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Research Paper

A CASE STUDY ON DIFFERENT STRAIN LEVELS OF BURIED CONTINUOUS PIPE LINE SYSTEM FOR DEHRADUN CITY

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The performance of buried continuous pipe lines during an earthquake has been a major concern as these structures are classified into the lifeline category. Moreover, the absence of any specific standard or guidelines for seismic evaluation of these structures in India has always called for site specific response evaluation. Post Bhuj earthquake, the Gujrat State Disaster Management Authority had initiated the study in a more holistic approach and Indian Institute of Technology, Kanpur came up with guidelines incorporating different provisions and commentary. The present article is a parametric study of pipe diameter on the seismic performance of the continuous pipeline system comparing different strain levels. Along with, the effect of installation depth is investigated. A case study on pipeline systems of Dehradun city, Uttarakhand (India) is also presented. Four different earthquakes are considered to generate near- field and far field effects. The study shows that pipes having diameters more than 2.2 m slip at any depth of installation.

Keywords: Continuous pipeline system, Axial strain due to operation and wave propagation, Soil pipe line friction interface, Design PGV, Slippage analysis

INTRODUCTION

Buried pipelines are one of the most important lifeline structures damaged extensively during an earthquake and thus causing havoc in the society in terms of fire, economic losses and disability of lifeline networks. The 1995 Hyogo-Ken Nanbu earthquake in Japan has caused leakage of gas from buried pipelines at 234 different places and subsequently, fire spread over 1 sq. km area (EQE summary report, 1995; Scawthorn and Yanev, 1995). Similarly the damage in the natural gas pipelines in Chi Chi Earthquake, 1999 in Taiwan caused an approximate economic lose of US$ 25 mn (Chen *et al.*, 2000). The 1985 Michoacan earthquake, famously known as the Mexico

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City earthquake had jeopardized the whole portable water system because of large soil displacement (Berrones and Liu, 2003). The performance of the pipe line system at or near T-junctions, elbows, joints and other hard points are critical as revealed by the past earthquakes (Hahn and Sritharan, 1994). During the 2001 Bhuj Earthquake, India, extensive damage caused to the natural gas and oil pipelines, which are designed as a continuous system has induced the necessity of study on the topic as there is no standard procedure or guidelines available on the same. At the same time, the state of practice of seismic design of buried pipelines in India is still at infancy compared to international standards.

The strain levels in the pipeline system which are generated due to its operational mechanism and/or due to seismic wave propagation are often referred to in its design procedure. The current study basically considers three different levels of strain, i.e., axial strain due to operation, axial strain due to earthquake excitation and strain induced in the pipe line by friction at the soil pipe interface. The first two levels of strain are well documented in the literature and numerous procedures are available for their computation, starting back to 1967 when Newmark suggested the simplest method assuming that the pipeline strain and the ground strain parallel to pipeline axis are equal. However it has been observed that for very large deformation, some slippage at pipe soil interface occurs due to which we can conclude the pipe strain to be lesser than that of soil (Berrones and Liu, 2003). Often the effect of wave propagation is considered to be more severe for segmented pipes as it produces axial and bending stresses (Berrones and Liu, 2003), yet the slippage should not be neglected in case of continuous pipeline system as it is associated with joint failures and even may lead to failure of the pipeline near support due to buckling. The conventional seismic wave propagation analysis generally neglects the slippage at the soil pipe interface due to small amplitude (Akiyoshi and Fuchida, 1984). The current study tries to evaluate the slippage in continuous pipeline system in terms of axial strains due to operational mechanism, seismic wave propagation and strain induced by friction at the soil pipe interface.

The performance of buried pipelines in Dehradun region during an earthquake is a matter of serious concern as it will affect the whole socioeconomic scenario of Uttarakhand state. Any fire hazard resulting from the leakage of inflammable natural gas and oil pipelines would cost life and economy in an unprecedented manner. To evaluate the site specific response, theoretical one dimensional ground response analysis is performed using the software SHAKE2000. Several researchers have already carried out ground response analysis for many cities in India e.g. Govindraju *et al.* (2004) for Gujarat; Rajiv Ranjan (2005) for Dehradun; Boominathan *et al.* (2007) for Chennai; Mohanty (2007) for Delhi; Raghukanth (2008) for Guwahati; and Choudhuri and Shukla (2011a) and (2011b) again for Gujarat. Kowk and Stewart (2006) showed that 1-D ground response analysis can be useful in predicting the average effects of sediment nonlinearity. Nath and Jakka carried out 1-D ground response analysis to evaluate the effect of bedrock depth on dynamic site characterization (Nath Ritu Raj and Jakka Ravi Sankar, 2012). In this paper four different earthquakes are considered as the input motion to generate the peak ground acceleration considering near field and far field effect. These PGA values are used to compute the axial strains due to seismic wave propagation.

