BURIED PIPELINE UNDER SEISMIC EXCITATIONS: A REVIEW

Sanjoy Das[1], Md Aftabur Rahman*[2] and Sultan Mohammad Farooq[3]

[1]*Assistant Professor, Deparment of Civil Engineering, CUET, Chattogram-4349, Bangladesh, e-mail: sanjoy0701098@gmail.com*
[2]*Assistant Professor, Deparment of Civil Engineering, CUET, Chattogram-4349, Bangladesh, e-mail: maftabur@cuet.ac.bd*
[3]*Associate Professor, Deparment of Civil Engineering, CUET, Chattogram-4349, Bangladesh, e-mail: farooq_sm@cuet.ac.bd*

***Corresponding Author**

ABSTRACT

Buried Lifelines are the systems & facilities that provide essential services to the function of an industrialized, modern country & important to emergency response & recovery after disastrous events. From previous post seismic failures, it was evident that the majority of the pipelines are buried in relatively shallow depths and are critically susceptible to damage during seismic excitations in earthquake prone areas. Damage or interruption of these underground lifelines could cause major, even catastrophic, disruption of essential services. If such disruption is caused by an earthquake, the effect of the loss of vital service would be greatly amplified by impeding fire-fighting, preventing essential energy transmission, communications, transportation, and causing widespread disease. To evaluate the seismic response of buried pipelines, a lot of researches was performed experimentally, numerically & analytically. Hence it is quite necessary to investigate proper soil-buried pipe interaction, proper modelling techniques & seismic behavior of buried pipelines. In this perspective, the present study explains a state-of-the-art review of the response of Buried lifelines under seismic excitations. The review includes existing modelling techniques of soil-pipe system, different failure modes of buried continuous pipelines subjected to seismic excitations, methods of response analysis of buried pipelines, seismic behavior of buried pipelines under different parametric variations, seismic stresses at the bends & intersections of network of pipelines, pipe damage in earthquakes & seismic risk analysis of buried pipelines. Based on the review, research gaps have been evaluated & future scopes for further research are identified, which may be helpful for researchers & designers.

Keywords: *Buried lifelines, Soil-buried pipe interaction, Seismic analysis.*

1. INTRODUCTION

Pipelines are often referred to as "Lifelines" because of their role in the delivery of life-dependent resources. Some examples of lifelines are natural gas or oil pipes, sewage and water supply pipelines, storage facilities, tunnels, power lines and communications lines. Although its importance is underestimated or even unknown to the common society or public, its failure can result in drastic effects to the public. It is therefore important in all circumstances to preserve the integrity of these' lifelines.

A large proportion of lifelines are placed underground. Interruption of these underground lifeline systems may result in major disruption to essential services, even catastrophic ones. The damage to the buried lifelines during an earthquake is evident and reported in many technical writings. For instance, the San Francisco earthquake in 1905 destroyed many buried lifelines. The rupture of water supplies in Yokohama caused fire and flooding. Moreover, in Kanto 1923, Long Beach 1933, Fukui 1948, Alaska 1964, San Fernando 1971, Managua 1972 earthquakes, there have been extensive damage to the underground pipelines. The 1952 Kern County earthquake caused serious damages to four railroad tunnels ("Response of underground lifeline systems to earthquakes'," 1975). literature study revealed that pipelines are subjected to high stresses during earthquake and ultimately lead to failure of the pipelines. Depending on the material transmitted via the pipeline, pipeline failure may trigger the sources of pollution, water crises, fire, explosion, etc. The mitigation of such hazards has been realized by the researcher and they emphasized on estimating the responses of buried structures during extreme event. The research in buried pipeline was first reported when Newmark developed the procedure to analyse the buried pipeline under fault rupture. Later, other researcher developed some sophisticated models to account for fault effect on buried pipeline. The high computation facilities encouraged the researchers to numerically simulate the response of buried pipeline under fault rupture. To date, a significant number of analytical and numerical model has been developed to understand the behaviour of buried pipeline during fault movement. However, the direct response of buried pipeline under seismic loading is seldom found in technical writings. In addition to analytical and numerical modelling, some experimental observations are also available. over the last few years, researchers have paid more attention to the complex behaviour of buried pipelines in order to properly understand the phenomenon of soil-pipe interaction. The dynamic behaviour of the buried pipelines depends on several factors, such as the type and frequency of incoming waves, the properties of the surrounding soil, the material and dimensions of the pipe the flexibility of the joint, the internal pressure, etc. In addition to the remaining straight portion of the pipe, it was found that more pressure would produce at the pipeline intersection. A thorough understanding of the pipe-soil interaction is needed for dynamic analyses of the buried pipeline, because it has an important role to play during seismic excitement.

