International Journal of Engineering Research
Volume No.5, Issue Special 1 pp : 116-119

ISSN:2319-6890(online),2347-5013(print)
8 & 9 Jan 2016

Dynamic Behavior of Underground Structures during Earthquake: A Critical Review

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ABSTRACT: During earthquake there is a considerable damage to structures which are above the ground level as well as to those structures which are completely underground. Several studies were carried out for analysing dynamic behavior of these structures. The underground structures themselves do not have their own natural period and mode of vibration hence the deformation of underground structures is governed by relative displacements of the surrounding ground during earthquakes. The effects of soil-structure interaction, stratification of soil, material non homogeneity, ground water table fluctuation, and inherent properties of soil strata needs due consideration in dynamic behavior of underground structures. This paper aims to review the effects of different parameters on dynamic behavior of underground structures and conclusions are drawn based on the review which may help in formulating new ideas for further research work.

Keywords: dynamic, earthquake, underground structures, relative displacements, soil-structure interaction.

I. Introduction

An earthquake is the sudden shaking of the Earth crust, which can be violent enough to cause damage and disruption to the properties which are above as well as below ground. With rapid growth of industrialization and urbanization potential rate of damage and disruption has increased considerably. Hence it is necessary to limit the structural damage as well as reduce the impact of earthquake on society. Damage and disruption to underground structures mainly buried pipelines carrying utility services like water, sewage, oil and gas etc. as well as tunnels may lead to loss of vital services or more precisely lifeline services. Failure of oil and gas pipeline may lead to detrimental effects on environment and public at the same time a chance of fire also increases with electric sparks. Also rehabilitation work also becomes difficult because of failure of water pipelines. The Loma Prieta earthquake and earthquake of Northridge California, and earthquake of Kobe Japan were the well-known examples of lifeline failures.

Due to the importance of the problem, researchers are trying to work out new ideas in this contest. In this paper few papers have been critically reviewed and conclusions are drawn based on the review for formulating new ideas for further research work.

II. Factors Affecting Dynamic Behavior Of Buried Pipelines:

Behavior of structures, which are present above ground mainly, depends upon inertia force and amplification of structure corresponding to ground or more precisely foundation of structure. But for the structures which are below ground soil structure interaction and ground motion characteristics play vital role in analysis. Field observations and various studies indicate that damage to the underground structures mainly buried pipelines during earthquake is due to excessive axial and bending stresses, and strains developed at various points along length of pipes due to various reasons like wave propagation characteristics, large displacements resulting from fault movements, uplifting or landslide caused by soil liquefaction, etc.

Hashash et al. (2014) presented a report of summary of the current state of seismic analysis and design for underground structures which describes approaches used by engineers in quantifying the seismic effect on an underground structure. The report also briefly discusses development of appropriate ground motion parameters, including peak accelerations and velocities, target response spectra, and ground motion time histories.

A. Soil Pipe Interaction

Interaction of soil and pipe has a remarkable effect on the behavior of buried pipe subjected to earthquake excitations. During earthquake excitation differential deformation may occur due to difference in dynamic properties of buried pipelines and soil medium surrounding the same. This will cause development of differential strain and corresponding differential stress. This will ultimately result in development of axial and bending stresses and may lead to failure of pipeline either by crushing or buckling. Dynamic behavior considering soil pipe interaction has been illustrated by various researchers. Behnamfar et al. (2015) studied soil pipe interaction effect on bend and concluded that axial strain at bends is larger in stiffer soil due to smaller slippage and the bend strain is directly, whereas the soil-pipe relative displacement is inversely proportional to the D/t ratio. Dwivedi et al. (2010) and Mavrids et al. (1996) proved analytically that axial analysis is the critical analysis and dynamic soil-pipe interaction (SSI) effects of the pipeline for axial response are considerable whereas for lateral response

doi : 10.17950/ijer/v5i1/025

those are negligible. The authors also performed sensibility analysis of critical parameters like the propagation velocity of seismic wave, pipe radius and the frequency of ground excitation to illustrate their influence on the ratio of the pipe to ground displacement amplitudes and consequently to the induced pipe strains.

