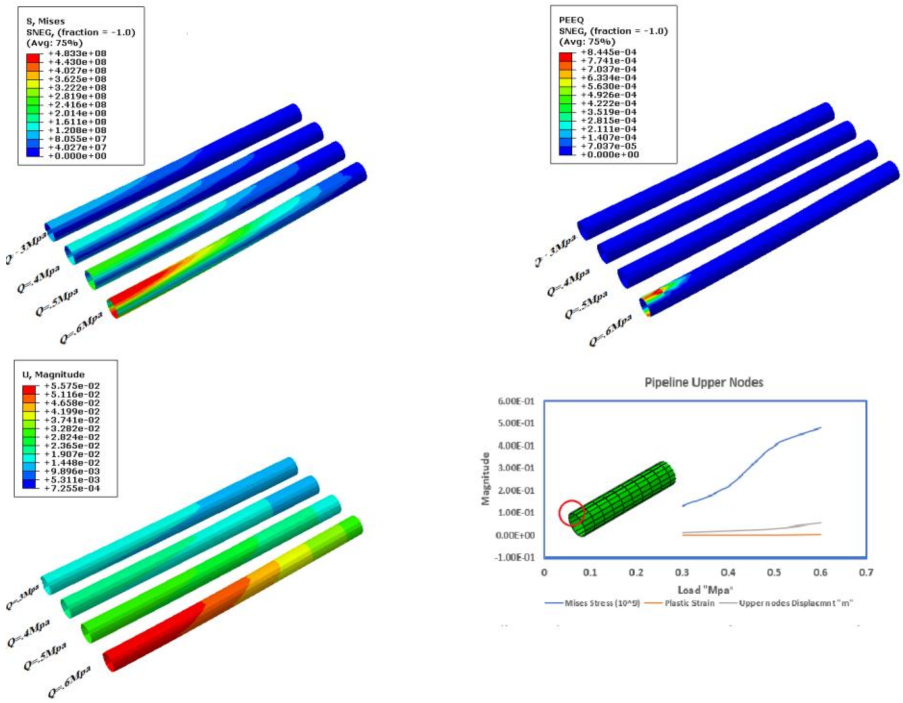

Figure 6:Mises, strain and displacement effect under various load for 2" pipeline in Silt soil

4.2 EFFECT OF EXTERNAL PRESSURE UNDER DIFFERENT TYPE OF SOIL FOR 1" PIPELINE:

For small diameter pipeline i.e 1-iunch pipeline due to small diameter high bending moment induces which results is in inducing the plastic strain at more than 1 Place as shown in Fig7 and Fig 8. When 1-inch pipeline was analyzed in clay soil stress at which the pipeline approach yielding is .7 Mpa and the resulting Plastic strain induces is 0.09 and pipeline vertical displacement at Pipeline top nodes at yielding point is 0.9m as shown in Fig 7. As compared to this when 1-inch pipe is analyzed in silt soil the yielding of pipeline occurs under external stress of .5 Mpa and the resulting plastic strain at yielding is 0.03 and vertical displacement at upper nodes is 0.1m. Fig 8. As 28% increase in Yielding Stress observed for clay soil as compared to silt soil for 1-inch pipeline.

