3D Nonlinear Modeling of Buried Continuous Pipeline Subjected to Ground Compression

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SUMMARY:
Pipeline generally extends over long distances traversing through wide variety of soil conditions with different seismicity. Majority of past work mainly restricted to pipelines exposed to strike slip fault motion or transverse permanent ground deformation that too cases of pipelines under tension. The study of buried pipeline under compression is of extreme importance, especially pipelines passing through thrusting sub-continent like India, where majority of pipelines are exposed to compression. In compression pipelines fail in material as well as in geometry.

In this paper past work is reviewed and 3D finite element based model is proposed to compare pipeline performance subjected to different types of ground motion. The proposed model includes material non-linearity as well as effect of large geometric changes. In this proposed model displacement control Arc-length technique is implemented to solve the nonlinear behavior. To reduce the computational time of analysis a parallelization tool kit of MATLAB is utilized.

Keywords: Buried continuous pipeline, large ground deformation, FEM

1. GENERAL

1.1. Introduction and past work

Seismic hazard of pipelines is well demonstrated and documented during past several earthquakes all over the world. Seismic hazard related to pipelines can be classified in three categories. First, due to seismic waves, this mainly damages weakened pipelines either by corrosion or at welds of poor quality, second due to fault slip and last due to permanent ground deformation (PGD). Very few cases of buried pipeline damages were reported due to ground vibration compared to fault motion or PGD. The damage due to fault slip and PGD is intense for shorter spans. Pipelines are subjected to tension or compression depending on its orientation with ground deformation. Pipeline when subjected to compression can lead to both material and geometric failure, where as in case of tension only material failure occurs.

Predominant study for seismic hazard of pipeline started after 1971 San Fernando earthquake. Newmarks and Hall (1975) did pioneer work for pipeline crossing the fault by assuming pipe as a cable. The only force considered acting on the pipeline is the frictional force at the pipe-soil interface along the longitudinal direction without lateral force offered by the soil. This model further modified by the Kennedy et al. (1977) by incorporating the lateral pressure offered by the soil. In 1985 Wang and Yeh further modified this model by dividing pipe in to three regions depending on the curvature of pipeline. Karamitros et al (2007) introduced number of refinements in the method proposed by Wang and Yeh (1985). Previous method has overlooked the effect of axial force on bending stiffness. Karamitros et al suggested most unfavourable combination of axial and bending would not necessarily take place at the end of high curvature portion, but might occur within the zone or closer to the fault crossing point.

In addition to analytical models several numerical models were proposed, one of which includes beam on nonlinear Winkler foundation. In which pipe is modelled with beam/shell elements and soil with springs (Takada et al 1998), nodes of the shell elements of the pipe are attached to soil, which are modelled as springs.

1.2. Scope

Though improved analytical models provide a good result but models are developed with fundamental assumptions, like curvature of the pipeline on either side of fault plane is symmetrical. In case of strike slip fault-pipeline crossing, pipe essentially deforms in the horizontal plane were soil on either side of the pipeline extends to very large or infinite distances. This offers the symmetric lateral resistance on either side of pipeline in the plane of pipe deformation. This symmetry also takes care of point of contra-flexure drawing closer to the pipeline fault crossing. Hence, the past analytical models developed are applicable to strike slip fault motion cases only. For dip slip fault motion, the lateral soil resisting in vertical plane are dissimilar due to great variation of soil depth. Lesser depth of the soil above the pipe offer less resistance compared to bottom soil for deformed pipe. In addition to this deformation of the pipe greatly depends on the soil movement of the upper layer which usually differs in hanging wall and footwall. Hence, assumptions for identical curvature on either side of the fault plane no longer valid for dip-slip fault motion cases. Analytical studies have also restricted to pipelines subjected to tension cases only. Pipeline under compression usually involves general as well as local geometric instability effects (e.g. pipeline during 1999, Izmit, Turkey earthquake (EERI, 1999)). Handling structural instability is hard to model in analytical studies. Faulting itself is phenomenon of large geometric changes hence, theory of small deformation no longer suitable for pipeline fault crossing which were used in past. Hence, the study of the pipeline under compression needs appropriate understanding as it involves both material and geometric failure.

However numerical models proposed by Takada et al (1998), LIU Ai-wen et al (2004) for buried pipeline using shell element and nonlinear springs for pipe and soil respectively, which can perform for pipeline under compression. Post yielding of soil spring gives higher strain value in pipe that could be result of inadequacy by the spring models to incorporate the actual soil behaviour during soil yielding. In addition, these models do not consider the large geometric changes of upper soil layer, which has significant effect on pipeline performance. Stiffness of each individual spring is independent i.e. each spring behaves independently disregarding the effect of lateral soil confinement.