Identifying the need for seismic response analysis of buried pipeline, a compilation of so far developed procedure is necessary. Therefore, this research aims to sum up the available soil pipe modeling techniques and analysis methodologies from previous research projects. The study prop oses certain research lacunes that need to be further explored based on the merits and denerves of exis ting methods.

2. DYNAMIC BEHAVIOUR OF BURIED PIPELINES

Interactions and features of ground motion play a key role in the study of structures below the ground Field observations and various studies indicate that damage to underground structures, mainly buried pipelines during the earthquake, is due to excessive axial and bending stresses and strains developed at various points along pipe lengths due to various reasons such as wave propagation characteristics, large displacements due to fault movements, uplifting or landslides caused by soil liquefaction. (Youssef M. A. Hashash, Jeffrey, J. Hook, 2014) published a summary report on the current state of seismic analysis and layout of underground structures, which explains the methods used by engineers to measure the seismic effect on the underground structure. The study also briefly addresses the design of appropriate ground motion parameters, including peak accelerations and velocities, target response spectra and ground motion time histories.

2.1 Soil Pipe Interaction

The soil and pipe interactions have a profound effect on the behavior of the buried pipe that is subject ed to earthquake excitations. (F. Behnamfar, n.d.),2015 studied the effect of soil pipe interaction on bending of buried pipeline and concluded that the axial strain at bends is larger in stiffer soil due to smaller slippage and that the bend strain is direct, whereas the relative displacement of the soil pipe is inversely proportional to the diameter to thickness ratio. Analytically, (J. P. Dwivedi, 2010) & (Pitilakis, 1996) have shown that axial analysis is the critical analysis and the pipeline's dynamic soil-pipe interaction (SSI) effects for axial response are significant while those are negligible for lateral response. (Liu, n.d.) found that the soil around the pipeline plays a very important role in the seismic activity of the pipeline. He showed that soil pipe contact induces both axial and bending stresses in continuous pipelines, which may ultimately lead to the buckling and crushing of pipelines. (V. Corrado, B. D'Acunto, N. Fontana, 2009) demonstrated that interaction between the soil structure and the end constraint can significantly affect the dynamic response of a buried, seismically excited finite pipe. They also showed that the end points of the pipe are the weakest areas, where high stresses can cause breaks or fractures.

2.2 Permanent Ground Deformation

The permanent ground deformation (PGD) is nothing but a large-scale deformation of the ground caused by soil liquefaction, landslide or fault movement. Effect of permanent ground deformation (PGD) on dynamic behaviour has been studied by various researchers.(Arya, A. K., Shingan, B., and Prasad, 2015) presented guidelines for calculating seismic resistance and outlined various measures to be taken to prevent oil and gas continuous buried steel pipeline failure under various seismic events such as fault, landslide, etc. causing permanent deformation of the ground.(LI Hongjing, 2008) found that permanent ground deformation (PGD) due to faults in buried pipelines, peak stress increases rapidly as the ratio diameter to thickness ratio increases. The researchers have demonstrated that the buried pipeline's seismic response increases with soil displacement and crossing angle increases and decreases with buried depth increases. The greater the angle of crossing, the greater the pipe's response under normal movement. The greater buried depth, the pipe's poorer performance.

2.3 Wave Propagation

There are primarily two types of seismic waves, body waves and surface waves. Body waves are slower waves of high propagation velocity. There is much less ground strain caused by the propagation of body waves. On the other hand, the frequency of surface wave propagation is much lower and the resultant ground stress is higher. Therefore, surface waves are more dangerous than body waves for submerged pipelines. Effect of wave propagation on dynamic behaviour of buried pipeline has been studied. (Othman A. Shaalan, Tarek N. Salem, Eman A. El shamy & Mansour, 2014) found that stiffer soils tend to intensify and encourage earthquake waves to move faster, whereas softer soils tend to dampen movement values slightly and hamper the movement and propagation of earthquake waves. (Hosseini, 2015) indicated that stress levels or rotations along the pipelines are negligible in joint pipe networks under the influence of transient ground waves and that effective damage is likely only at the intersection points or where the direction of the lines has shifted, i.e. at the bends.