4.2.1 I" PIPELINE:

4.2.1.1 CLAY SOIL:

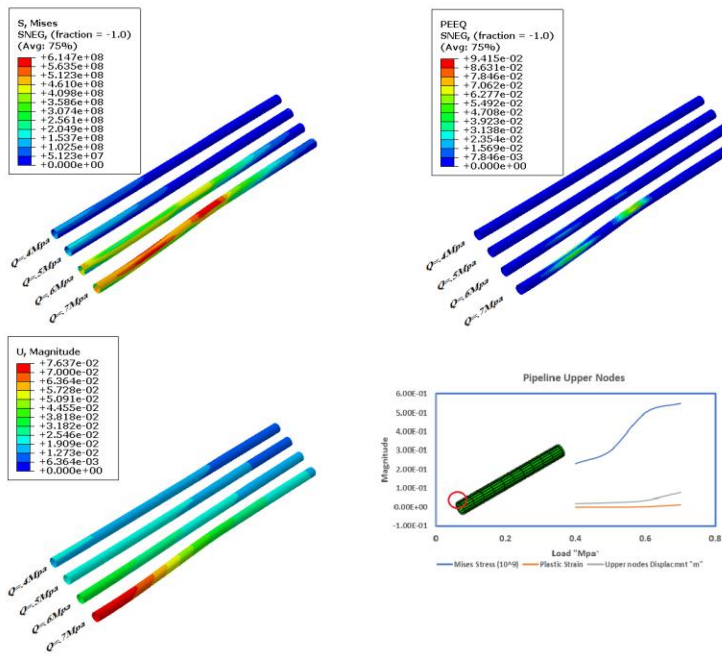

Figure 7:Mises , strain and displacement effect under various load for 1" pipeline under clay soil

4.2.2.2 SILT SOIL:

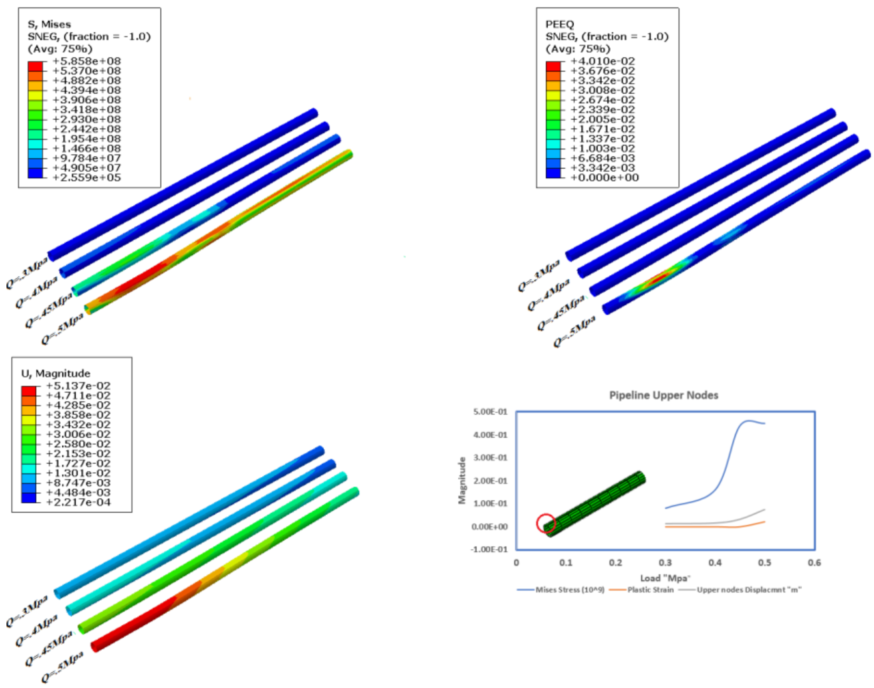

Figure 8:Mises , strain and displacement effect under various load for 1" pipeline under silt soil

4.3 Effect of internal pressure on the pipeline at different depth:

Increase in internal pressure can effect normal operation of the pipeline This could be in form of ovality or burst of the pipeline what may prove fatal to living creatures. In this section, the plastic strain developed due to internal pressure discussed at different soil depths. Results for critical internal Yielding pressure at different depth for 2-Inch and 1-inch Pipeline is summarized in Fig 9 and Fig 10

4.3.1 2" Diameter pipeline:

At 1 feet the magnitude of internal pressure that can cause yielding of pipeline is 30Mpa the stress distribution maximum at the center and yielding pattern start at upper and bottom periphery and simultaneously move toward middle of pipline.At 2 feet there magnitude of stress at yielding is 140 Mpa and Stress is distributed in oval around the pipeline, The percent increase in yielding internal pressure between 1 and 2 feet is 333% .At 3 feet the internal pressure that cause yielding is 150 Mpa and the stress pattern is distributed along whole periphery and the resulting increase in yielding stress between I and 3 feet is 400%.So for safe operation the internal pressure should be kept lower than critical pressure given in Fig 9 for safe operation of pipeline