AXIAL STRAIN GENERATED DUE TO OPERATIONAL MECHANISM

As per JSCE (2000b), the internal pressure for oil and gas pipeline, can be classified as below. The guidelines prepared by IITK-GSDMA also incorporate the same for India

High pressure $P \geq 10$ kgf/cm^2
Medium pressure $3 < P < 10$ kgf/cm^2
Low pressure $P \leq 3$ kgf/cm^2

In this study API X-52 grade pipe is used. Since stress-strain relationship of the pipe material is not evaluated from lab experiment, so the authors have followed Ramberg-Osgood relationship for the pipe material. The relation is shown in the Figure 1.

Figure 1: Stress Strain Relation of Pipe API-52 Grade Steel Pipe Material

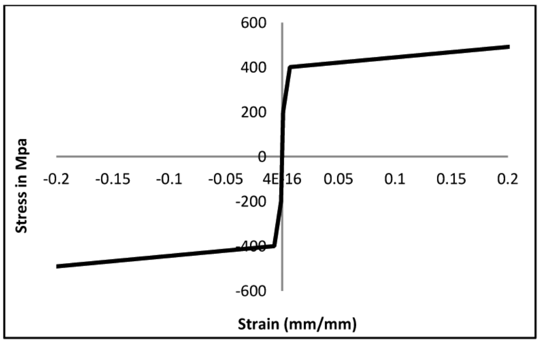


Table 1: Pipe Material Characteristics

Grade of Pipe	X-52
Yield stress (MPa) of the pipe material	358
n	9
r	10

The Ramberg-Osgood parameters (*n, r*) for pipe materials are shown in Table 1 [IITK-GSDMA guideline].

The initial stress in the pipeline is developed due to internal pressure and temperature change due to installation and operation. The longitudinal stress (S_p) in the pipe due to internal pressure is calculated as per the guidelines prepared by IITK- GSDMA.

$$S_p = \frac{PD_\mu}{2t} \quad \text{...(1)}$$

where P Max internal operating pressure in pipe
D Outside diameter of the pipe
μ Poison's ratio (0.3 for steel)
t Nominal wall thickness of the pipe

Using Ramberg-Osgood stress-strain relationship, the longitudinal strain in the pipe will be

$$\varepsilon_p = \frac{S_p}{E}\left[1 + \frac{n}{1+r}\left(\frac{S_p}{\sigma_y}\right)^2\right] \quad \text{...(2)}$$

where ε_p Longitudinal strain in pipe
σ Stress in the pipe
E Initial young's modulus
σ_y Yield strain of the pipe material
n, r Ramberg-Osgood parameters

The longitudinal stress in pipe due to temperature change is expressed as

$$S_r = E\alpha_t\left(T_2 - T_1\right) \quad \text{...(3)}$$

where E Modulus of elasticity
α_t Linear coefficient of thermal expansion of steel

T_1 Temp in the pipe at the time of installation

T_2 Temp in the pipe at the time of operation

The longitudinal strain in the pipe due to temperature change will be

$$\varepsilon_t = \frac{S_t}{E}\left[1 + \frac{n}{1+r}\left(\frac{S_t}{\sigma_y}\right)^r\right] \qquad ...(4)$$

The total strain in the continuous pipeline due to internal pressure and temperature is

$$\varepsilon_{op} = \varepsilon_p + \varepsilon_t \qquad ...(5)$$

The guidelines prepared by IITK-GSDMA have approved the use of above calculated strain as the operational strain in pipe ignoring the strains due to installation imperfection or initial bending.

AXIAL STRAIN GENERATED DUE TO SEISMIC WAVE PROPAGATION

Owing to ground shaking and Permanent Ground Displacement (PGD), differential ground displacement occurs during an earthquake. The other causes of PGD can be broadly enlisted as surface faulting, lateral spread displacement, triggered landslide displacement and settlement from compaction or liquefaction (Guidelines for seismic design of buried pipelines, 2007). The seismic vulnerability assessment of buried pipelines includes calculation of transitory strains caused by differential ground displacement. As per ALA-ASCE 2001 guidelines, the approximate axial strain µaw induced in a buried pipe due to wave propagation can be calculated as:

$$\varepsilon_{aw} = \frac{V_g}{\alpha_{\in} C_s} \qquad ...(6)$$

where V_g Design peak ground velocity

$\alpha_{\in}$ Ground strain coefficient (= 2 as per GSDMA)

C Velocity of seismic wave propagation (= 2 km/s, assuming shear wave velocity effect is dominating)

The same equation is adopted by IITK-GSDMA guidelines for seismic design of buried pipelines considering Indian scenario.

