JSEE Vol. 26, No. 3, 2024 DOI: 10.48303/jsee.2024.2032628.1105

Research Paper

Effect of Burial Angle on Pipeline Response to Landslide: 1 g Shake Table Tests

Morteza Rajabigol[1*], **Sadjad Hadei**[2], **Fardin Jafarzadeh**[3] **and Hadi Farahi Jahromi**[2]

1. Ph.D. in Geotechnical Engineering, https://orcid.org/ 0000-0002-5658-1786 Instructor, Civil Engineering Department, Sharif University of Technology, Tehran, Iran, *Corresponding Author; email: m.rajabigol68@sharif.edu
2. Ph.D. Candidate, Civil Engineering Department, Sharif University of Technology, Tehran, Iran
3. Associate Professor, Civil Engineering Department, Sharif University of Technology, Tehran, Iran

Received: 21/06/2024
Accepted: 09/07/2024

ABSTRACT

Buried pipeline response to earthquake induced landslide is one of the challenging problems in geotechnical earthquake engineering. In this study, two physical models were constructed to investigate the effect of burial angle of the pipes on their response to the landslide. Similitude laws for 1g shake table tests were employed to construct the physical models. In each model, four aluminum pipes were installed at different positions but at identical depths from the model surface. All the properties in both models - except the pipes angles relative to the slope - are the same. The pipes were heavily instrumented with pair strain gauges to measure pure bending strain. Input shaking consisted of 25 sinusoidal cycles of loading with amplitude of 0.32 g and frequency of 5 Hz. The results showed that reduction of pipe burial angles from 90 to 70 degrees in relative to the slope direction, decreased bending strain in the pipes. Therefore, reduction of burial angle of the pipes can be considered as one of the remediation methods against landslide. Also, in both models, the lower part of the slope was the most critical location for buried pipes.

Keywords:
Pipeline; Slope; Burial angle; Earthquake; Shake table test; Physical modeling

How to cite the article:
Rajabigol, M., Hadei, S., Jafarzade, F., & Farahi Jahromi, H. (2024). Effect of Burial Angle on Pipeline Response to Landslide: 1 g Shake Table Tests. *Journal of Seismology and Earthquake Engineering*, *26*(3), 1-7. DOI: 10.48303/jsee.2024.2032628.1105

1. Introduction

Buried pipeline systems used for fluids transmission over long distances are very important lifelines to modern society. Therefore, the safe operation of buried pipelines has crucial importance for industry and has aroused wide attention. As reported in many post-earthquake studies performed at countries like the USA, China and Japan, earthquake-induced Permanent Ground Deformation (PGD) like landslides can significantly cause severe damages to buried pipelines, economic losses and disability of lifeline networks. In recent years, the mechanical response and integrity of pipelines under PGDs have been of major challenges in geotechnical earthquake engineering, and some researchers have performed numerous analytical, numerical or physical modeling investigating various aspects of the phenomenon. For example, Jafarzadeh et al. (2024) conducted a shake table test to investigate the effect of pipe position in the slope on its response to landslide. Chaudhuri and Choudhury (2020) carried an analytical and numerical study to investigate pipe-soil interaction in a sloping ground. In that research, the pipe was perpendicular to the landslide direction. Jafarzadeh et al. (2019) conducted a series of shake table experiments to evaluate various methods in prediction of soil lateral movement due to seismic induced landslide. Farahi et al. (2018) conducted three shake table tests to study the effect of burial depth on the response of pipes to earthquake induced landslide. They found that increasing burial depth had negative correlation with pipe deformations at toe and lower section of a slope face. Tsatsis et al. (2016) developed a finite element model to investigate the response of a buried pipe to the landslide. In that research, the pipe was located parallel to the ground slope.