2.4 Other governing factors

Pipe diameter, burial depth and other soil and excitation characteristics play a major role in underground pipeline seismic behaviour. (Hassan Sharafi, 2015) found that soil friction angle, pipe diameter and pipe burial depth played an important role in the uplifting actions of shallow buried pipelines caused under cyclic loading by soil liquefaction. (Prashant Mukherjee, N U Khan, 2013) found that slippage depends mainly on pipe diameter and installation depth in the pipe line network. As the diameter of the pipeline increases, its axial strain also increases as it is a direct function of the diameter of the pipeline that ultimately increases the pipeline slippage. While the likelihood of slippage decreases with an increase in burying depth as the depth increases the confining stress. (Seyyed Omid Hosseiny & Vaghefi, 2014) investigated the effect on pipe stability during earthquake excitation of various fluid properties such as fluid density and velocity, pipe slope, soil depth and soil behaviour.

3. DOMINANT FAILURE MODES OF BURIED CONTINIOUS PIPELINES

The various buried steel pipeline failure modes reported by (Psyrras & Sextos, 2018), (Singh & Kareem, n.d.) are subjected to seismic excitation.

3.1 Shell mode buckling

The result of this kind of buckling is compressive load or pure bending. This is the most common type of buckling and this type of buckling is usually observed in large pipes buried in deep trenches. fig. 1(a).

3.2 Beam mode buckling

In this type of buckling, compressed pipe will bend upward and soil will attempt to resist it. Such type of failure occurs in pipes with a comparatively smaller diameter that are shallowly buried. It was clear from the past earthquake that the probability of failure in this category is low compared to buckling in shell mode. fig. 1(b).

3.3 Tensile failure

Such failure occurs when there is tension in the pipelines. Pipelines with more ductile actions are less likely to fail. In the pipeline, seismic hazards such as fault, landslide liquefaction and relative ground motion are causing tensile strain. fig. 1(c).

3.4 Cross section Ovalization

Under bending stress, this type of failure occurs. The initial pipe diameter will change in this case and its shape will also change from circular to oval. fig. 1(d).

3.5 Local buckling

Local pipe wall instability causes local pipeline buckling and wrinkling. Both wave propagation and geometric distortion caused by ground deformation due to local shell wrinkling initiation tends to concentrate on these wrinkles. Therefore, circumferential cracking of the pipe wall and leakage occurs in the pipe wall due to the expansion of the local curvature.

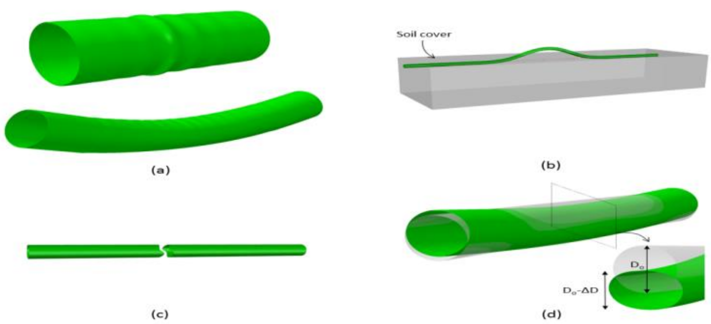

Fig. 2. Common failure mechanisms in buried, continuous steel pipelines: (a) shell-mode buckling due to uniform axial compression (top) and pure bending (bottom); (b) beam-mode buckling; (c) tensile fracture and (d) crosssection ovalization.

4. DOMINANT FAILURE MODES OF BURIED SEGMENTED PIPELINES

4.1 Axial pull-out

The common failure mechanism of a segmented pipeline in the areas of tensile ground strain is axial pull-out at joints as the shear strength of the joint caulking material is significantly less than that of the pipe.

4.2 Crushing of Bell & Spigot joints

Crushing of bell-and-spigot joints is a very common failure mechanism in compressive strain areas.

4.3 Flanged joint failure

Due to the breaking of the flange connection the flanged joint pipeline can fail at the joint in the tensile ground strain areas.

4.4 Circumferential flexural failure & joint rotation

When a segmented pipeline is bent due to lateral permanent ground movement or seismic shaking, any combination of joint rotation and flexure in the pipe segments accommodates the ground curvature. Over a wide geographical area, pipelines are usually buried. Continuous pipeline failures are a tensile rupture local or beam buckling, and unnecessary joint bending in individual pipelines are the main modes of segmented pipeline failure.