AXIAL STRAIN TRANSMITTED BY SOIL FRICTION

The importance of a frictional interface in soil pipe interaction during an earthquake was investigated by Akiyoshi and Fuchida (1984). They showed that in a branch pipe system in soft soils, there is remarkable slippage in main pipe which subsequently increases the stresses in auxiliary pipes. As per ALA-ASCE 2001 guidelines, for a continuous system the axial strain µaf induced by friction at the soil pipe interface can be calculated as:

$$\varepsilon_{af} \leq \frac{T_u \lambda}{4AE} \qquad ...(7)$$

where T_u Peak friction force per unit length at soil pipe interface

λ Apparent wavelength of seismic waves at ground surface, sometimes assumed to be 1.0 km without further information

A Pipe cross sectional area

E Steel modulus of elasticity

The same equation is adopted by IITK-GSDMA guidelines for seismic design of buried pipelines considering Indian scenario. Slippage in the pipe occurs when ε_{aw} exceeds ε_{af}.

GENERATION OF DESIGN PGV

It is understood from Equation (6) that computation of µaw requires calculation of design peak ground velocity beforehand. The design peak ground velocity *Vg* as described in Equation (6) can be then calculated by multiplying the peak ground velocity with an importance factor which is specified in Table 3 in the IITK-GSDMA Guidelines for Seismic Design of Buried Pipelines considering Indian scenario. ALA-ASCE 2001 guidelines defined as the ratio of PGV to PGA as a function of both source (in terms of moment magnitude) and path (in terms of source-to-path distance) of an earthquake. This paper attempts to find out peak ground accelerations in Dehradun city for different earthquakes by performing one dimensional ground response analysis using SHAKE2000. The modulus reduction curves and damping ratio curves are chosen from the database.

For a typical case study the following parameters are chosen:

Depth of bed rock = 32.77 m from the ground surface.

Soil stratification = clay-soil-gravel-rockfill-bedrock.

Shear wave velocity of clay = 207 m/s

Shear wave velocity of soil = 250 m/s

Shear wave velocity of gravel = 332 m/s

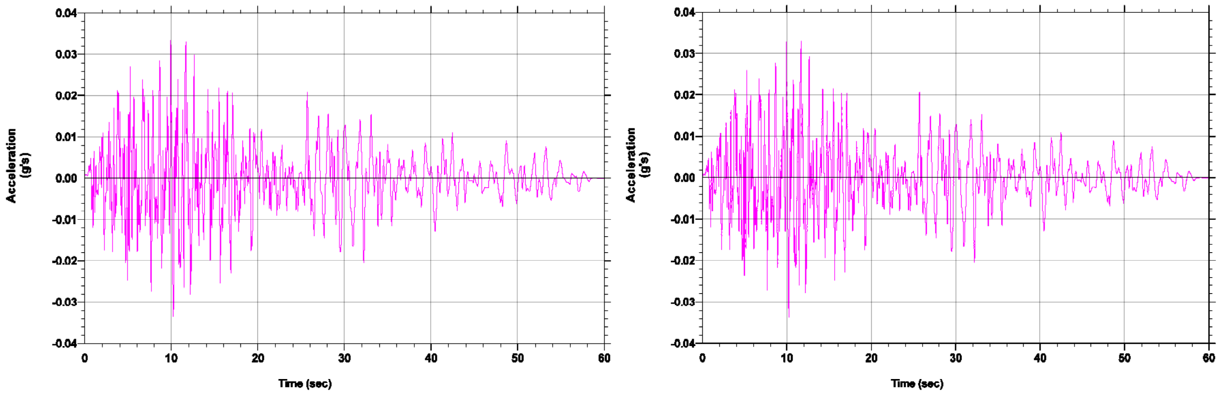
Shear wave velocity of rock-fill = 406 m/s

Shear wave velocity of bed rock = 650 m/s

Depth of WT = 12 m from the ground surface.