Despite valuable findings of last studies, understanding behavior of buried pipelines during land-slides requires much more researches. In the current study, the effects of burial angle of the pipes on their response to landslide are investigated. To achieve this aim, a series of physical modeling experiments have been conducted using 1-g shaking table at Sharif University of Technology. The models have been constructed in a rigid box, and model buried pipes have been installed at different locations regarding the slope. Harmonic sinusoidal loadings have been applied at the base of the rigid box, and soil accelerations and pipes strain at different locations have been measured. In this paper, the modeling procedure and the main results focusing on strains at various sections of the pipes will be presented.

2. Physical Modeling

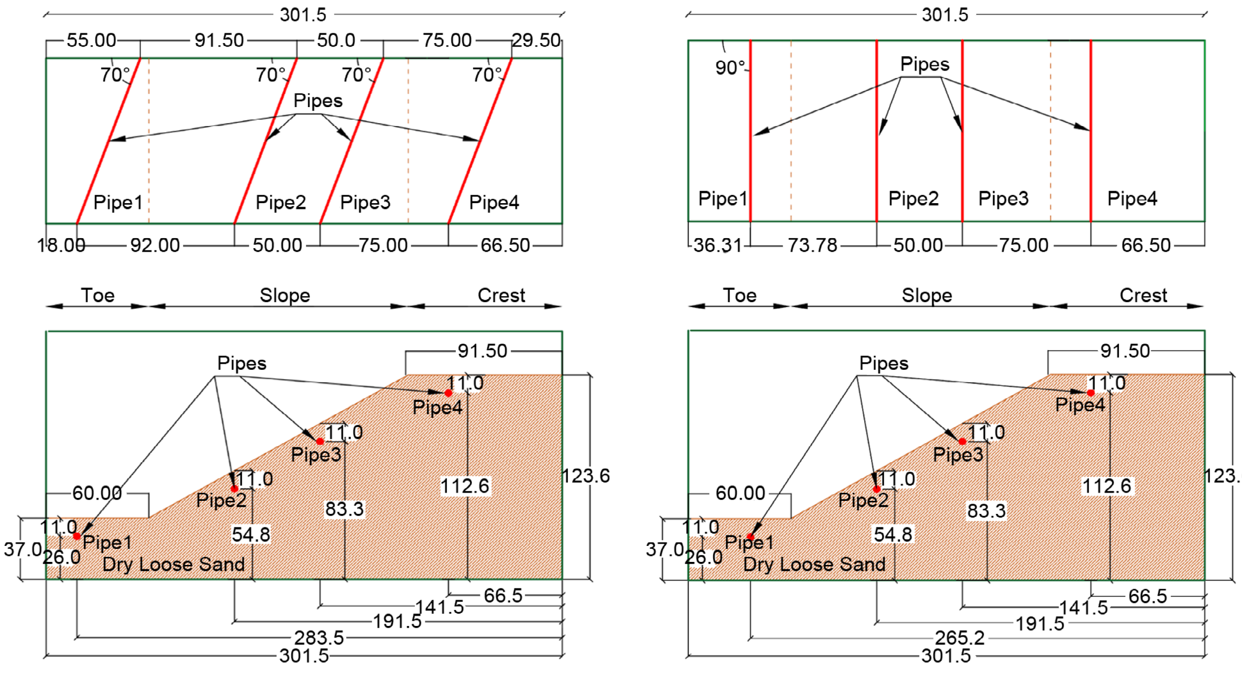
In this study, Sharif University of Technology shake table (Figure 1a) was employed to conduct the physical modeling tests. SUT shake table is a 4×4 m^2, 3-degree-of-freedom facility, capable of taking models of up to 300 kN. To build the physical model, a rigid box (Figure 1b) with dimensions of 301 cm length, 101 cm width, and 155 cm height was constructed and used as the model container. In order to have a side vision of the model during the test, one side of the box was made of transparent Plexiglass.

In order to construct the physical models, similitude laws presented by Iai (1989) and Iai et

(a) SUT Shake Table

(b) Rigid Box Container

Figure 1. Photos of devices used in this study.