Berrones et al. observed that the soil around a pipeline plays a very important role in relation to its seismic behavior of pipeline. They illustrated that soil pipe interaction causes axial as well as bending stresses in continuous pipelines which may ultimately result in buckling and crushing of pipelines. They also suggested some measures to improve seismic performance of continuous and segmental pipelines like the use of stronger materials and a thicker walls and use of flexible joints. For the pipelines buried in soil strata susceptible to liquefaction, measures like dynamic or vibratory compaction, or any other procedure to improve the in situ density like replacing liquefiable soils in the pipe vicinity with non-liquefiable materials, such as coarse gravel. Corrado et al. (2009) proved that soil-structure interaction and the end constrains can significantly influence the dynamic response of a buried pipe of finite length under seismic excitation. Moreover they showed that end points of the pipe represent the most vulnerable sections, where high stresses can cause breaks or fractures. The absolute maximum strain occurs in the initial section and the maximum strain during the transient often occurs at the ends of the pipe.

Halabian et al. (2008) developed a 3D hypo-elastic, soil-pipeline model to study the dynamic behavior of pipelines embedded in liquefiable soils and performed numerical simulation of the full-process of liquefaction for an underground pipeline. They used effective stress method which also predicted the loss of soil strength consistent with the liquefaction process to study development and dissipation of pore water pressure during a seismic excitation.

B. Permanent Ground Deformation

Permanent ground deformation (PGD) is nothing but large scale ground deformation produced due to soil liquefaction, landslide or fault movement. Pipelines are usually buried at shallow depths. Hence if there are chances of PGD due to any of above mentioned effect, region affected will experience sudden changes in geometry as well as geotechnical properties of soil which ultimately result in development of sudden high stresses and there are possibilities of local as well as whole failure. Effect of permanent ground deformation (PGD) on dynamic behavior has been studied by various researchers. Arya et al. (2015) provided guidelines for calculating the seismic resistance and described various measures to be adopted to prevent failure of oil and gas continuous buried steel pipeline under various seismic events like fault, landslide etc. causing permanent ground deformation. Chaudhary et al. (2014) illustrated that compression failure behaviour of the pipelines crucially depend on the pipe wall thickness and it is catastrophic in nature as it leads to sudden buckling. Also geometrical behaviour of buried pipelines is more important than material behaviour or its failure when subjected to PGD due to thrust fault motion. Hongjing et al. (2008) found that for buried pipelines subjected permanent ground deformation (PGD) due to faults, peak stress increases rapidly with the increase of the ratio diameter to thickness ratio. The authors also proved that Seismic response of buried pipeline increases with the increase of the soil displacement and crossing angle and decreases with increase in buried depth. The greater the crossing angle, the greater response of the pipe under normal-movement. The greater buried depth, the poorer performance of the pipe.

C. Wave Propagation

Seismic waves are mainly of two types, body waves and surface waves. Body waves are faster waves having high velocity of propagation. The ground strain produced due to propagation of body waves is much less. On the other hand velocity of propagation of surface waves is much less and ground strain produced is higher. Hence surface waves are more hazardous to buried pipelines than body waves. Effect of wave propagation on dynamic behaviour of buried pipeline has been studied Boorboor et al. (2015) suggested that in jointed pipe networks under the effect of transient ground waves, stress level or rotation along the pipelines is negligible, and an effective damage is probable only at the intersection points or where the lines' directions changed i.e. at the bends. This is because by increasing the velocity and consequently decreasing the phase difference, damages are reduced. The authors also found that there is no direct relationship between the rotations and the maximum stress values as rotations are recorded at the connections, while the maximum stress occurs at a point outside of the connection. Jafarzadeh et al. (2010) showed for PVC pipeline buried in dry sandy soil layer that the horizontal strains in the soil surrounding the pipe are averagely ten times greater than the strain in the pipe. The authors also found that the RAA (acceleration amplification ratio) values trend to unity as the relative density of the soil approached to 100%. Regardless of the frequencies of the excitation, increasing the base acceleration caused more deformations of the pipe. Shaalan et al. (2014) found that stiffer soils tend to amplify and allow faster movement of the earthquake waves, whereas softer soils tend to slightly dampen the movement values and hinder the earthquake wave movement and propagation. They designed a tunnel linings considering the effect of earthquakes considering soil domain as a plane strain problem. Numerical analysis showed that during the dynamic analysis, reversals of bending moments with large values in both directions are noticed.