Limitations of previous models have been considered for this study and at the same time latest technology for faster computations are used. In this study, more realistic program is developed using three dimensional FEM for buried continuous pipelines. This program is developed using isoparametric brick element. The developed model takes care of material and large geometric changes to comprise fault motion.

2. METHODOLOGY

2.1 Numerical Modeling

The governing nonlinear finite element equation for solid continuum can be obtained from principle of virtual work. Eqn. 1 is adaptation from the one presented by K. J. Bathe (1996) and J.N. Reddy (2004) for updated Lagrangian approach.

$$\left({}^{t}_{t}K_{L}+{}^{t}_{t}K_{NL}\right)\Delta U^{(i)}={}^{t+\Delta t}R-{}^{t+\Delta t}_{t+\Delta t}F^{(i-1)} \tag{1}$$

Where

$${}^{t}_{t}K_{L}=\int_{{}^{t}V}{}^{t}_{t}B_{L}^{T}\,{}_{t}D\,{}^{t}_{t}B_{L}\,d\,{}^{t}V$$

$${}^{t}_{t}K_{NL}=\int_{{}^{t}V}{}^{t}_{t}B_{NL}^{T}\,{}^{t}\tau\,{}^{t}_{t}B_{NL}\,d\,{}^{t}V$$

$${}^{t+\Delta t}_{t+\Delta t}F^{(i-1)}=\int_{{}^{t}V}{}^{t}_{t}B_{NL}^{T}\,{}^{t}\hat{\tau}\,{}^{t}_{t}B_{NL}\,d\,{}^{t}V$$

${}^{t}\hat{\tau}$ = Cauchy stress vector

B = Transformation matrix

${}^{t+\Delta t}R$ = vector of externally applied loads at time $t+\Delta t$

The numerical integration is performed according to Gaussian quadrature rule. A code is developed in MATLAB for three dimensional FEA using 8 nodded isoparametric elements.

The successes of any nonlinear analysis is primarily depends on the accuracy, convergence, efficiency and stability of nonlinear solution technique. The nonlinear Eqn. 1 can be solved by various nonlinear solution techniques available in the literature. Among this, full or modified Newton-Raphson method is simple to understand, implement and generally converges in less iterations. However, this method fails to trace the nonlinear equilibrium path through the limit or bifurcation points. In vicinity of limit points, tangent stiffness matrix becomes singular and the iteration procedure diverges. This is common in buckling and strain softening nonlinear material behaviour type of analysis. The displacement boundary condition in nonlinear analysis needs linearization of the prescribed boundary displacement, which can be easily incorporated in other methods like arc-length method. Hence, more robust arc-length method is employed for this work. Arc-length method originally developed by Riks (1972; 1979) and Wempner (1971) and later modified by several researchers.

2.2 Validation of Code

For the validation of developed code, tests have been performed on the 3D cantilever beam. Load-deflection curve is compared with commercially available finite element package ANSYS-12. Material behaviour assumed for validation is same as pipe material. Beam dimensions, meshing and point load considered at free end are given in Table 1. Fig. 1 shows perfectly matching load-deflection curve obtained from developed code and Ansys.

Table 1. Comparison of Code and ANSYS results

L x D x B (m)	Element size (m)	Point load (kN)	U_{max} (m)	
			Model	Ansys
3.0 x 0.2 x 0.05	0.05 x 0.05 x 0.05	80	0.130	0.135

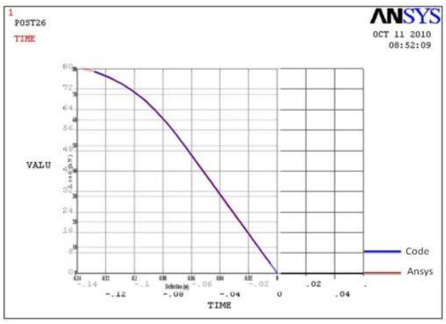
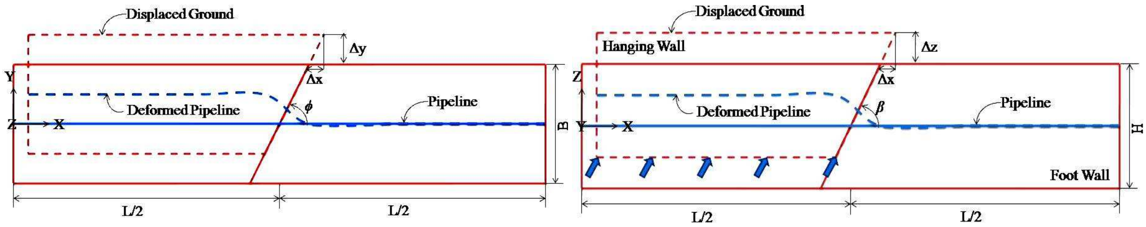


Figure 1. Comparison of results between ANSYS and developed code.