4.3.2 " Diameter Pipeline:

Small diameter Pipeline are more susceptible to internal pressure effect because of their decrease surface area. At 1 feet, the Yielding of pipeline due to internal pressure occurs at 8Mpa and Stress distribution is mainly at upper and bottom periphery of the pipeline. At 2 feet, magnitude of internal pressure to initiate Yielding is 14 Mpa and stress distribution is around the periphery of the pipline.75% increase is Yielding pressure is observed between 1 and 2 feet. At 3 feet the 23 Mpa internal pressure starts the yielding initially there small spot at the center and then the stress start to move toward the periphery. The increase in critical pressure between 1 and 3 feet is 187.5%.So for 1-inch pipeline for its safe Working Internal pressure should not exceed value mention in Fig 10.

4.4 Effect of External load Applied under different soil depth:

External load applied also varies significantly under different soil depth. Also, critical stress that can cause yielding varies significantly with depth. it increases as burying depth increases. This increase in external load for 2-inch and I inch diameter pipeline is summarized in Fig 11 and Fig 12

4.4.1 2" Diameter pipeline:

Four 2-inch pipeline external stress applied that initiate yielding is.8 Mpa and stress distribution oval around the Pipeline. At 2 feet, this external Yielding stress increases to 1.3Mpa due to increase in amount of backfill soil. The percent increases between critical external load stress between 1 and 2 feet is 62%. At three feet the 1.35nap external stress is required to initiate the plastic deformation. 69% increase is external yielding stress between 1 and 3 feet.

4.4.2 1" Diameter Pipeline:

Four 1-inch pipeline plastic deformation at 1 foot plastic deformation starts at. 7mpa. For 2 foot increase in yielding stress at 1 Mpa the percent increase in external critical stress between 1 and 2 feet is 49%. At 3 feet the plastic deformation starts at 1.35 Mpa and percent increase in critical external applied stress between 1 and 3 feet is between 92%. So these stresses should be avoided if we ensure the pipeline safe operation