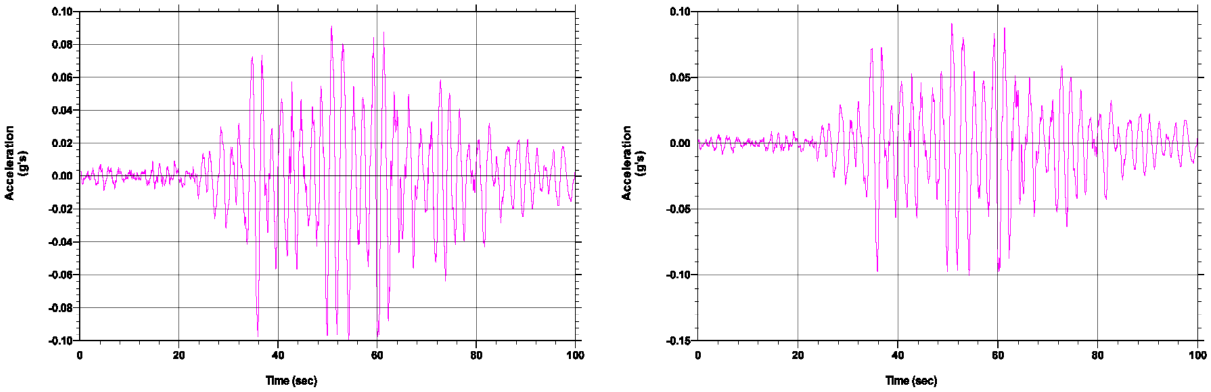
The generated surface acceleration time histories and input ground motions are shown in Figures 2a, 2b; 3a, 3b; 4a, 4b; and 5a, 5b.

Figure 2: (a) Input Bed Rock Motion due to Borred Mountain 10/21/42, EL Centro Array (b) Surface out Crop Motion due to EL Centro Array Earthquake, with max PGA = 0.0674g at *t* = 2.85 s



(a) (b)

Figure 3: (a) Input bed rock motion due to Mexico City Earthquake (b) Surface out crop motion at Mexico City with max PGA = 0.0977 g at *t* = 54.18



(a) (b)

Figure 4: Input bed rock motion due to KOBE Earthquake, JMA RECORD, Near Fault, (b) Surface out Crop Motion with max PGA = 0.627 g at *t* = 8.44 s

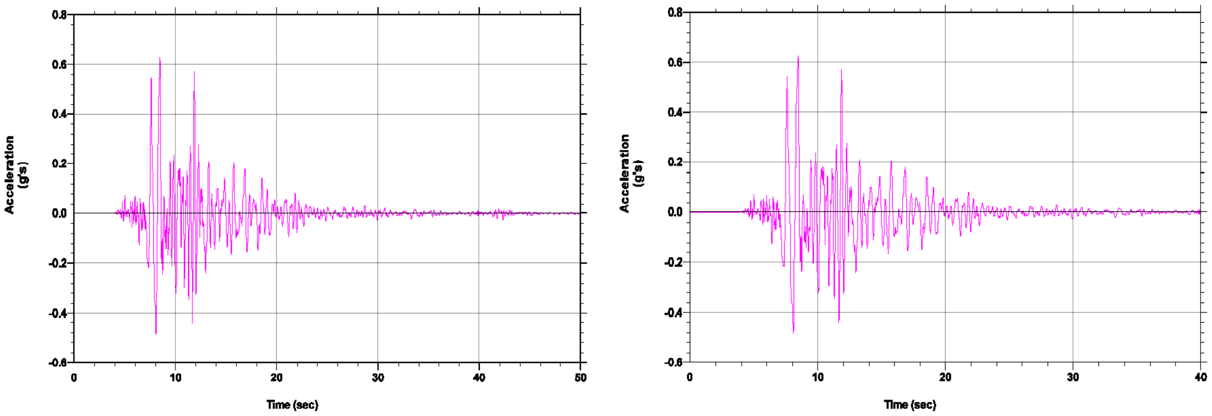
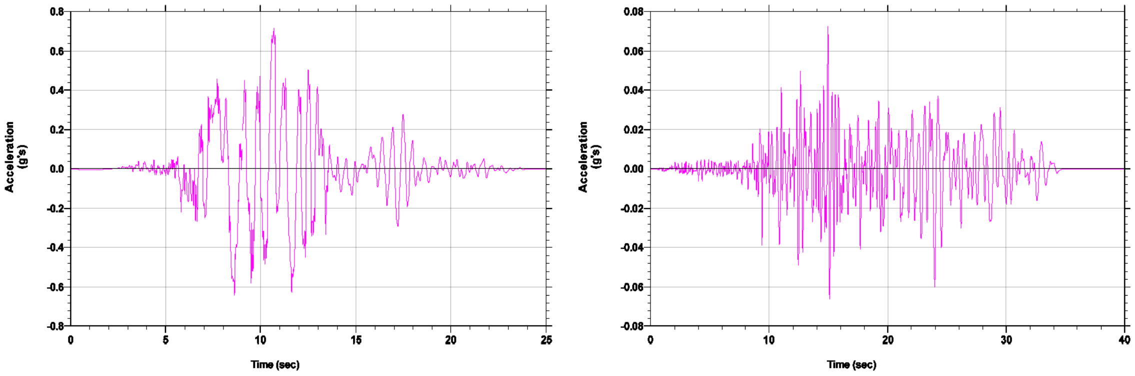