(a) Model 1

(b) Model 2

Figure 2. Schematic plan and cross section views of the models (cm).

al. (2005) were employed. In this research, the geometrical scaling factor of 10 was selected. Schematic plan and section views of the models are shown in Figure (2). In each model, four buried pipelines made of aluminum were installed. The only difference between two models is that in the Model 1, the pipes were installed perpendicular to the ground slope direction, whereas in the Model 2, the pipes were placed with 70 degrees relative to the ground slope direction. Top view photo of the installed pipes in the Model 2 is shown in Figure (3). Properties of the pipes were determined by the similitude laws proposed by Iai (1989) and Iai et al. (2005). The model pipes had outer and inner diameters of 16 and 14 mm, respectively. All pipes in the models were installed at depth of 110 mm. Pipe 1 placed in the toe of the slope, Pipe 2 placed in lower slope part, Pipe 3 placed in the upper slope part, and Pipe 4 placed in the crest. The end of the pipes was rotationally free, whereas they were restrained against horizontal and vertical displacement.

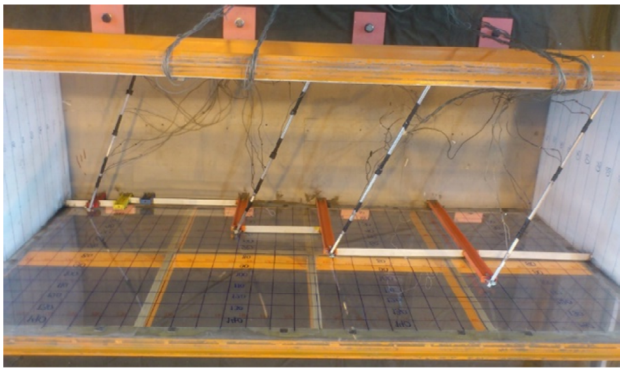


Figure 3. Top view of the installed pipes in the rigid box before model construction.

The model grounds consist of one soil layer made of loose Babolsar sand, which is uniform and common sand in geotechnical experimental studies in Iran. It is dark unified clean sand with mean diameter of 0.261 mm. To construct a very loose soil layer, dry Babolsar sand was deposited by air pluviation method. Relative density of the model was approximately 35 %. The slope was almost 30 degrees which is near to friction angle of very loose Babolsar sand. Friction angle of this sand was determined by the results of direct shear test.

3. Results

In this research, a dynamic data acquisition system with 64 channels was employed to record with a sampling rate of 1000 data per second. Input shaking consisted of 25 sine cycles loading with amplitude of 0.32 g and frequency of 5 Hz. These cycle numbers of loading equals to an earthquake with M_w of 8.2 (Kramer, 1996). The loading was applied parallel to the ground slope.

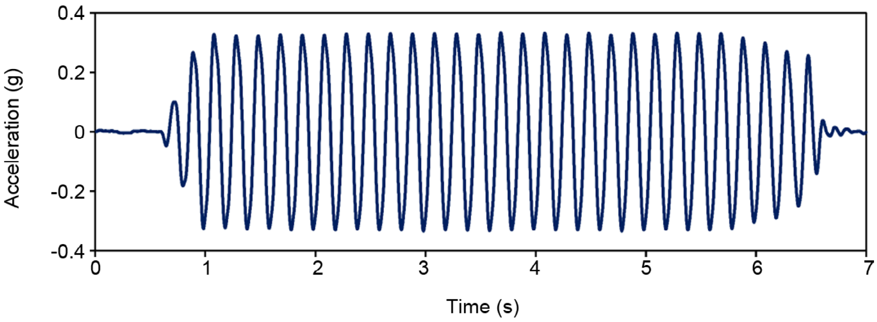


Figure 4. Time history of the applied acceleration as input motion in this study.

The time history of acceleration for input motion is shown in Figure (4). Some of the main results of this paper has been presented in a conference paper, Rajabigol et al. (2024).

Images of the Model 1 from the side point, before and after the test shaking are exhibited in Figure (5). Due to the shaking, a planar landslide occurred in the model, which can be observed from the transparent wall of the container. It can be deduced by observation of the ground surface settlement and also displacement of the white soil lines. The landslide occurrence has been exhibited and discussed in detail in another paper, Jafarzadeh et al. (2019).