2.3 Model Dimensions

The coordinate system and notations used for this work are shown in Fig. 2. In reality, soil media does not have any fixed boundaries or can be assumed at infinite distance, which is virtually impossible to incorporate in numerical model, hence model dimensions are determined for boundary effect and it considered as 80m (L) x 12m (H) x 15m (W).



(a) (b)

Figure 2. (a) Plan view of buried pipeline model for strike-slip fault motion. (b) Sectional view of buried pipeline model for dip-slip fault motion.

The pipe near the fault usually suffers large deformation, which is not so long, about 10m ~ 30m, and the damaged point of pipe also occurred in this pipe segment (LIU Ai-wen, 2004). For this, meshing of varying element lengths is considered to optimize the memory and time usage. Finer meshing of 0.5 m element lengths are used nearer the fault region for 20m distance on either side. Then for remaining length 1m, element size is used. Pipe is divided in eight equal divisions in circumferential direction and single division is made for wall thickness. Near the pipe, soil is meshed by small elements with varying size for the square region of 1.2m (Fig. 3). Elements size of soil, which is far from the pipe, is taken as 1.5m.

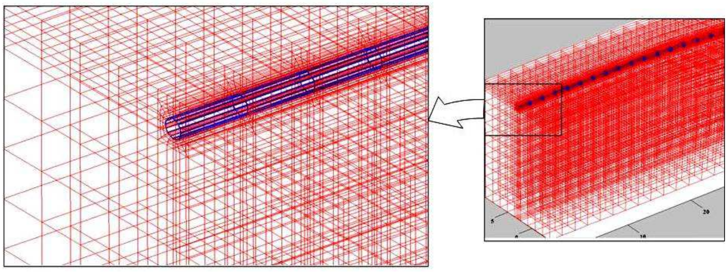


Figure 3. Proposed finite element model of buried pipeline.

Default parameter in evaluation of pipeline performance are considered as maximum fault offset (Δ_{max}) = 0.6m, pipeline fault crossing angle (ϕ) = 90^0, diameter of the pipeline (D) = 0.61m (24 inches), pipeline wall thickness (t_p) = 0.0095m (0.375 inches) and depth of the buried pipeline s(d_b) = 0.91m (3feet). Performance is evaluated for no internal pressure condition. In this proposed model we assumed that there is perfect bond between the soil and pipe material.

2.4 Boundary Condition

The target ground displacements are applied at the bottom, with top boundary as free. While for side boundaries, all nodal degree of freedoms other than, in the direction of the components of targeted displacements are constrained. The total soil mass block is divided in to two parts, on either side of the fault plane. The fault displacement (Δ) is applied to first block by keeping other one fixed.

2.5 Material Modeling

The For pipe Ramberg-Osgood relationship is one of the most widely used models (M. O'Rourke(1999), IITK-GSDMA GUIDELINES (2007)), while for soil hyperbolic is common (S.L Kramer (2007)). Hence, the same are used in this study which are summarised below.

$$\varepsilon = \frac{\sigma}{E}\left[1 + \frac{n}{1+r}\left(\frac{\sigma}{\sigma_y}\right)^r\right] \tag{2}$$

Where

ε = Engineering strain

σ = Stress in the pipe

E_i = Initial Young's modulus

σ_y = Yield strain of the pipe material

r, n=Ramberg - Osgood parameters adopted as r = 31.50 & n = 38.32 Karamitros (2007)

$$\tau = \frac{G_{\max}\gamma}{1+(G_{\max}/\tau_{\max})|\gamma|} \tag{3}$$

Where

τ=shear stress,

γ= shear strain,

G_{max} = maximum shear modulus and

τ_{max}=maximum shear stress

The API5L-X 65 steel pipe is frequently used in literature (Newmark-Hall (1975), Karamitros (2007) etc) hence the same is adopted for this study. Table 2 show the properties used for API5L-X 65 pipe material. While soil is assumed as typical sand with initial Young's modulus as E_i = 50Mpa and Poisson's ratio 0.4. Table 3 show constants used in hyperbolic model.

