Experimental study of uplift of buried pipe liquefiable soil at different depths by shaking table

Sima Bahram Ghannad[1]*, Masoud Hajialilue Bonab[2], Maral Ghorbani Barazin[3]

1-Sima Bahram Ghannad, MSc. graduate of geotechnical engineering, University of Tabriz, sima.bahrami72@yahoo.com

2- Masoud Hajialilue Bonab, Professor of Faculty of Civil Engineering, University of Tabriz, mhbonab@gmail.com

3- Maral Ghorbani Barazin, MSc. graduate of geotechnical engineering, University of Tabriz, M.Ghorbani95@ms.tabrizu.ac.ir

Abstract

Many buried structures, including tunnels and lifelines, have been severely damaged in recent earthquakes. It is noteworthy that the phenomenon of soil liquefaction has played a significant role in the occurrence of these damages. Damage caused by the uplift of lifelines has motivated the study of the uplift of buried structures. Therefore, in this study, an attempt has been made to experimental study of the uplift of buried pipes in liquefiable soils by physical modeling at different depths. The soil used in this study is Gum Tape sand and shaking table has been used to simulate seismic load. Also, due to the importance of the deformation mechanism in this process, the particle image velocimetry method has been used to find out how the soil around the pipe moves during liquefaction. Buried pipe at three depths: 1.5, 2.5 and 5 times the diameter of the pipe has been subjected to seismic load and the degree of elevation and deformation mechanism have been investigated. The results show that with decreasing the buried depth of the pipe, due to the relatively high pore water pressure in the lower depth of the soil, the overpressure created after dynamic loading tends to be wasted and flows towards the low pressure points (surface part). And because in the surface areas, the flow is upward, so the uplift continues to some extent. Also, the displacement vectors on the sides of the pipe are in the form of circular rings that try to raise the pipe.

Keywords

Liquefaction, uplift, Buried pipe, Particle Image velocimetry, Physical Modeling

Corresponding Author: Email: mhbonab@gmail.com

1. Introduction

Today, the increase in population and, consequently, the increase in demand, has highlighted the role of lifelines in human life.

Natural disasters such as earthquakes can cause damage to these lines. According to statistics, the rise of pipes is one of the obvious failures that the occurrence of which will lead to other damages [1, 2]. Therefore, it is important to find out the cause of uplift.

What makes the conditions more suitable for the occurrence of soil liquefaction is three factors: 1- Loose sand soil 2- High groundwater level 3- Earthquake that aggravate the conditions for its occurrence. It is worth noting that liquefaction is one of the destructive factors of lifelines that has been studied in this study. Loose sand soils have high permeability, but if this type of soil is saturated and subjected to seismicity, despite the high permeability, due to high loading speed and tendency to reduce soil volume, the opportunity for water exit is not provided and undrain condition governs the problem [3]. As a result, with the occurrence of undrain condition, the role of effective stress, as a representative of soil resistance due to increased water pressure will be diminished, and as a result, the soil loses its shear strength and will behave like a liquid. In other words, it can be stated that the soil has become liquefied [4]. By reducing the shear strength, the soil does not tolerate the maintenance of the buried pipe and the conditions for the rise of the pipe are provided [5, 6]. In the study of Tokida et al. [14], the effect of liquefiable soil thickness under buried substructure and the width of the structure on the amount of uplift caused by liquefaction has been investigated experimentally and shaking table has been used to simulate the earthquake load. The results show that by stopping the applied load, deformation and uplift also stop and by reducing the thickness of liquefied soil and the thickness of the buried structure, the amount of uplift decreases.. In this research, shaking table has been used to model the seismic load. By considering the relative density of soil as the studied variable, it was concluded that the amount of uplift in the samples with loose sand at the beginning of the experiment was 5 to 15 mm, while there is no significant change in dense samples. However, at the end of seismic loading, the elevation of dense specimens increased significantly (about 100 mm = buried depth). The elevation of subway stations as a result of soil liquefaction was studied as numerical modeling (finite difference-finite element) by Ji-Lei et al. [16] and the results showed that liquefaction because of seismic load can initiate elevation but cannot be main reason. The uplift starts gradually from the first stage of liquefaction and increases with the amount of liquefied area, and finally with the complete liquefaction of the area, the amount of uplift occurs more intensely. It should also be noted that with the seismic stop, the simultaneous ascent does not stop. In previous studies, the PIV method has been performed only in modeling by centrifuge. In order to use this method in shaking table tests, the walls of the box are made of Plexiglas and also seismic loading has been applied by the shaking table. Huang et al. [30] believed that the rise of the pipe stops when the loading is complete. Therefore, in this research, the stopping time of the uplift will be evaluated in proportion to the loading.