Figure 5: (a) Input bed rock motion at SAC Steel Project; Near Field; Loma Prieta, 1989, (b) Surface out crop motion due to SAC Steel Project; Near Field; Loma Prieta (1989), with max PGA = PGA= 0.073 g at 14.94 s



SLIPPAGE ANALYSIS OF BURIED PIPELINES

From the discussions in the previous sections it is clear that slippage analysis of a buried pipe line system depends on axial strain levels generated due to seismic excitation and friction at soil pipe interface. It is also learned that axial strain due to soil friction is a parameter of its cross sectional area and burying depth. This article tries to provide different axial strain levels due to soil friction varying both the diameter of pipe and its depth from the ground surface. Similarly, axial strain generated due to wave propagation is varied with respect to different PGA values as discussed in the previous section. Table 2 shows maximum axial strain developed in the pipe line due to both wave propagation and soil friction considering four

Table 2: Slippage Analysis at Constant Depth of burying = 1.5 m from the GS (with Varying Diameter)

D (m)	ε_{op}	t_u (N/m)	Max Pipe Axial Strain due to					Difference in Strain Levels at Different PGVs				Slippage (Y/N)
			Wave + Operational Design PGV (m/s)				Soil Friction					
			0.078	0.227	1.317	1.503		0.078	0.227	1.317	1.503	
0.6	8.9E-04	70335	9.1E-04	9.4E-04	1.2E-03	1.3E-03	7.364E-03	0.0065	0.0064	0.0061	0.0061	N
0.7	9.8E-04	82058	9.9E-04	1.0E-03	1.3E-03	1.4E-03	7.352E-03	0.0064	0.0063	0.0060	0.0060	N
0.8	1.1E-03	93780	1.1E-03	1.1E-03	1.4E-03	1.4E-03	7.344E-03	0.0063	0.0062	0.0060	0.0059	N
0.9	1.2E-03	105503	1.2E-03	1.2E-03	1.5E-03	1.5E-03	7.337E-03	0.0062	0.0061	0.0059	0.0058	N
1	1.2E-03	117225	1.3E-03	1.3E-03	1.6E-03	1.6E-03	7.332E-03	0.0061	0.0060	0.0058	0.0057	N
1.1	1.3E-03	128948	1.3E-03	1.4E-03	1.7E-03	1.7E-03	7.328E-03	0.0060	0.0059	0.0057	0.0056	N
1.2	1.4E-03	140671	1.4E-03	1.5E-03	1.7E-03	1.8E-03	7.324E-03	0.0059	0.0058	0.0056	0.0055	N
1.3	1.5E-03	152393	1.5E-03	1.6E-03	1.8E-03	1.9E-03	7.321E-03	0.0058	0.0058	0.0055	0.0054	N
1.4	1.6E-03	164116	1.6E-03	1.7E-03	1.9E-03	2.0E-03	7.318E-03	0.0057	0.0056	0.0054	0.0053	N
1.5	1.7E-03	175838	1.7E-03	1.8E-03	2.1E-03	2.1E-03	7.316E-03	0.0056	0.0055	0.0053	0.0052	N
1.6	1.9E-03	187561	1.9E-03	1.9E-03	2.2E-03	2.2E-03	7.314E-03	0.0054	0.0054	0.0051	0.0051	N
1.7	2.1E-03	199283	2.1E-03	2.1E-03	2.4E-03	2.4E-03	7.312E-03	0.0052	0.0052	0.0049	0.0049	N
1.8	2.3E-03	211006	2.3E-03	2.4E-03	2.6E-03	2.7E-03	7.311E-03	0.0050	0.0049	0.0047	0.0046	N
1.9	2.7E-03	222728	2.7E-03	2.8E-03	3.0E-03	3.1E-03	7.310E-03	0.0046	0.0045	0.0043	0.0042	N
2	3.3E-03	234451	3.3E-03	3.4E-03	3.6E-03	3.7E-03	7.308E-03	0.0040	0.0039	0.0037	0.0036	N
2.1	4.3E-03	246174	4.3E-03	4.3E-03	4.6E-03	4.6E-03	7.307E-03	0.0030	0.0030	0.0027	0.0027	N
2.2	5.7E-03	257896	5.7E-03	5.8E-03	6.0E-03	6.1E-03	7.306E-03	0.0016	0.0015	0.0013	0.0012	N
2.3	8.0E-03	269619	8.0E-03	8.0E-03	8.3E-03	8.3E-03	7.305E-03	-0.0007	-0.0007	-0.0010	-0.0010	**Y**
2.4	1.1E-02	281341	1.1E-02	1.1E-02	1.2E-02	1.2E-02	7.304E-03	-0.0041	-0.0041	-0.0044	-0.0045	**Y**
2.5	1.7E-02	293064	1.7E-02	1.7E-02	1.7E-02	1.7E-02	7.304E-03	-0.0092	-0.0093	-0.0095	-0.0096	**Y**

different design PGVs for a constant burying depth with varying pipe diameter. The difference between them is also calculated to determine any slippage in the system.