Table 2. Properties of AP15L-X 65 Pipe

Properties for API5L X-65 Pipe	**Magnitude**
Initial Young's Modulus (E_i)	210 Gpa
Yield Stress (σ_y)	490 Mpa
Failure Stress (σ_f)	513 Mpa
Failure Strain (ε_f)	4%
Poisson's ratio (µ)	0.3
Density (ρ_p)	7.8g/cm³

Table 3. Constants for Hyperbolic Model

Medium density sand properties	**Magnitude**
Maximum Shear Modulus (G_{max})	60 Mpa
Maximum shear Strength (τ_{max})	0.0216 Map
Failure Stress (σ_f)	513 Mpa
Density (ρ_s)	1.44/cm³

3. RESULTS AND DISCUSSION

3.1 Pipeline Subjected to Strike Slip Fault Motion

The performance of continues buried pipeline subjected to compressional ground motion is studied using proposed finite element models. Performance of the pipeline can be more understand by associating its behavior for compression with tension case and strike with dip slip fault motion. Parameters considered for proposed study are maximum fault offset ($\Delta_{\max}$) = 0.6m, diameter of the pipeline (D) = 0.61m (24 inches), pipeline wall thickness (t_p) = 0.0095m (0.375 inches) and depth of the buried pipeline (d_b) = 0.91m (3feet). Performance is evaluated for no internal pressure condition. Parametric studies can be done by changing various geometric parameters of pipe and ground motion. However, compression behavior can be seen with change of pipeline fault angle and pipe wall thickness which are among the prime factors.

3.1.1 *Effect of the Pipeline Fault Angle*

The pipeline fault angle is most vital parameter related to the pipeline performance. Hence effect of the pipeline-fault angle (ϕ) is studied by varying the pipeline-fault angle from 40^0, 60^0, 80^0, 90^0, 100^0, 120^0 to 140^0 with fault offset of 0.6m. The foremost point that can be observed in the strain distribution curve plotted in Fig. 4 is maximum strain developed for negative pipeline fault angle (ϕ <90^0) is much higher than the positive pipeline fault crossing angle (ϕ >90^0). The reason for this can be understood as, when pipeline is subjected to the compression, pipe has a chance to bend and/or buckle, hence the ground motion is accommodated by the geometric changes without much internal deformation in pipe material. There are two fundament troubles associated with the pipeline buckling, firstly it is a sudden phenomenon and may have adverse affect on the operational pipelines. Secondly, the large geometric distortion during buckling further causes fluid pressure loss in the pipeline, which is significant parameter for the petroleum pipeline. In case of pipeline under tension, total ground motion at the pipe fault crossing is needed to accommodate by the internal deformation of pipeline material. From Fig. 4 it can also observe that for $\pm 80^0$ angle, total normal strain distributions are similar on the opposite side of zero strain axis. This indicates that the buckling of the pipe does not take place up to this pipeline fault angle.

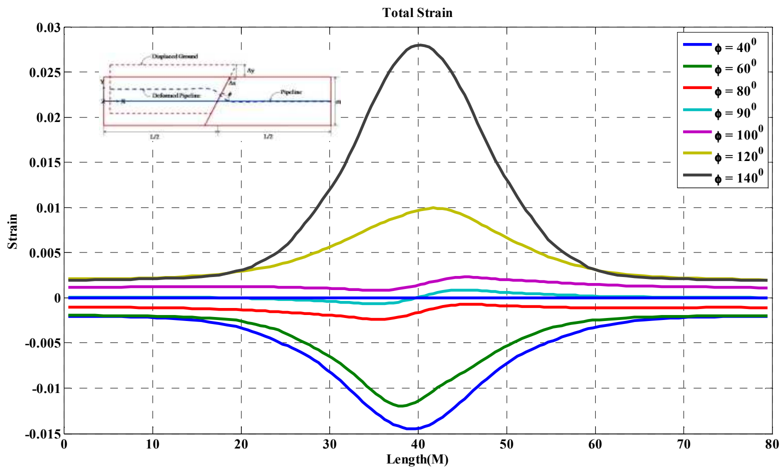


Figure 4. Effect of pipeline fault angle on total normal strain distribution for strike slip with Δy = 0.6m

3.1.2 Effect of Pipeline Wall Thickness to Diameter Ratio

In general design, wall thickness is the main function of internal pressure. Where it is designed for hoop and longitudinal stresses after that check is done for secondary loads like overburden and live loads. Nevertheless, the present study shows that thickness to diameter ratio has great hold on the pipeline performance crossing strike slip fault, especially when pipeline is subjected to compression. To understand the effect of the wall thickness here three different ratios of wall-thicknesses to diameter ratios are considered i.e. 0.0095, 0.0136 and 0.0190. To have an effect of geometric failure under compression, parametric study is performed for ϕ = 40^0 where pipe can be subjected to sufficient compression. The maximum fault offset applied is 0.47m, after which pipe will be subjected to large geometric changes which further causes soil failure and diverges numerical analysis.