The variation of shear forces during the earthquake event is also very large reaching. Peixin Shi (2015) while analysing the joint pull-out movement of jointed concrete cylinder pipelines (JCCPs) and cast iron (CI) pipelines under surface wave propagation (WP) effects on buried segmented pipelines found that the relative joint displacement of CI pipelines is mainly affected by the variability of the joint tensile capacity. When there are locally weak joints with reduced tensile capacity in the pipeline, the joint displacement accumulates at the locally weak joints and the displacement of the locally weak joints increases almost linearly with the reduction of its tensile capacity. J.H. Wood (2015) advanced analysis method first described by Yang (1993) to provide suitable design approach for small structures and preliminary design for large structures. The author found that earthquake ovaling or racking deformations developed in an underground structure when the seismic waves propagate in a direction perpendicular or with a significant component perpendicular to the longitudinal axis, needs to be considered in the design of underground structures.

D. Other Factors

Pipe diameter, burial depth and other characteristics of soil and excitation play important role in seismic behavior of underground pipelines. Sharafi et al. (2015) found that friction angle of soil, diameter of pipe and burial depth of pipe played important role in the uplift behavior of shallow buried pipelines caused by soil liquefaction under cyclic loading. By increasing these values up to optimum value floatation can be reduced. They also found that increasing the density ratio of sands uplift of pipe could be reduced. Mukherjee et al. (2013) showed that slippage in pipe line system depends mostly in pipe diameter and its depth of installation. As diameter of pipeline increases, its axial strain also increases because it is direct function of pipe diameter which subsequently increases slippage of pipeline. Whereas, with increase in the burying depth, the probability of slippage decreases because as the depth increases the confining pressure increases. The case study on pipeline systems of Dehradun city, Uttarakhand (India) showed that continuous pipe line system of the city needs a site specific seismic performance analysis with a more holistic approach especially for larger diameter pipes.

Mukherjee et al. (2013) observed that maximum pipe bending moments and corresponding bending strains are generated in medium (Type-II) soil. This is because pipe bending moment is also a function of the ratio of peak ground velocity (PGV) to its characteristic parameter (T0) which is found to be the highest for medium soil. Also it was observed that with the increasing pipe diameter, bending moment increases in all seismic zones. Moreover it was observed that near the support, pipe bending moment increases exponentially and this increment becomes linear as we move away from the support. Shaalan et al. (2014) found that stiffer soils tend to amplify and allow faster movement of the earthquake waves, whereas softer soils tend to slightly dampen the movement values and hinder the earthquake wave movement and propagation. They designed a tunnel linings considering the effect of earthquakes considering soil domain as a plane strain problem. Numerical analysis showed that during the dynamic analysis, reversals of bending moments with large values in both directions are noticed. The variation of shear forces during the earthquake event is also very large reaching.

Hosseiny et al. (2014) examined the impact of various fluid properties like fluid density and velocity, pipe slope, soil depth and soil behaviour in pipe stability during earthquake excitation. The authors found that the amount of applied tension to the pipe increases with degree and acceleration of earthquake, also applied shear increases with time of earthquake. The role of pipe bed in pipe displacement was very crucial. Moreover, any increase in or change in weight or density of the fluid would result in pipe deformation. Furthermore, it was revealed that the increase in fluid velocity had no role in axial and horizontal displacement, also increase in buried depth due to overload and system limitation would decrease system displacement.