Top views of Model 1, before and after shake loading are exhibited in Figure (6). The schematic view of the lines of white soil before and after test shaking is shown in this figure. It should be noticed that ground movement due to the seismic loading was identical for Models 1 and 2 since all the properties of the models are identical except the burial angle of the pipes.

In the present tests, all pipes were heavily instrumented with strain gauges. For each pipe,

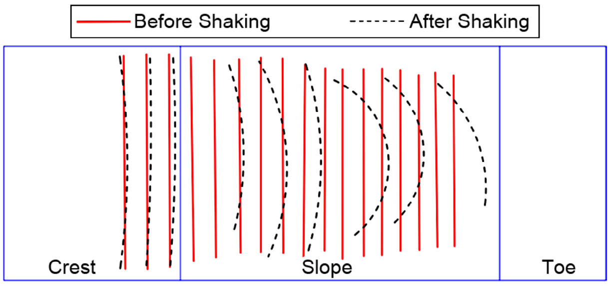
(a) After Construction and Before Shaking

(b) After Shaking

Figure 5. Side view of Model 1.

(a) After Construction and Before Shaking

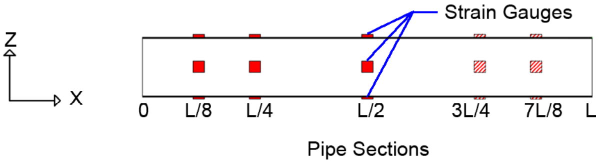
(b) After Shaking



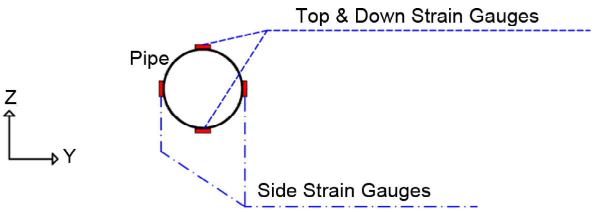
(c) Schematic View

Figure 6. Top view of Model 1.

pair strain gauges were attached to the sections of one-eighth, one-fourth and half of the pipe to detect the strains induced by pure bending. Schematic arrangement of the strain gauges of the pipes is shown in Figure (7). Pipes strains due to pure bending are also categorized into top & down and side strains according to strain gauge arrangements illustrated in this figure. The strain gauges at sections 3L/4 and 7L/8 were drawn with dash lines, because the strain gauges were not installed in these sections. Hence, it is assumed that due to symmetric distribution of strains along the pipe length, the strains at sections 3L/4 and 7L/8 were the same as those of sections L/4 and L/8, respectively. The maximum strains represent the highest experienced deformation of buried pipes during the tests.

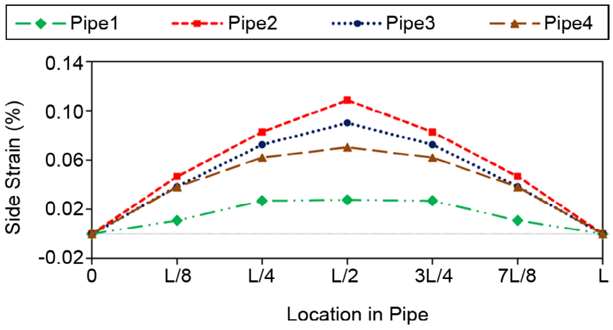


(a) Pipe Sections with Pair Strain Gauges

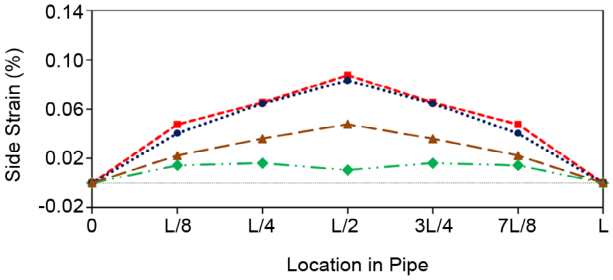


(b) Top & Down and Side Strains Definition in this Experiment

Figure 7. Schematic instrumentation of the pipes.