Geometric failure of the pipe can be more clearly understood by observing the deformed pipe hence for deformed shapes of the pipes with different wall thickness to diameter ratios are plotted in Fig. 5. From Fig. 5, it can be clearly seen that pipe with thicker wall thickness is subjected to more geometric changes than the pipe with thinner wall thickness. However, thicker wall pipe has higher internal deformation capacity, which can be observed in the strain distribution Fig. 6. Nevertheless, for less strain thicker pipe has undergone more damage, this clearly indicates geometric failure of the thick wall pipe. The reason for this is quite understandable that thinner wall pipe has lesser moment of inertia, which leads for easy bent and deform, accommodating the fault displacement. On other hand thicker wall pipe, which is subjected to less strain indicate that lesser internal deformation, therefore thick wall pipe needs to accommodate fault displacement by large geometric deformations. From the above discussion, it is clear that when pipe is subjected to strike-slip fault with $\phi < 90^0$, thicker pipe is more vulnerable to geometric instability.

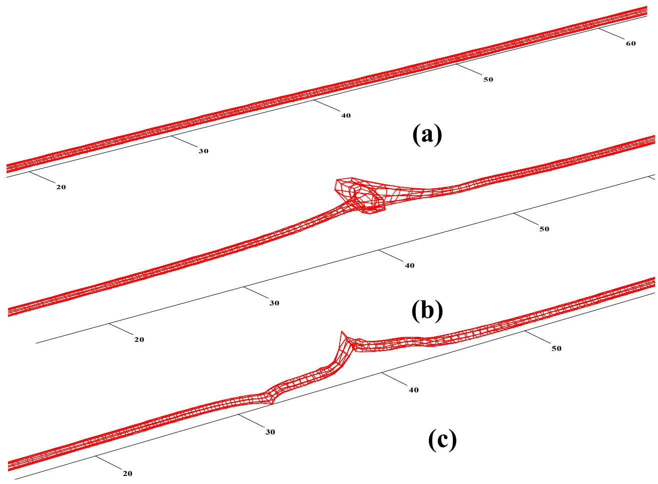


Figure 5. Deformed shape of pipe with t_w/D = (a) 0.0095, (b) 0.0136, and (c) 0.0190 for strike slip with Δy = 0.47m and $\phi = 40^0$

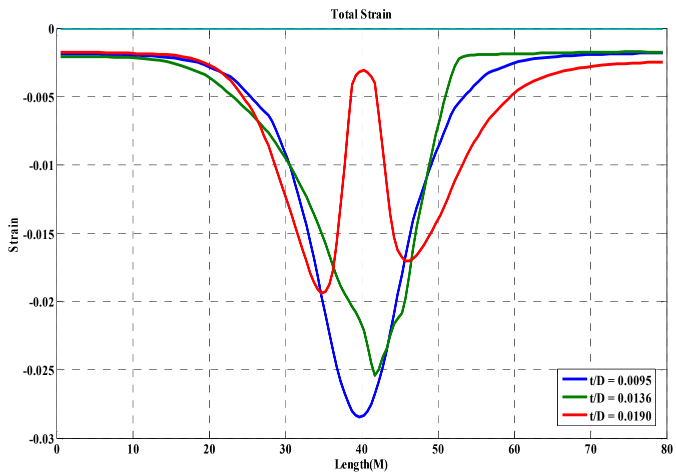


Figure 6. Effect of pipeline wall thickness to diameter ration for strike slip with Δy = 0.46m and $\phi = 40^0$