5. AVAILABLE MODELING TECHNIQUES OF SOIL-BURIED PIPE SYSTEM

Different types of modeling of the underground pipelines are available, starting from extremely simple to complex threedimensional modeling of the soil–structure system. (Datta, 1999) stated that one of the following four ways of simulating soil-pipe interaction systems can be modelled as a soil-pipe system. As shown below, each strategy has some advantages and disadvantages.

5.1 Beam model on elastic springs

Figure 2(a) shows the beam model in elastic foundation modelling where the pipe is defined as a long beam and the surrounding soil is represented as a spring. Spring stiffness and dashpot coefficient can provide soil-pipe interaction. This technique is not capable of capturing dynamically loaded pipeline buckling and fracturing phenomenon. This model is used to represent long buried pipelines in which bending and axial deformations are of main concern.

5.2 Shell model

Instead of single-dimensional beam objects as shown in figure 2(b) the pipe can also be represented by three-dimensional cylinder shells. In contrast to beam component, the shell integrates pipeline buckling and fracturing phenomenon. The shell model is assumed to be resting within a viscoelastic medium.

5.3 Plane strain model

Buried pipelines can be viewed as a plane strain problem, as the dimension is much larger than the other two cross directions in an axial direction for pipelines. The plane strain model is shown in Figure 2(c). This method of modelling can be used to evaluate hoop stress and radial deformation.

5.4 Hybrid model

In the hybrid model shown in Fig. 2(d), the interior region (R1) is modeled by the finite element method (FEM), while the outer region (R2) is modeled by the half space continuum. A planestrain model is adopted for both regions. Continuity of displacement and strain is maintained at the interface boundaries between the two regions.

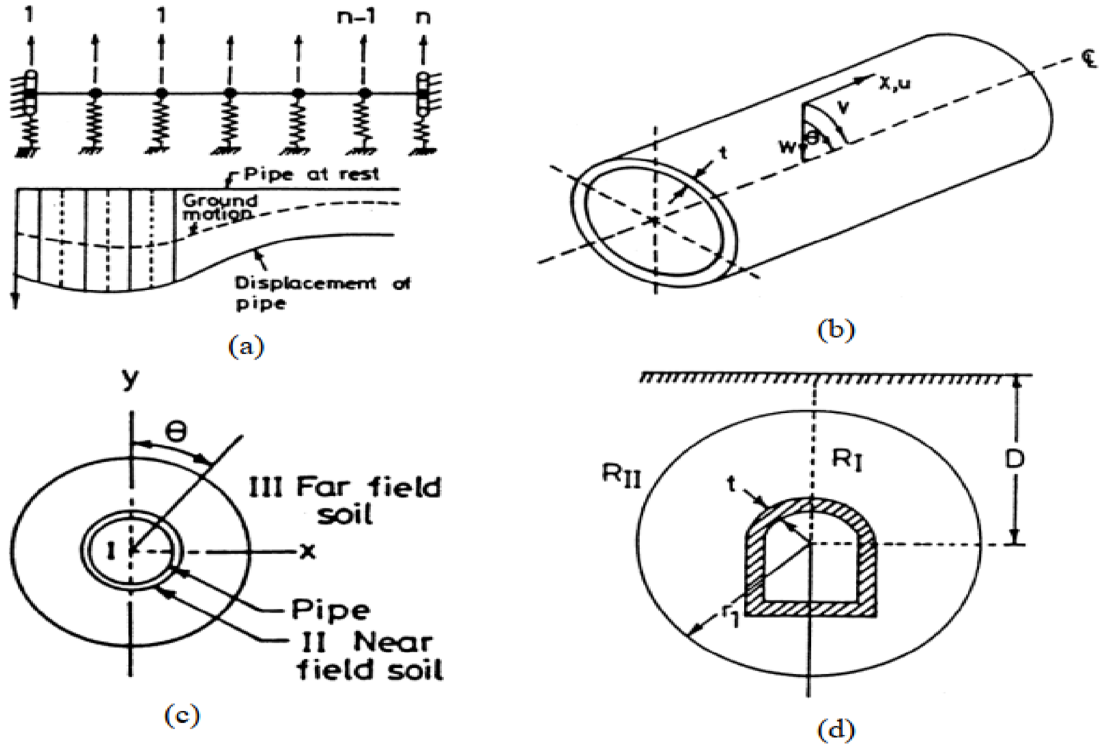

Figure 2. (a) Beam on elastic foundation (b) Shell model (c) Plane-strain model and (d) Hybrid model (Datta, 1999)

6. ANALYSIS METHODOLOGIES

At the beginning of the study, the soil-pipe relationship has not been addressed. Later, other experiments were also conducted with a view to complex pipe-to-soil interactions. The following parts are categorically defined by the current soil-pipe system response methodologies under seismic excitation.