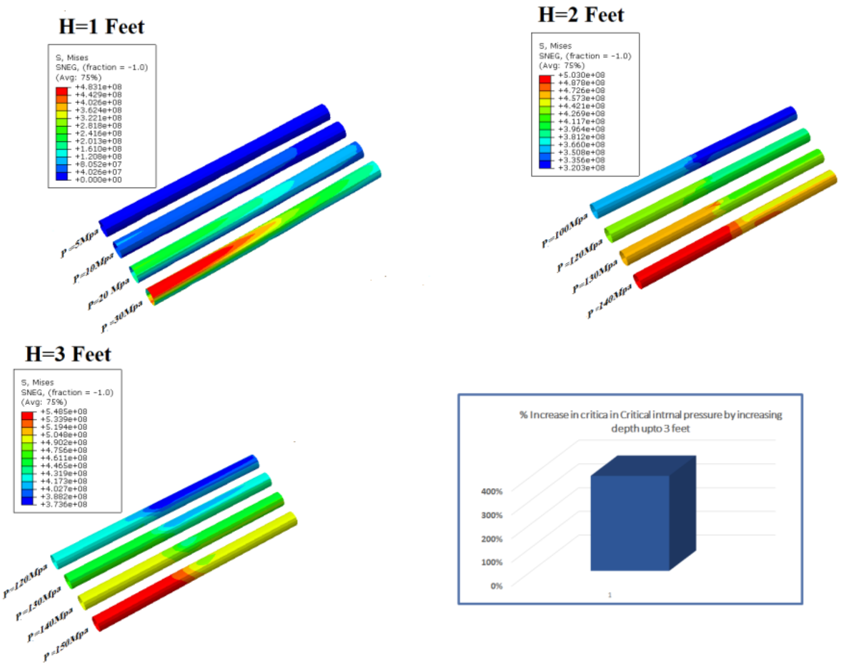

Figure 9:Yielding internal pressure for 2-inch pipeline at different soil depth

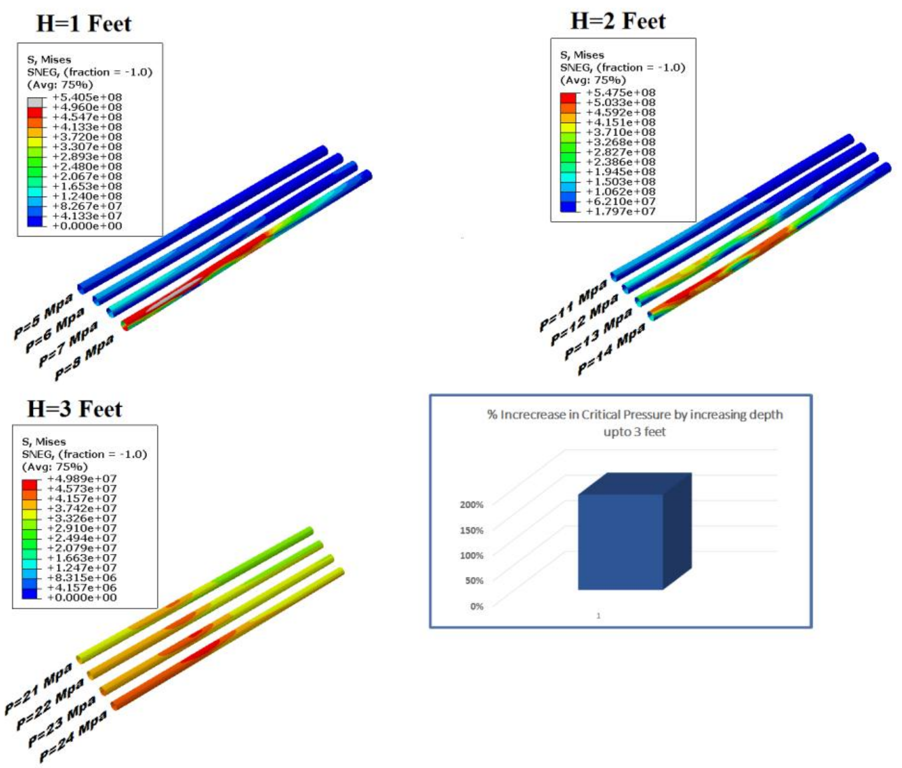

Figure 10:Yielding internal pressure for 1-inch pipeline at different soil depth

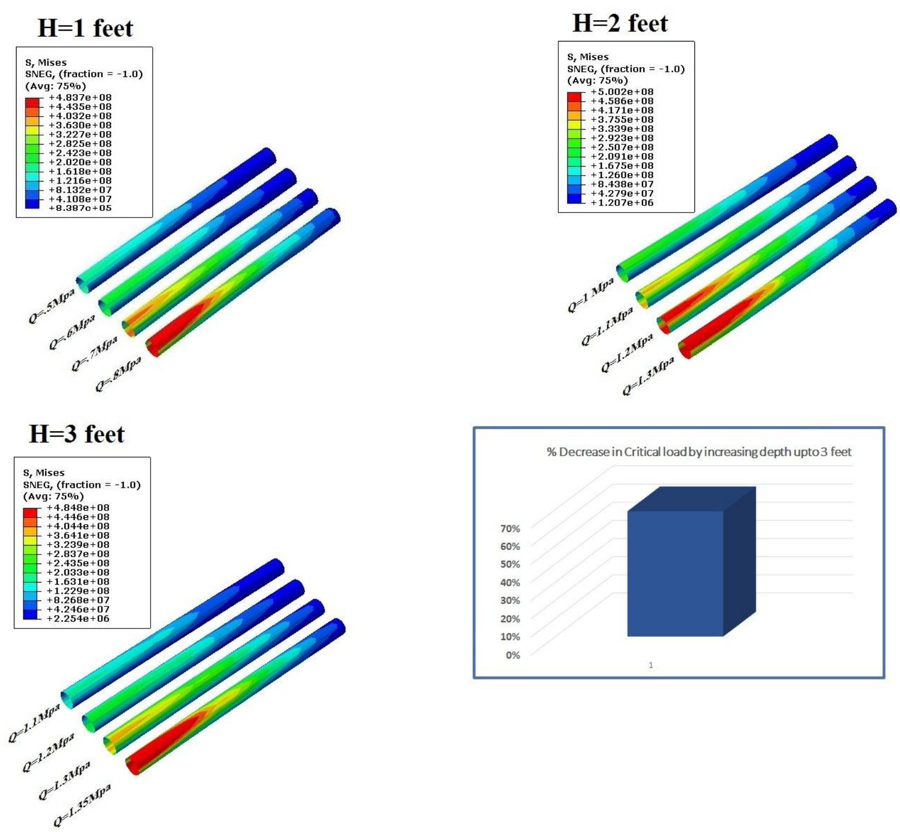

Figure 11:Variation of external load for 2-inch pipeline at different soil depth

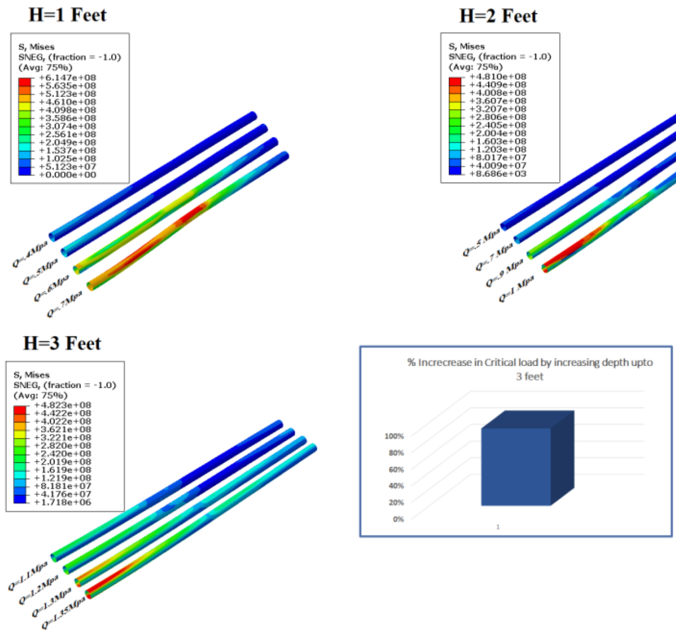

Figure 12:Variation of external load for 1-inch pipeline at different soil depth

5. CONCLUSION:

- Four2-inch pipeline, the 25% increase in critical stress observed inclay soil as compared to silt soil. As clay soil provides more damping to external. The yielding of the pipeline is Clay soil occurs at.8 Mpa and Yielding of pipeline in silt soil occurs at.6 Mpa
- Four 1-inch Pipeline, 28% Increase in critical stress observed in clay soil as compared to Silt soil. Yielding stress for 1-inch pipeline in clay soil is.7 Mpa while it is.5 in Silt soil
- It can be seen that difference in critical stress between 2-inch pipe and 1-inch pipeline under different soil is only 3%.
- Four 2-inch pipeline the internal pressure to initiate Yielding at Soil level of 1,2 and 3 feet are 30Mpa ,140Mpa and 150Mpa respectively.Andfor 1-inch pipeline the Yielding at above soil levels occurs at 8Mpa,14Mpa and 23Mpa respectively. It means small diameter pipeline is more Susceptible to internal pressure effects
- Four 2-inch pipeline yielding due to externally applied stress at soil level of 1 ,2 and 3 feet is.8 Mpa, 1.3Mpa and 1.35Mpa respectively, whilefor 1-inch pipe under above soil level Yielding stress is.7Mpa ,1Mpa and 1.35maps respectively

ACKNOWLEDGMENT:

Our research was sponsored by Sui Northern gas pipeline limited.We are would also like to show our gratitudeto DrJie Zhang (Incharge Key laboratory of Oil and Gas Southwest Petroleum university Chengdu, China) and Dr Ashfaq (Incharge SNGPL lab UET Peshawar, Pakistan) for theirsupport and sharing their pearls of wisdom with us during the course of this research. It was a great learning experience working with them

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