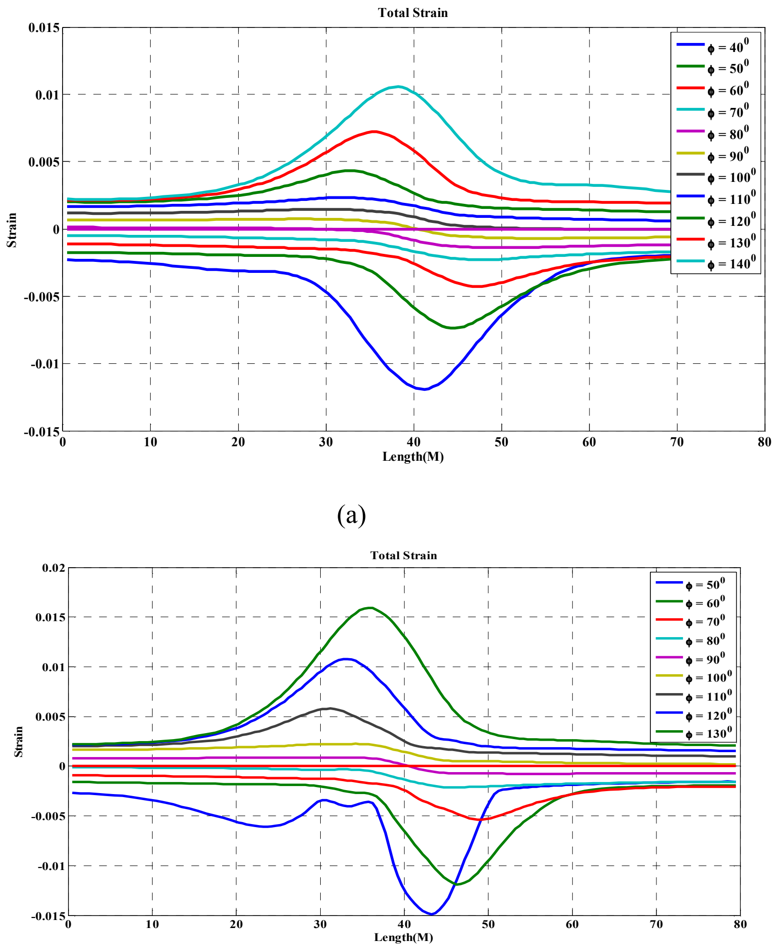
From Fig. 5, it can be seen that pipe with 0.0095 wall thickness to diameter pipe is deformed only in the horizontal plane, which indicates bending of the pipe with strike-slip fault motion. While in case of t_w/D = 0.0136 pipe is little moved with fault and then bulged in horizontal plane indicating geometric failure in plastic stage. Finally in case t_w/D = 0.0190 pipe is purely buckled in vertical plane, which is catastrophic geometric failure. At much lesser depth, the depth of top soil compared to three remaining directions offer lesser resistance to the thicker pipe buckling.

3.2 Pipeline Subjected to Dip Slip Fault Motion

In case of dip slip motion, the asymmetry shifts the point of contra-flexure towards the lesser resistance offering soil depth. In addition to this, inequality in deformation of soil hanging and footwall also plays role in location of the point of contra-flexure. As pipelines are always laid in upper soil layer, the influence length fault and its location has great effect on the pipeline response.

3.2.1 Effect of The Pipeline-Fault Angle

For this case, dip slip dip angle typically becomes the pipeline fault angle. Here the effect of the dip angle (ϕ) on the pipeline performance is discussed with dip angle from 40^0 to 140^0 and for the fault offset of 0.3m and 0.5m. The fault offset of 0.3m and 0.5m selected such that effect of dip angle can be seen for the maximum strain and to compare behaviour under tension and compression. While fault angle is varied such that pipeline can undergo to high negative to high positive strain.



(a)

(b)

Figure 7. Effect of dip angle ϕ on total normal strain with (a) Δz = 0.3m and (b) Δz = 0.5m

For Fig. 7.a, it can be seen that there is no significant change as such present in the strain distributions of the pipeline for the corresponding negative and positive dip angle except the sign of strain. The major difference in the performance of the pipeline during compression and tension occurs mainly when there is a geometric failure (buckling) in compression. For the fault offset of 0.3m, no such failure is detected; this means pipe has not buckled for any angle with 0.3m fault offset. For such case normal strain developing in the pipe are mainly due to bending and direct strain. This is the case when pipe does not exert any additional pressure on the surrounding soil. Unlike in case of buckling high stiffness pipe exerts pressure on the surrounding soil, which leads to the local soil failure. This kind of local soil failure generally fails in convergence of the numerical solution. The other important point here can be seen is that the location of maximum strain point. The maximum strain point moves almost 20m distance for the considered dip angle. As the maximum strain in the pipeline is located where the pipe bends more, which mainly depends on the soil deformation as stated in previous section. Geometrically negative and positive dip angle does not make much sense as soon as soil behaviour is assumed to equal in tension and compression until the geometric failure take place.

For higher fault offset geometric failure takes place, which can be seen in Fig. 7.b where 0.5m fault offset is applied. The point here can be mention is that, for relatively smaller offset when compared to the case of strike slip, pipeline shows higher geometric failure. The justification for this can be stated in terms of confinement of the pipeline in plane pipeline bending. For the case of pipeline fault crossing the buckling mode of the pipe is like predefined owing to the pipe bending along the fault motion. Hence, for dip slip fault motion pipe should essential bend in vertical plane, where it gets less confinement unlike strike-slip case.