Corresponding Author: Email: mhbonab@gmail.com

2-Materials and methods

Due to the presence of relatively large impurities, sifted soil has been used. The type of soil used in the experiments is Gum Tape sand. In this study, Lai modeling law [31] has been used. The dimensional analysis used is similar to the dimensional analysis used in the study of Otsubo et al. [32], in this study, liquefaction and strategies to diminish it, were examined. It is noteworthy that in the modeling of the Otsubo study, the law of Lai modeling has been used for dimensional analysis. The scale for the model geometry specified by the NG parameter. The scale for the pipe diameter and loading frequency is specified by the Ndp and Nf parameters, respectively, and is 5. The reason for increasing the frequency 5 times is because the scaled modeling has a lower natural period and in order to scaling, it is necessary to increase the frequency 5 times. The test platform of the shaking table is a rectangle with dimensions of m2 × m3, which is made of steel sheet and the capacity of the shaking table is up to 6 tons. The test box is of rigid type with dimensions of 100 m (length) * m62 (width) * 64 m (height). Also, the walls of the rigid box are made of Plexiglas to take advantage of the PIV method. In this study, in order to investigate the effect of buried depth of the pipe, three physical models were performed according to Table 3. In this table, the buried depth of the pipe with parameter H, the diameter of the pipe with parameter D, and the relative density of the sample with parameter Dr are specified (Table 1). In this research, a new PIV Technic has been used as a suitable method for use in modeling and geotechnical experiments. Sequential images are taken of the soil surface during deformation, and then the soil deformation is determined between each pair of consecutive images using particle image velocimetry analysis.

Table 1. Test program

modeling	frequency	acceleration	Dr	H/D
Model 1	8 Hz	0.5 g	30 %	1.5
Model 2	8 Hz	0.5 g	30 %	2.5
Model 3	8 Hz	0.5 g	30 %	5

2. Results and discussion

3-1 uplift of pipe

The amount of uplift decreases with increasing depth, so that when the depth of the pipe becomes 3.33 times, the ratio of the uplift of the pipe to the diameter of the pipe decreases by 56%. The reason for this can be attributed to the increase in resistive force due to the weight of the soil above the pipe. The onset of uplift occurs when excess water pressure forms inside the soil. It is also important to note that uplift does not stop with the end of the load, although it continues in small amounts. Therefore, it can be concluded that seismic load is not only the initiator of uplift in buried structures during liquefaction, and the excesses pore water pressure also plays a role in this phenomenon. It is noteworthy that when the buried depth of the pipe increases 3.33 times, the ratio of the excesses pore water pressure to the effective stress is reduced by 75%.

3-2 Soil deformation mechanism

While liquefaction, the displacement vectors on the right side of the closed loop are moving from the top to the bottom of the pipe and in the between of two closed loops have direction from the bottom to the top to lift the pipe. The soil around the pipe participates in this action is a limited area, so that the maximum area involved (impact) in the rise of the pipe is 3D. In addition to the uplift at the top of the pipe, consolidation has also occurred in areas far from the pipe.

3. Conclusion

The results of this study are as follows:

1-In this study, when the buried depth of the pipe increases 3.33 times, the ratio of the excess pore water pressure to the effective stress decreases by 75%. 2-When the buried depth of the pipe decreases, the rising of the pipe continues even after the loading is completed. 3-In order to reduce the shear strength of the soil due to the liquefaction, the soil will behave like a liquid. 4-Excesses pore water pressure during seismic loading is one of the most important and effective variables in the elevation of buried pipes. 5- As a result of soil liquefaction, in addition to the occurrence of uplift at the top of the pipe, subsidence also occurs in the outer areas. In order to investigate the effect of the buried depth of the pipe, the maximum width of the influenced area is 6D. 6- with decreasing the buried depth of the pipe, the vertical displacement contours as a pipe uplifting indicator have become larger.

4. References

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