6.1 Analysis avoiding soil-structure interaction

In this situation, it was believed that the pipe was moving with the ground, i.e. no relative motion between the pipe and the soil. Few studies have been carried out in the buried pipeline area without recognizing the interaction of soil-structure (Newmark, N.M. & Rosenblueth, 1971) (Hindy, A. & Novak, 1979)(Shah, H. & Chu, 1974) .The researchers primarily proposed several simplistic methods to obtain responses in seismic loads by neglecting soil-structuring interactions. This phenomenon is acceptable for certain conditions, for example if the stiffness of soil that surrounds the pipe are very high compared to the pipes itself, the interaction of the soil pipes may be ignored.

6.2 Quasi static analysis with soil–structure interaction

In this analysis, the soil deformations are matched by a combination of pipe deformations and relative deformations of joints. In order to obtain the response from a buried structure with flexible joints during earthquake agitation, (Singhal, A.C, Zuroff, 1990), with the concept of beams on elastic foundations suggested a quasi static analysis.

6.3 Analysis Considering soil–structure Interaction Phenomenon

In this case, the pipe should consider the phenomenon of soil-pipe interaction if the pipe passes through a soil that is relatively soft and soil stiffness is not much greater than the pipe stiffness. Initially, dynamic analysis was carried out on the basis of Beam on Elastic Foundation Theory

(Hindy, A. & Novak, 1979), (Datta, T.K. & Mashaly, 1986) which integrates the effect of soil-structure interactions. Nevertheless, these methods did not integrate the phenomenon of buckling and fracturing of the pipeline under seismic loading. The pipe was later modelled as a cylindrical shell, instead of a beam to resolve these demerits (Datta, S.K., Shah, A.H., & El-Akily, 1982),(Muleski, G.E. & Ariman, 1985). In addition, the existence of pipeline motion during an earthquake has indicated that a beam or a cylindrical shell did not consider modifying free field motion (Wong et al., 1986). The plain strain model or finite-element analysis, which represents a practical conduct for the complete interaction of soil-structures ((Datta, S.K., Shah, A.H., & Wong, 1984),(Patil, M., Choudhury, D., Ranjith, P.G., & Zhao, 2018). Considerable work was carried out in the context of simple beam theory, i.e. the theory of beam on the elastic foundation or the perception of pipes as cylindrical shells. But there is very little work on seismic analysis of the pipeline with respect to the method of three-dimensional finite elements. Such numerical analyses are conducted using Finite Element Method or Finite Differences Method-based computers like ABAQUS, FLAC, PLAXIS2D etc. ((Saeedzadeh, R. & Hataf, 2011), (Boron, P. & Dulinska, 2017), (Ghiasi, V. & Mozafari, 2018).

6.4 Time history analysis

This is a dynamic analysis that is nonlinear. A selective earthquake ground motion is applied directly to the structure base in this analysis process. Instantaneous stresses throughout the structure were measured at small intervals during the entire duration of the earthquake. The time history method is not generally used in an analysis system due to its long running machine, but this method provides more accurate results compared to a pushover test as it inculcates real earthquake information as an input file.

7. RESPONSE OF BURIED PIPELINE UNDER SEISMIC EXCITATION

Responses to seismic excitement of buried pipelines include changes in pipe dimensions, pipe stiffness, soil conditions surround, burial depths, and so forth. (Lee, D.H., Kim, B.H., Lee, H., & Kong, 2009) conducted a comparative study of the seismic activity of the buried gas pipeline. Three different conditions of soil media have been considered, such as soft clay, loose and dense sand. The authors adopted different types of end support of the pipe and it was observed that under seismic excitation, at the end of the pipe, maximum strain is more dangerous among all types of end restrain fixed-fixed end condition. Furthermore, the maximum strain along the length of the pipeline is considerably higher in the case of soft clay than compared with dense or loose sand and this effect can be kept to a minimum by increasing pipeline burial depth. Hindy and Novak (1979) found that considering dynamic soil-pipe interaction decreases axial and bending stress responses relative to the case of no-interaction. In addition, the method of nonlinear finite elements provides more accurate results than the simplified methods stated by (Chen, 1995). The emphasis should be on the position of the pipe bend and pipe intersection (T or L intersection) in order to obtain dynamic responses as more stress is produced at these locations as seen from previous research (Soliman, H.O. & Datta, 1996). (Karamanos, S.A., Sarvanis, G.C., Keil, B.D., & Card, 2017) emphasized that by increasing the wall thickness of the pipe or by putting soft backfill around the pipe dynamic stresses on the pipe can be minimized. Nevertheless, care should be taken to put soft backfill as pipe buckling can be increased in such situations.