3.2.2 Effect of Pipeline Wall Thickness to Diameter Ratio

To understand the effect of the wall thickness to diameter ratio of the pipeline subjected to dip slip fault motion. Here three ratios are considered 0.0095, 0.0136 and 0.0190. For small dip angle, pipe failure is catastrophic in geometry with little fault offset. Hence here $\phi = 60^0$ is assumed so that pipe can strain adequately before it buckles. The remaining parameters are considered as default as mentioned in previous sections.

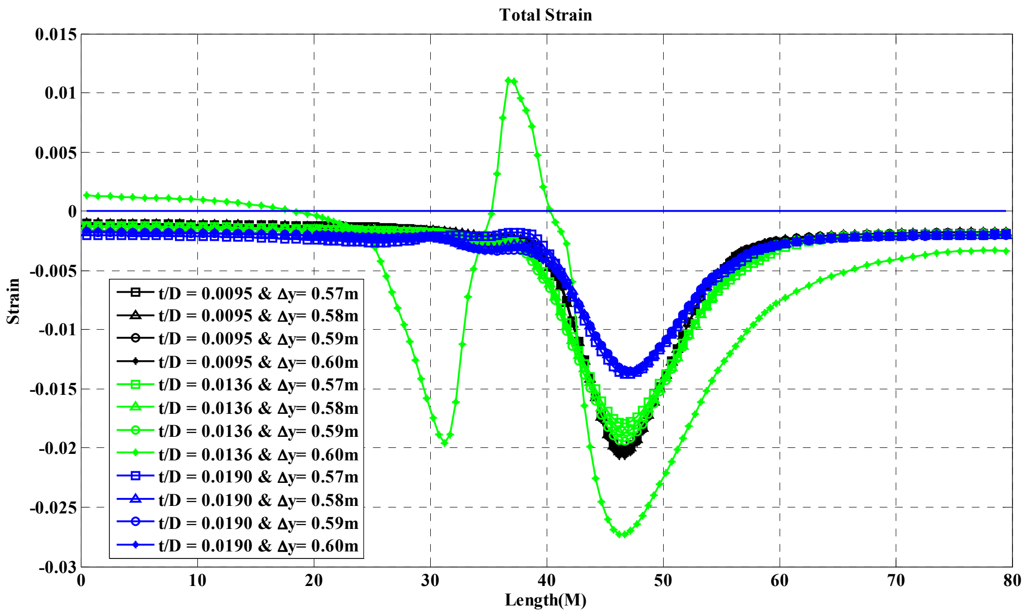


Figure 8. Effect of t_w/D ratio on Strain distribution for dip slip with $\phi = 60^0$

Form Fig. 8, one can see that thicker pipe subjected to the lesser strain (maximum strain in 0.0095, 0.0136 and 0.0190 thickness to diameter ration pipe are 0.0138, 0.0194 and 0.021 respectively), which indicates lesser damage in the pipe. However, from Fig. 9 results suggest those thick pipelines are subjected to high geometric deformation. That means thin pipe, which is more flexible and can easily bend subjected to material failure (Fig. 9a), while thick pipe with high stiffness subjected to intensive geometric deformation (Fig. 9c). The possible reason for this is already discussed in previous section. The further exploration for thickness to diameter ratio effect here can be observed for overall damage of pipe, which makes pipeline unfunctional after the fault motion.

From Fig. 8 and Fig. 9.a, one can see pipe with thin wall thickness is strained heavily but strain does not reached ultimate strain. From this, it can be said that pipe may not be function due to heavy material straining but it is sustain leakages as it does not reached ultimate strain. For the case of thick (Fig. 9c) pipe subjected to high geometric changes, pipe material does not strain heavily. That indicates pipe may not be useful because of high geometric deformation as it further causes pressure head loss but it is safe in martial strain point of view. For the case of medium wall thickness pipe, it can be seen that pipe is subjected to high geometric changes (Fig. 9b). In addition, Fig. 8 shows that it has sufficiently entered in the plastic stage before it buckles. The highly crumbled pipe in Fig. 9.b points out that pipe material is in highly plastic stage. In addition, there can be few more factors which are influencing the deformed shape of the pipe, like the assumption of perfect bonding between the pipe materials and surrounding deformed soil. The computational error involved numerical analysis in highly deformed structure. However, medium thick pipe buckles at highly plastic stage destroying it complete and may lead to fuel leakages. For the above results we can be conclude that, strength in pipe material remains before the buckling. At the same time buckling is also important factor from fuels leakage point of view during the fault motion itself.