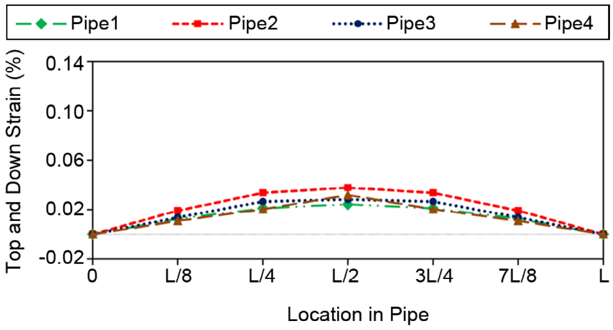


(a) Model 1

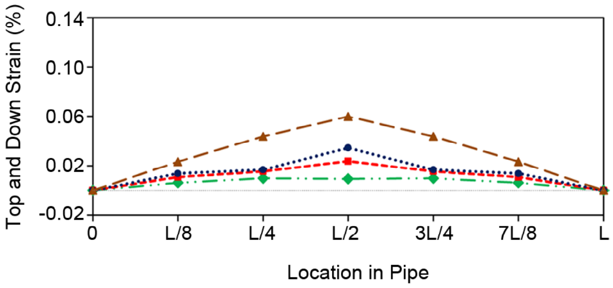


(b) Model 2

Figure 8. Diagrams of maximum side strain along the pipes.



(a) Model 1

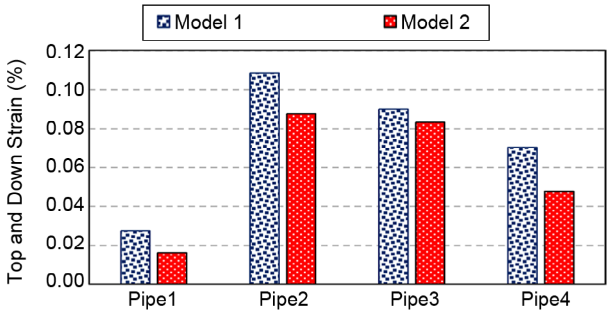


(b) Model 2

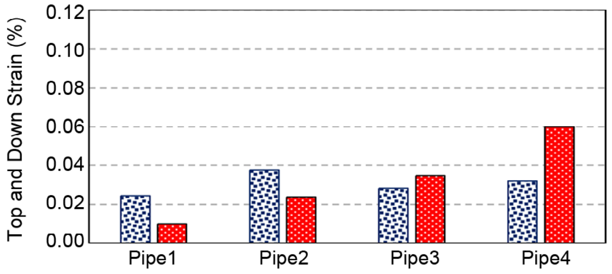
Figure 9. Diagrams of maximum top & down strain along the pipes.

Diagrams of distribution of maximum side and top & down strains in pipes due to pure bending are displayed in Figures (8) and (9), respectively. It should be noticed that these diagrams are drawn assuming symmetric distribution of strains in the pipe length. The diagrams demonstrate that maximum strains occurred at the half section of the pipes. It means that imposed loads on middle sections of pipes is more than that on sections near to supports. It can be attributed to the fact that soil in the middle section of the box width, moved more than that near the sides of the box.

Bar graphs of maximum strains generated in the pipes are presented in Figure (10). It should be noticed that all the measured strains at the pipes were less than yield strain of the pipes, i.e. 0.2%. It can be seen that in both models, Pipe 2 is subjected to the maximum pure bending induced strains and Pipe1 subjected to minimum bending induced strains. Therefore, Pipe 2 which was placed at the lower part of the slope is in the most critical position among the pipes in this study.