Sahoo et al. (2013) for Zone IV (PGA of 0.24g) of seismic zone map of India found that for single pipeline, the variation of displacement below the burial depth and the stress variation when the burial depth is equal to or more than twice the pipe diameter is not significant. Also for double pipeline there is no variation of displacement with pipe spacing. Aly El-Kafrawy (2012) studied the dynamic behavior of buried town gas pipelines under the effect of the response spectrum of an earthquake and the time history analysis of a truck crosses the pipeline. They prepared a computer model to readily identify which modes if excited, could potentially cause large dynamic stresses.

S.-S. Jeon (2013) studied stresses and strains mobilized in both brittle and ductile pipelines constructed by the design criteria and construction specifications of both Korea and the US and found that differences in the stress and strain rates are negligible when these pipelines were embedded in dense sand overlying three different in situ soils.

III. Conclusions

Failure of buried pipeline may cause detrimental effects on social life as it may lead to loss of vital services. In general, it is observed that less attention has been given to study the dynamic behaviour of underground structures compared to structures above ground level. Available literature shows that various aspects of dynamic behaviour of underground structures have been studied by researchers. However, it is observed that further detailed studies are required to completely understand the behaviour of underground structures during earthquake. This literature survey may help in laying foundation for further research in this area. Following points should be considered for studying dynamic behaviour of underground structures:

- To study the earthquake effects a detailed seismic analysis should be carried out by considering the type of soil and site conditions.
- Underground structures should be designed for imposed seismic ground deformations rather than inertial forces.

- Modelling of seismic excitation can be done by considering propagation of P, S or Rayleigh wave parallel, perpendicular or skew to longitudinal axis of pipeline.
- Longitudinal seismic analysis should be carried out along with transversal analysis, also dynamic analysis should be carried out for evaluating stresses and strains at critical points.
- To model the soil-structure interaction effects, the dynamic time-history analysis using 3D finite element modelling should be carried out.
- Experimentation is deemed necessary by considering various combinations of variables.

Acknowledgement

This work is carried out at Department of Civil Engineering, Dr. Babasaheb Ambedkar Technological University, Lonere. Support and motivation from dr. S. R. Bhagat and dr. S. M. Pore is greatly acknowledged.

References

i. *Youssef M. A. Hashash, Jeffrey, J. Hook, Birger Schmidt and John I-Chiang Yao (2014). Seismic design and analysis of underground structures, Pipelines 2014: From Underground to Forefront of innovation and sustainability. ASCE 2014, 1005-1019.*

ii. *Arya, A. K., Shingan, B., and Prasad, Ch. Vara (2015). Seismic Design of Continuous Buried Pipeline. International Journal of Engineering and Science, 1(1), 6-17.*

iii. *Alireza Boorboor and Mahmood Hosseini, "Sensitivity Analysis of Buried Jointed Pipelines Subjected to Earthquake Waves", Open Journal of Earthquake Research, vol. 4 (2015) pp74-84.*

iv. *F. Behnamfar, M. Vafaeian and M. Saberi, "A Continuum Shell-beam Finite Element Modelling of Buried Pipes with 90-degree Elbow Subjected to Earthquake Excitations", International Journal of Engineering, vol. 28, issue 3 (March 2015) pp 338-349.*

v. *F. Jafarzadeh, H. Farahi Jahromi and E. Abazari Torghabeh, "Investigating Dynamic Response of a Buried Pipeline in Sandy Soil Layer by 1G Shaking Table Test", International Journal of Civil Engineering, vol. 8, issue 2 (June 2010) pp 107-124.*

vi. *Hassan Sharafi, Sahar Jalali and Payam Parsafar, "Uplifting Behavior of Shallow Buried Pipelines Within Liquefiable Soils Under Cyclic Loading", Electronic Journal of Geotechnical Engineering, vol. 20, bundle 16 (2015) pp 9675-9684.*

