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Experimental Investigation of Uplift Capacity of Buried Pipes

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Abstract- Buried pipes are subjected to uplift loads, under certain circumstances such as earthquake-induced faulting, urban excavations, high internal pressure caused by explosion and offshore slope failures. Reliable design of buried pipes against these effects requires the uplift capacity to be estimated. In this study, a laboratory model-scale investigation has been carried out to determine uplift capacity of buried pipes in sand. The results of laboratory model-scale tests designed to investigate the influence of the embedment ratio of pipe and the density of sand on the uplift capacity of buried pipes are presented. The results show that the uplift capacity is affected substantially from pipe embedment ratio and density of sand.

Keywords Buried pipe, uplift capacity, model-scale test, embedment ratio, sand.

1. Introduction

Buried pipes are used in daily utilities such as oil and gas lines, sewer lines, culverts, drain lines, telephone and electrical conduits, water mains, and heat distribution lines. Buried pipes are subjected to different loads such as pressure and uplift forces. Buried pipe systems are generally designed against pressure. However, in some circumstances uplift forces are important criteria to design buried pipes. Uplift forces appear due to earthquake-induced faulting, urban excavations, high internal pressure caused by explosion and offshore slope failures, to name a few. In literature, there are many experimental and observational studies to examine the behaviour of buried piping systems.

1989 Loma Prieta [1, 2], 1993 Nansei-Oki [3] and 1995 Kobe [4, 5, 6] earthquakes have been studied and investigated by many researchers as case studies.

When the damages due to earthquakes are examined, it is seen that especially the pipes embedded in weak and liquefy soils are exposed to movements in the upward and downward directions due to low shear strength of the soil and they are deformed above the design criteria of buried pipes.

In addition to observational studies, there are many experimental and numerical studies on the behaviour of buried pipe systems. A few of these experimental and numerical studies are presented below.

Dickin [7] experimentally examined the behaviour of pipes subjected to uplift force using a centrifuge modelling technique. A number of experiments have been carried out on the effect of parameters such as pipe diameter, depth of buried pipe and density of sand on the uplift capacity of the pipes. With increasing depth of pipes and density of sand, the uplift capacity of buried pipes has increased significantly, and these parameters have affected uplift behaviour. In the study, differences between the behaviour of embedded pipes and strip anchors were investigated. Behaviour of the pipe was found to be very similar to the anchor strip.

Ling et al. [8] investigated the stability of large diameter pipes in the liquefied zone against the liquefication. Using the centrifugal modelling technique, the behaviours of the pipes embedded in the lamina frame were investigated by 8 shake-table experiments on the scale formed under 30g gravity. In this study, time - dependent behaviours were investigated by measuring the pressures and accelerations of groundwater in the ground. In addition, the pipelines system in the liquefied ground was isolated with geogrid reinforced soil, and the effect of reinforcement on displacement was examined. In the case of segregation with geogrid reinforced soil, it was observed that the vertical displacements along the pipe decreased significantly.

Liu and Song [9] investigated the behaviour of pipes in liquefiable soil with numerical modelling. In the study, the behaviour of the buried pipe in the case of circumferential isolation with cut-off walls was investigated. It has been observed that in case of use of cutting wall in liquefaction soil, pipe movements upwards are restricted significantly. In addition, the displacement of the pipe increases with the increase in the distance between the walls on both sides of the pipe, and wall thickness and wall stiffness also affect pipe behaviour considerably.

Abdoun et al. [10] examined the behaviour of a buried pipe under dynamic loads by centrifugal model tests. They performed 10 centrifugal tests and simulated horizontal faulting in tests. The effect of the loading rate on the buried system was investigated by using different loading speeds in the horizontal fault strike. According to the results obtained, the lateral load carrying capacity of the pipe was affected with the variation of the pipe diameter, and the scale effect significantly affected the results. Moreover, it is seen that the embedment ratio of the pipe is an important parameter affecting the strength of the pipe, and the diameter-to-wall thickness ratio is also an important factor in the soil-pipe interaction.

Oliveira et al. [11] investigated the soil-pipe interaction in clay soil by using centrifuge modelling. The lateral movements of buried pipes at different depths were investigated and it was observed that the lateral bearing capacity of pipe increased with the increase of embedment ratio.

In this study, a laboratory model-scale investigation has been carried out to determine uplift capacity of buried pipes in sand. The results of laboratory model-scale tests designed to investigate the influence of the embedment ratio of pipe and the density of sand on the uplift capacity of buried pipes are presented. The results show that the uplift capacity is affected substantially from pipe embedment ratio and density of sand.