8. CONCLUSIONS

In order to study the dynamic behaviour of underground structures, the following points should be considered:

- A detailed seismic assessment should be carried out to study the effects of the earthquake, taking into account the type of soil and site conditions.
- Underground structures should be designed instead of inertial forces for imposed seismic ground deformations.

- Seismic excitation simulation can be achieved by considering parallel, perpendicular or skewed propagation of the P, S or Rayleigh wave to the longitudinal axis of the pipeline.
- Longitudinal seismic analysis should be conducted in combination with transversal analysis, and dynamic analysis should also be performed at critical points to determine stresses and strains.
- The dynamic time-history analysis using 3D finite element models should be conducted to model the soil-structure interaction effects.
- Experimentation is considered necessary by considering different variables combinations.

This review study presented a state of the art in buried pipeline's seismic behaviour. This study includes various modes of failure, modelling techniques, analysis methods, and buried pipeline responses considering the phenomenon of dynamic soil-pipe interaction with and without it. It was found that very little analytical research was conducted considering pipe as a shell model capable of simulating the phenomenon of buckling and fracture. However, less attention was paid to three-dimensional numerical analysis using methods of finite elements involving nonlinear interaction between soil and pipe. Due to the complex dynamic soil-pipe relationship, the activity of the buried pipeline under seismic loading is still not properly understood. The variance of the field conditions and the nonlinearity of the soil should also be included in the analyses. These could lead us to avail ourselves of the future scope of work.

REFERENCES

American Society of Civil Engineers. (1974). Earthquake damage evaluation and design considerations for underground structures a Public Service paper, var.pag.

Arya, A. K., Shingan, B., and Prasad, C. V. (2015). Seismic Design of Continuous Buried Pipeline. *International Journal of Engineering and Science*, *1*(1), 6–17.

Boron, P. & Dulinska, J. (2017). The dynamic analysis of a steel pipeline under a seismic shock. *Procedia Engineering*, *199*, 104–109.

Chen, Y. (1995). Simplified and refined earthquake analyses for buried pipes. *Mathematical and Computer Modelling*, *21*(11), 47–60.

Datta, S.K., Shah, A.H., & El-Akily, N. (1982). Dynamic behavior of a buried pipe in a seismic environment. *Journal of Applied Mechanics*, *49*(1), 141–148.

Datta, S.K., Shah, A.H., & Wong, K. C. (1984). Dynamic stresses and displacements in buried pipe. *Journal of Engineering Mechanics*, *110*(10).

Datta, T.K. & Mashaly, E. A. (1986). Pipeline response to random ground motion by discrete model. *Earthquake Engineering & Structural Dynamics*, *14*(4), 559–572.

Datta, T. K. (1999). Seismic response of buried pipelines : a state-of-the-art review, *192*, 271–284.

F. Behnamfar, M. V. and M. S. (n.d.). A Continuum Shell-beam Finite Element Modelling of Buried Pipes with 90-degree Elbow Subjected to Earthquake Excitations. *International Journal of Engineering*, *28*(issue 3), pp 338-349.

Ghiasi, V. & Mozafari, V. (2018). Seismic response of buried pipes to microtunnelling method under earthquake loads. *Soil Dynamics and Earthquake Engineering*, *113*, 193–201.

Hassan Sharafi, S. J. and P. P. (2015). Uplifting Behavior of Shallow Buried Pipelines Within Liquefiable Soils Under Cyclic Loading. *Electronic Journal of Geotechnical Engineering*, *20*(16), 9675–9968.

Hindy, A. & Novak, M. (1979). Earthquake response of underground pipelines. *Earthquake Engineering and Structural Dynamics*, *7*(5), 451–476.