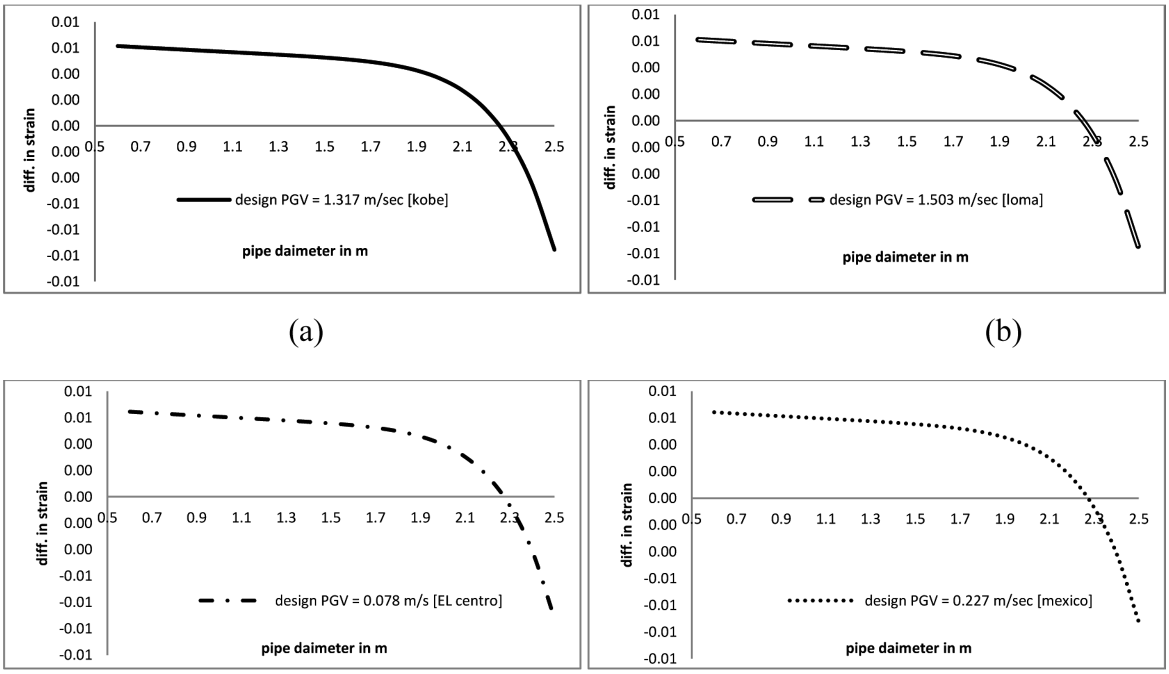
DISCUSSIONS

From Table 2 it is seen that the pipe line system tends to slip as its diameter increases and for pipe lines having diameters greater than 2.2 m slippage occurs. This trend is justified as axial strain due to operation is a direct function of pipe diameter which subsequently increases total axial strains (due to operation and wave propagation). The same pattern has been observed for all earthquakes (both near field and far field) which are demonstrated in Figures 6a to 6d.

The figures also show that the pipe lines having diameter more that 2.0 m are more prone to slippage (rapid increase in strains due to operation and wave propagation). Now the effect of installation depth on slippage of pipe line system is investigated. For that purpose, four different diameters, i.e., 1.5 m, 2 m, 2.5 m and 3 m are chosen against which the burying depth of pipe is varied from 1 m to 3 m. The same exercise is repeated for all generated PGAs which are shown in Tables 3 to 6.