(a) Side Strain



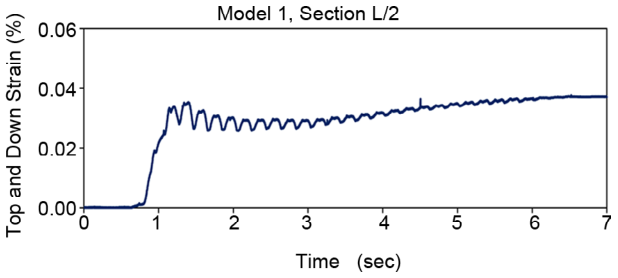
(b) Top and Down Strain

Figure 10. Bar graphs of maximum strain generated in the pipes.

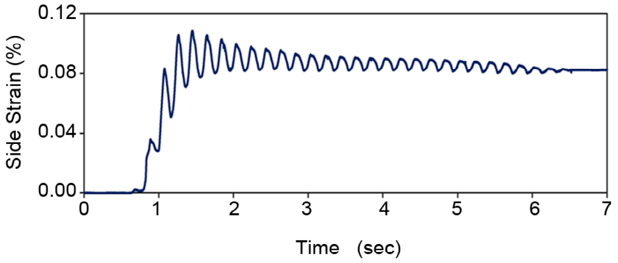
In other words, the lower part of the slope is the most critical position for placement of pipes. At the other hand, Pipe 1 placed at the toe of the slope is subjected to minimum strains, thus toe of the slope is the safest position for placement of pipes in earthquake-prone areas.

Another important point extracted from Figure (10) is that for almost all the cases, the pipes in Model 1 experienced greater strain than those in Model 2. In other words, reduction of pipe burial angles from 90 to 70 degrees in relative to the slope, decreased bending strain in the pipes. Therefore, reduction of burial angle of the pipes can be considered as one of the remediation methods against landslide-induced damages.

Time histories of bending strain in the critical section (i.e., L/2) for the most critical pipe (i.e., Pipe 2) of Models 1 and 2 are shown in Figures (11) and (12), respectively. As seen in these figures, the bending strain increased significantly at the initial cycles of the loading due to landslide occurrence. Then, the bending strain fluctuated in a constant value as the ground slope angle decreased noticeably and the soil lateral movement decreased. The fluctuation of side strain was remarkably much more than that of top and down strain due to direction of soil movement.

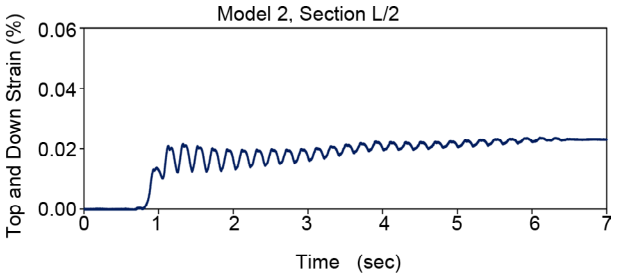


(a) Top and Down Strain (%)

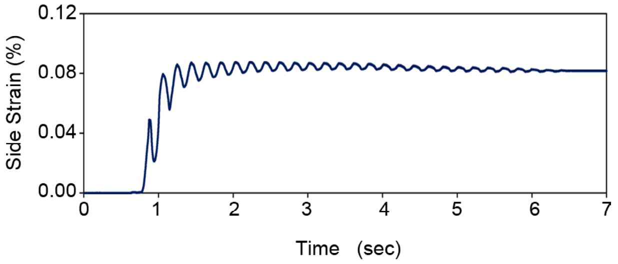


(b) Side Strain (%)

Figure 11. Time history of bending strain in section L/2 of the pipe 2 in Model 1.



(a) Top and Down Strain (%)



(b) Side Strain (%)

Figure 12. Time history of bending strain in section L/2 of the pipe 2 in Model 2 (Jafarzadeh et al., 2024).