Hosseini, A. B. and M. (2015). Sensitivity Analysis of Buried Jointed Pipelines Subjected to Earthquake Waves. *Open Journal of Earthquake Research*, *4*, 74–84.

J. P. Dwivedi, V. P. S. and R. K. L. (2010). Dynamic Analysis of Buried Pipelines under Linear Viscoelastic Soil Condition. *Advances in Theoretical and Applied Mechanics*, *3*(12), 551–558.

Karamanos, S.A., Sarvanis, G.C., Keil, B.D., & Card, R. J. (2017). Analysis and Design of Buried Steel Water Pipelines in Seismic Areas. *Journal of Pipeline Systems Engineering and Practice*, *8*(4), p.04017018.

Lee, D.H., Kim, B.H., Lee, H., & Kong, J. S. (2009). Seismic behavior of a buried gas pipeline under earthquake excitations. *Engineering Structures*, *31*(5), 1011–1023.

LI Hongjing, J. L. and Y. B. (2008). Response Analysis of Buried Pipelines Due to Large Ground Movements. In *14th World Conferences on Earthquake Engineering (WCEE), Beijing China, Oct 12-17*.

Liu, R. F.-B. and X. L. (n.d.). Seismic vulnerability of buried pipelines. *Geofisica Internacional, 42*(2), 237–246.

Muleski, G.E. & Ariman, T. (1985). A shell model for buried pipes in earthquakes. *International Journal of Soil Dynamics and Earthquake Engineering*, *4*(1), 43–51.

Newmark, N.M. & Rosenblueth, E. (1971). Fundamentals of Earthquake Engineering. *Prentice-Hall, Englewood Cliffs.*

Othman A. Shaalan, Tarek N. Salem, Eman A. El shamy, and R. M., & Mansour. (2014). Dynamic analysis of two adjacent tunnels. *International Journal of Engineering and Innovative Techniques*, *4*(4), 145–152.

Patil, M., Choudhury, D., Ranjith, P.G., & Zhao, J. (2018). Behavior of shallow tunnel in soft soil under seismic conditions. *Tunnelling and Underground Space Technology*, *82*, 30–38.

Pitilakis, G. A. M. and K. D. (1996). Axial and Transverse Seismic analysis of buried Pipelines. In *11th World Conferences on Earthquake Engineering (WCEE), Acapulco Mexico, June 23-28* (p. paper no.1605).

Prashant Mukherjee, N U Khan, B. B. P. and R. R. N. (2013). A Comparative Study of Lateral Pipe Bending Moment with Fixed Supporting Condition for Different Soil Types in India. *Electronic Journal of Geotechnical Engineering*, *18*(G), 1279–1291.

Psyrras, N. K., & Sextos, A. G. (2018). Safety of buried steel natural gas pipelines under earthquake-induced ground shaking: A review. *Soil Dynamics and Earthquake Engineering*, *106*(February 2017), 254–277. https://doi.org/10.1016/j.soildyn.2017.12.020

Response of underground lifeline systems to earthquakes'. (1975). *Unsolicited Research Proposal Submitted to the National Science- Foundation by Weidlinger Associates, New York*.

Saeedzadeh, R. & Hataf, N. (2011). Uplift response of buried pipelines in saturated sand deposit under earthquake loading. *Soil Dynamics and Earthquake Engineering*, *31*(10), 1378–1384.

Seyyed Omid Hosseiny, M. M. J. and M., & Vaghefi. (2014). Soil Structure Interaction Effects on the Seismic Behavior of Buried Pipeline. *International Journal of Current Life Sciences*, *4*(8), 4535–4543.

Shah, H. & Chu, S. (1974). Seismic analysis of underground structural elements. *Journal of the Power Division*, *100*, Proc. Paper 10648.

Singh, V. K., & Kareem, A. (n.d.). SEISMIC ANALYSIS OF BURIED PIPELINE : A STATE OF ART REVIEW.

Singhal, A.C, Zuroff, M. S. (1990). Analysis of underground and underwater space frame with stiff joints. *J. Comput. Struct*, *35*(1), 227–237.

Soliman, H.O. & Datta, T. K. (1996). Response of over ground pipelines to random ground motion. *Engineering Structures*, *18*(7), 537–545.

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

Youssef M. A. Hashash, Jeffrey, J. Hook, B. S. and J. Ic. Y. (2014). Seismic design and analysis of underground structures, Pipelines 2014: From Underground to Forefront of innovation and sustainability. *ASCE*, 1005–1019.