Tables 3 and 4 show that pipelines having diameters 1.5 m and 2.0 m (<2.2 m) have not slipped at any burying depth upto 3 m. However Tables 5 and 6 reveal that pipelines with diameters 2.5 m and 3.0 m (>2.2 m) actually

Figure 6: Percentage Difference Between Total Strain [Due to Seismic Wave and Operation] vs. Pipe Diameter [Soil Cover *H* is Constant]



(a) (b)

(c) (d)

Table 3: Slippage Analysis at Constant Diameter (D) = 1.5 m from the GS (with varying installation depth)

D (m)	t_u (N/m)	Max pipe axial strain due to					Difference in strain levels at different PGVs			
		Wave + Operational				Soil Friction				
		Design PGV (m/s)								
		0.078	0.227	1.317	1.503		0.078	0.227	1.317	1.503
1.0	164201	1.7E-03	1.8E-03	2.1E-03	2.1E-03	6.832E-03	5.1E-03	5.0E-03	4.8E-03	4.7E-03
1.5	175838	1.7E-03	1.8E-03	2.1E-03	2.1E-03	7.316E-03	5.6E-03	5.5E-03	5.3E-03	5.2E-03
2.0	187475	1.7E-03	1.8E-03	2.1E-03	2.1E-03	7.800E-03	6.1E-03	6.0E-03	5.7E-03	5.7E-03
2.5	199113	1.7E-03	1.8E-03	2.1E-03	2.1E-03	8.285E-03	6.5E-03	6.5E-03	6.2E-03	6.2E-03
3.0	210750	1.7E-03	1.8E-03	2.1E-03	2.1E-03	8.769E-03	7.0E-03	7.0E-03	6.7E-03	6.7E-03

Table 4: Slippage Analysis at Constant Diameter (D) = 2.0 m from the GS (varying installation depth)

D (m)	t_u (N/m)	Max pipe axial strain due to					Difference in strain levels at different PGVs			
		Wave + Operational				Soil Friction				
		Design PGV (m/s)								
		0.078	0.227	1.317	1.503		0.078	0.227	1.317	1.503
1.0	218935	3.3E-03	3.4E-03	3.6E-03	3.7E-03	6.825E-03	3.5E-03	3.5E-03	3.2E-03	3.1E-03
1.5	234451	3.3E-03	3.4E-03	3.6E-03	3.7E-03	7.308E-03	4.0E-03	3.9E-03	3.7E-03	3.6E-03
2.0	249967	3.3E-03	3.4E-03	3.6E-03	3.7E-03	7.792E-03	4.5E-03	4.4E-03	4.1E-03	4.1E-03
2.5	265483	3.3E-03	3.4E-03	3.6E-03	3.7E-03	8.276E-03	4.9E-03	4.9E-03	4.6E-03	4.6E-03
3.0	281000	3.3E-03	3.4E-03	3.6E-03	3.7E-03	8.759E-03	5.4E-03	5.4E-03	5.1E-03	5.1E-03

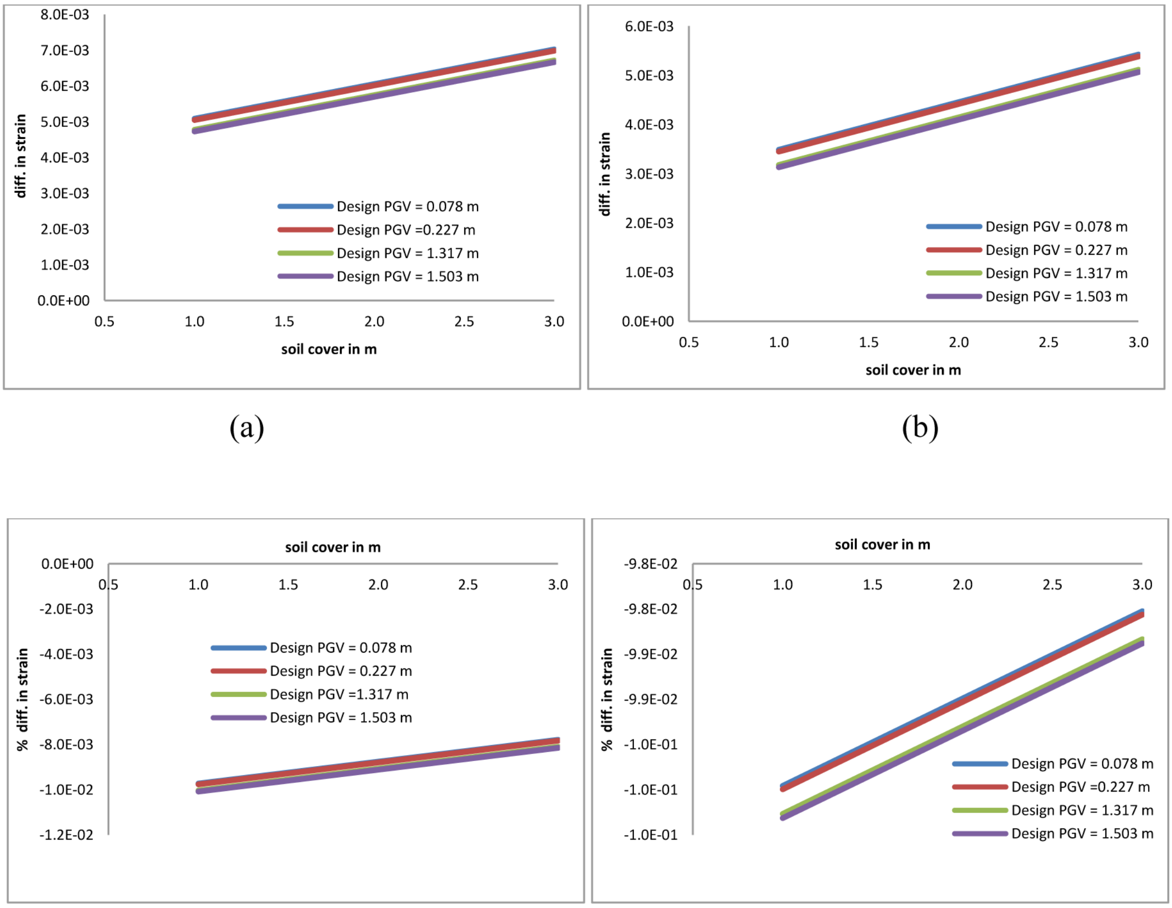
Table 5: Slippage Analysis at Constant Diameter (D) = 2.5 m from the GS (withvarying installation depth)