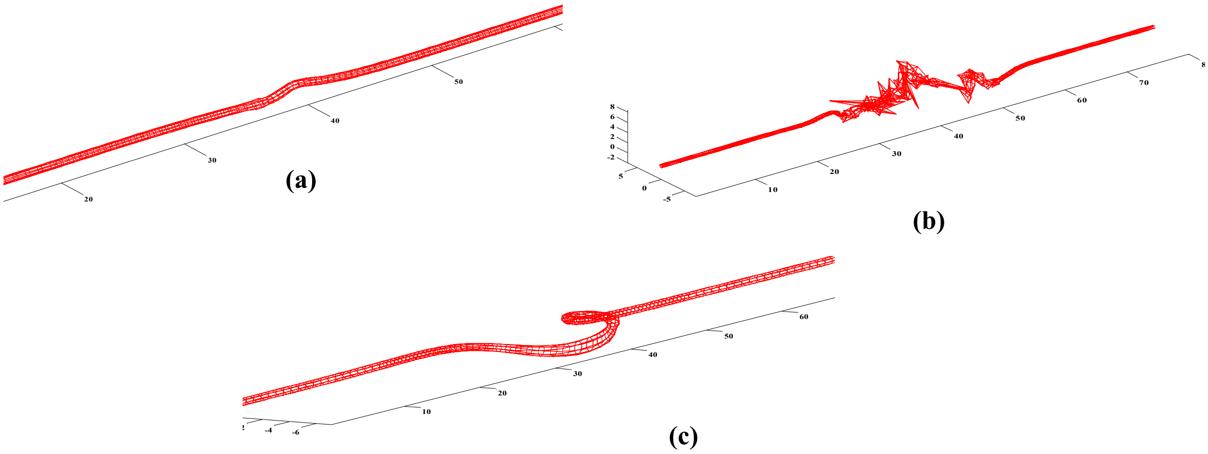


Figure 9. Deformed shape of pipe for different t_w/D ratio for dip slip with $\Delta z = 0.6$m and $\phi = 60^0$

4. CONCLUSION

Main conclusions of this study can be stated as following:

- Numerical modelling of physical problem if implemented with latest updated methods could yield much better results.
- Apart from material behaviour and its failure, geometrical behaviour becomes important when studies are done on pipes subjected to compressional motions.
- Compression failure behaviour of the pipelines is catastrophic in nature as it leads to sudden buckling, which is crucial and depends on the pipe wall thickness.
- Though here developed model is implemented on the fault motion but the same can be implemented for other kind of ground motions.

5. REFERENCES

Karamitros D. et al, "*Stress analysis of buried steel pipelines at strike-slip fault crossings*," **Soil Dynamics and Earthquake Engineering**, 27/3, 200-211, (2007).

Kennedy R P, Chow A W, William R A., " *Fault movement effects on buried oil pipeline*," **Transportation Engineering** ASCE, **103**: 617–633, (1975).

Liu Ai-wen et al, "*An equivalent-boundary method for the shell analysis of buried pipelines under fault movement*," **ActaSeismologicaSinica Vol.17.supp** 150-156 (2004).

O'Rourke M. J., Liu, X., "*Response of buried pipelines subject to Earthquake Effects*," Multidisciplinary centre for Earthquake Engineering and Research (MCEER), **Monograph No.3** (1999).

Takada et al, "*Shell-Mode Response of Buried Pipelines to Large Fault Movements*," **Journal of Structural Engineering, Vol.44A**, 1637-1646, (1998).

Wang, L. R. L. and Yeh, Y. H., "*A Refined Seismic Analysis and Design of Buried Pipeline for Fault Movement*," **Earthquake Engineering and Structural Dynamics, Vol. 13**, 75-96, (1985).

EERI, "The Izmit (Kocaeli), Turkey, Earthquake of August 17, 1999," **EERI Special Earthquake Report**, (1999).

Newmark N. M., and Hall W. J., "*Pipeline design to resist large fault displacements*," U.S. National Conference on Earthquake Engineering, Ann Arbor, Michigan, 416-425, (1975).

Bathe K.J, "*Finite Element Procedures*," Prentice-Hall of India Private Limited, New Delhi, (1996).

J.N. Reddy, "*An Introduction to nonlinear finite element analysis*," Oxford University Press, (2004).

IITK-GSDMA, "*Guidelines for seismic design of buried pipelines*," (2007).