4. Conclusions

In this study, two physical models were constructed and tested using 1-g shaking table at Sharif University of Technology to investigate the effects of burial angle of pipes in a sloped ground on their response to the seismic loading. Similitude laws proposed by Iai (1989) and Iai et al. (2005) for 1g shake table tests were employed to construct the physical models. In each model, four aluminum pipes were installed at different positions but at identical depths from the model surface. All the properties in both models - except the pipes angles relative to the slope - are the same. The pipes were heavily instrumented with pair strain gauges to measure pure bending strain. Input shaking consisted of 25 sinusoidal cycles of loading with amplitude of 0.32 g and frequency of 5 Hz. The results including bending strain of pipes at various sections are presented and discussed in this paper. The main findings of this study are summarized as below:

1. Reduction of pipe burial angles from 90 to 70 degrees in relative to the slope direction, decreased bending strains in the pipes. Therefore, reduction of burial angle of the pipes can be considered as one of the remediation methods against landslide.
2. Position of the buried pipes has a remarkable effect on their landslide-induced deformations.
3. Pipes placed at the lower part of the slope are subjected to the maximum strains. Therefore, lower part of slopes is the most critical position for placement of pipes.
4. Pipes placed at the toe of the slope experienced the lowest strains compared to the other pipes. Hence, the slope toe can be considered as the safest position for placement of the buried pipes.

5. Data Availability

All analyzed data including experimental model results will be made available upon reasonable requests.

6. Declarations: Conflict of Interest

The authors declare that there are no conflicts of interests or competing interests as far as this study is concerned.

Acknowledgment

This research work would have not been possible without the financial support of Tehran Gas Company (Grant code: 030762). The authors are grateful for the supports and collaboration of Sharif University Earthquake Center Chairs, Dr. Ali Bakhshi and Dr. Fayaz Rahimzadeh Rofooei.

References

Chaudhuri, C., & Choudhury, D. (2020). Buried pipeline subjected to seismic landslide: A simplified analytical solution. *Soil Dynamics and Earthquake Engineering*, *134*, 106155. https://doi.org/10.1016/j.soildyn.2020.106155

Farahi, H., Jafarzadeh, F., & Samadian Zakaria, M. (2018). Experimental study of burial depth effect on embedded pipe deformations in sandy slopes under dynamic landsliding. *Soil Dynamics and Earthquake Engineering*, *114*, 281-297. https://doi.org/10.1016/j.soildyn.2018.06.038

Iai, S. (1989). Similitude for shaking table tests on soil-structure-fluid model in 1g gravitational field. *Soils and Foundations*, *29*(1), 105-118. https://doi.org/10.3208/sandf1972.29.105

Iai, S., Tobita, T., & Nakahara, T. (2005). Generalized scaling relations for dynamic centrifuge tests. *Geotechnique*, *55*(5), 355-362, https://doi.org/10.1680/geot.2005.55.5.355

Jafarzadeh, F., Farahi, H., & Rajabigol, M. (2019). Applicability of rigid block based approaches in predicting sandy slope displacements by 1g shaking table tests. *Soil Dynamics and Earthquake Engineering*, *126*, 105576. https://doi.org/10.1016/j.soildyn.2019.02.020

Jafarzadeh, F., Farahi Jahromi, H., Hadei, S., & Rajabigol, M. (2024). Responses of buried pipelines to earthquake induced landslides: 1-g shake table tests. *Japanese Geotechnical Society Special Publication*, *10*(43), 1630-1634, ISSN 2188-8027. https://doi.org/10.3208/jgssp.v10.OS-32-07

Kramer, S.L. (1996). *Geotechnical Earthquake Engineering*. New Jersey: Prentice-Hall.

Rajabigol, M., Hadei, S., Jafarzadeh, F., & Farahi Jahromi, H. (2024). Effects of burial angle on pipeline response to earthquake-induced landslide. *Proceedings of the 9th International Conference on Seismology and Earthquake Engineering*, Tehran, Iran.

Tsatsis, A., Gelagoti, F., & Gazetas, G. (2016). Buried pipelines subjected to landslide-induced actions. *1st International Conference on Natural Hazards & Infrastructure*, Chania, Greece.