D (m)	t_u (N/m)	Max pipe axial strain due to					Difference in strain levels at different PGVs			
		Wave + Operational				Soil Friction				
		Design PGV (m/s)								
		0.078	0.227	1.317	1.503		0.078	0.227	1.317	1.503
1.0	273668	1.7E-02	1.7E-02	1.7E-02	1.7E-02	6.820E-03	-9.7E-03	-9.8E-03	-1.0E-02	-1.0E-02
1.5	293064	1.7E-02	1.7E-02	1.7E-02	1.7E-02	7.304E-03	-9.2E-03	-9.3E-03	-9.5E-03	-9.6E-03
2.0	312459	1.7E-02	1.7E-02	1.7E-02	1.7E-02	7.787E-03	-8.8E-03	-8.8E-03	-9.1E-03	-9.1E-03
2.5	331854	1.7E-02	1.7E-02	1.7E-02	1.7E-02	8.270E-03	-8.3E-03	-8.3E-03	-8.6E-03	-8.6E-03
3.0	351249	1.7E-02	1.7E-02	1.7E-02	1.7E-02	8.754E-03	-7.8E-03	-7.8E-03	-8.1E-03	-8.1E-03

Table 6: Slippage Analysis at Constant Diameter (D) = 3.0 m from the GS (varying installation depth)

D (m)	t_u (N/m)	Max pipe axial strain due to					Difference in strain levels at different PGVs			
		Wave + Operational				Soil Friction				
		Design PGV (m/s)								
		0.078	0.227	1.317	1.503		0.078	0.227	1.317	1.503
1.0	328402	1.1E-01	1.1E-01	1.1E-01	1.1E-01	6.817E-03	-1.0E-01	-1.0E-01	-1.0E-01	-1.0E-01
1.5	351676	1.1E-01	1.1E-01	1.1E-01	1.1E-01	7.301E-03	-9.9E-02	-1.0E-01	-1.0E-01	-1.0E-01
2.0	374951	1.1E-01	1.1E-01	1.1E-01	1.1E-01	7.784E-03	-9.9E-02	-9.9E-02	-9.9E-02	-9.9E-02
2.5	398225	1.1E-01	1.1E-01	1.1E-01	1.1E-01	8.267E-03	-9.9E-02	-9.9E-02	-9.9E-02	-9.9E-02
3.0	421499	1.1E-01	1.1E-01	1.1E-01	1.1E-01	8.750E-03	-9.8E-02	-9.8E-02	-9.8E-02	-9.8E-02

Figure 7: Difference in Strain Levels vs. Soil Cover for Diameter = 1.5 m (in Figure a), 2.0 m (in Figure b), 2.5 m (in Figure c) and 3.0 m (in Figure d)



(a) (b)

(c) (d)

slip at any depth of installation. The effect of soil cover in pipe slippage analysis has been shown in Figures 7(a-d).

From the Figures 7(a-d) it is seen that slippage in pipe line system depends mostly in pipe diameter rather than its depth of installation.

CONCLUSION

The study shows that with the increase in the burying depth, the probability of slippage decreases. The same pattern is also been observed in those system where slippage actually occurs (D > 2.2 m). This is because of the fact that as the depth increases the confining pressure increases and hence the axial strain due to soil friction. The study shows that continuous pipe line system of Dehradun city needs a site specific seismic performance analysis with a more holistic approach especially for larger diameter pipes.

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