vii. *J. P. Dwivedi, V. P. Singh and Radha Krishna Lal, "Dynamic Analysis of Buried Pipelines under Linear Viscoelastic Soil Condition", Advances in Theoretical and Applied Mechanics, vol. 3, issue 12 (2010) pp 551-558.*

viii. *Othman A. Shaalan, Tarek N. Salem, Eman A. El shamy, and Randa M. Mansour, "Dynamic analysis of two adjacent tunnels", International Journal of Engineering and Innovative Techniques, vol. 4, issue 4 (Oct. 2014) pp 145-152.*

ix. *Peixin Shi, "Surface wave propagation effects on buried segmented pipelines", International Journal of Rock Mechanics and Geotechnical Engineering, vol. 7, (2015) pp 440-451.*

x. *Prashant Mukherjee, N U Khan, B B Prasad and Ritu Raj Nath, "A Case Study on Different Strain Levels of Buried Continuous Pipe Line System for Dehradun City", International Journal of Structural and Civil Engineering Research, vol. 2, issue 2 (May 2013) pp .*

xi. *Prashant Mukherjee, N U Khan, B B Prasad and Ritu Raj Nath, "A Comparative Study of Lateral Pipe Bending Moment with Fixed Supporting Condition for Different Soil Types in India", Electronic Journal of Geotechnical Engineering, vol. 18, bundle G (2013) pp 1279-1291.*

xii. *Raúl Flores-Berrones and Xiangyue Li Liu, "Seismic vulnerability of buried pipelines", Geofisica Internacional, vol.42, Num. 2, pp 237-246.*

xiii. *Seyyed Omid Hosseiny, Mohammad Mahdi Jabbari and Mohammad Vaghefi, "Soil Structure Interaction Effects on the Seismic Behavior of Buried Pipeline", International Journal of Current Life Sciences, vol. 4, issue 8 (Aug. 2014) pp 4535-4543.*

xiv. *V. Corrado, B. D'Acunto, N. Fontana, M. Giugni, "Estimation of dynamic strains in finite end-constrained pipes in seismic areas", Mathematical and Computer Modelling, vol. 49, (2009) pp 789-797.*

xv. *Vasudeo Chaudhary, Venkata Dilip Kumar Pasupuleti and Pradeep Kumar Ramancharla, "Finite element analysis of buried continuous pipeline subjected to fault motion", International Journal of Structural Engineering, vol. 4, issue 4 (2013) pp 314-331.*

xvi. *Aly El-Kafrawy, "On the Dynamic Behavior of Town Gas Pipelines", Engineering, 2012, 4, doi: 10.4236, pp 24-36.*

xvii. *S.-S. Jeon, "Seismic behavior of buried pipelines constructed by design criteria and construction specifications of both Korea and the US", Natural Hazards and Earth System Sciences, 2013, 13, doi: 10.5194, pp 2271-78.*

xviii. *Amir M. Halabian, S. Hamid Hashemolhosseini and Mehdi Rezaei, "Nonlinear Seismic Analysis of Buried Pipelines during Liquefaction", 6th International Conference on Case Histories in Geotechnical Engg, Washington DC, August 11-16, 2008.*

xix. *George A. Mavrids and Kyriazis D. Pitilakis, "Axial and Transverse Seismic analysis of buried Pipelines", 11th World Conferences on Earthquake Engineering (WCEE), Acapulco Mexico, June 23-28, 1996, paper no.1605.*

xx. *J.H. Wood, "Earthquake design of rectangular underground structures", NZSEE conference 2005, session 9, paper no. 39.*

xxi. *LI Hongjing, JIN Liu and YAO Baohua, "Response Analysis of Buried Pipelines Due to Large Ground Movements", 14th World Conferences on Earthquake Engineering (WCEE), Beijing China, Oct 12-17, 2008.*

xxii. *S. Sahoo, S. Biswas, B. Manna and K. G. Sharma, "Dynamic Behaviour of Buried Pipelines under Seismic Condition - Finite Element Approach", Indian Geotechnical Conference (IGC), Roorkee, Dec. 22-24, 2013.*