2. Experimental Details

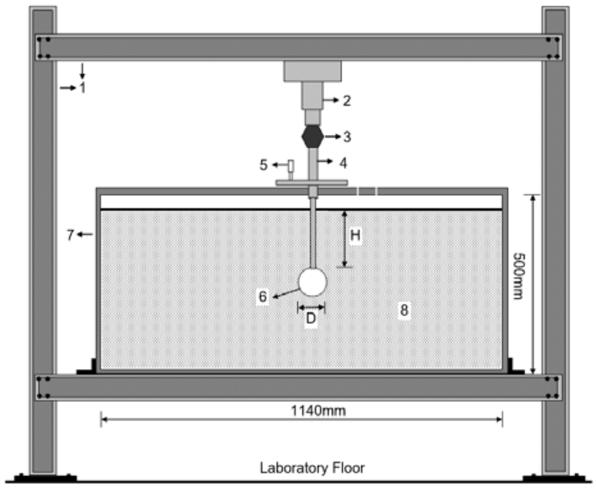
Experimental studies have been carried out using the facility in the Geotechnical Laboratory of the Çukurova University. The testing facility consists of three main parts, namely the loading system, the test box and the data acquisition system. Test setup is shown in Figure 1 [12].

2.1. Loading system

The loading system consists of the loading frame, control unit and the motor controlled hydraulic jack system. Uplift loads were applied to the pipe by a rod attached to hydraulic jack system. The hydraulic jack system attached to the loading frame located above the test box. The loading rate is controlled with an electronic remote unit.

2.2. Test box

The testing tank is designed as a steel frame with inside dimensions of 1140mm (length), 475mm (width) and 500mm (depth) as shown in Figure 2. The two sidewalls of test box are made of glass to see the sand sample during preparation and observe the sand particle deformations during the tests. The other surfaces of test box were made of wood.



1- Loading Frame	5- Displacement Transducer
2- Hydraulic Jack	6- Model Pipe
3- Load Cell	7- Steel Profile
4- Uplift Rod	8- Soil

Fig. 1. Test setup [12]

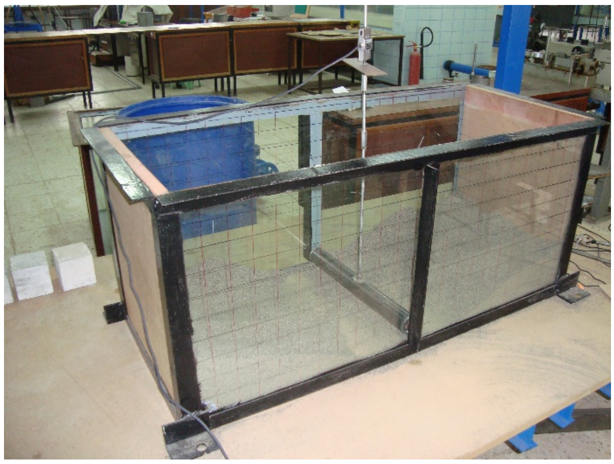


Fig. 2. Test box [12]

2.3. Data acquisition system

The test data was recorded automatically using TDS-530 data acquisition system. The uplift loads were measured by an electronic 25kN capacity load cell. Settlements were measured using two linear variable displacement transducers (LVDTs) with an accuracy of 0.01% of full range (50mm). The applied loads and vertical displacements were measured by data acquisition system.

2.4. Soil properties

The soil used for the model tests was uniform, clean and fine sand obtained from Seyhan River bed. The grain size distribution of sand is shown in Figure 3. The sand class is poorly graded sand (SP) in the Unified Soil Classification System. The maximum and minimum dry densities of the sand were determined using ASTM D4253 and D4254 [13, 14]. The specific gravity of sand was determined by picnometer test and Table 1 summarizes the general physical characteristics of the sand.

Table 1. Properties of sand

Property	Value
Coarse sand fraction (%)	0.0
Medium sand fraction (%)	46.9
Fine sand fraction (%)	54.1
D10 (mm)	0.20
D20 (mm)	0.30
D30 (mm)	0.50
Uniformity coefficient, Cu	2.78
Coefficient of curvature, Cc	1.00
Specific gravity, γ (kN/m3)	26.8
Maximum dry unit weight, γ_{dmax} (kN/m^3)	17.3
Minimum dry unit weight γ_{dmin} (kN/m^3)	14.4
Classification (*USCS*)	SP

2.5. Pipe Properties

The pipe diameters vary a wide range used for different purposes such as drainage, sewer, and petroleum systems, etc. The metal pipes used in the tests had 75mm external diameter, 2.2mm thickness and 470mm length. The length of the pipe is 0.5cm shorter than the width of the tank and the two ends of the pipe was clogged to block sand.

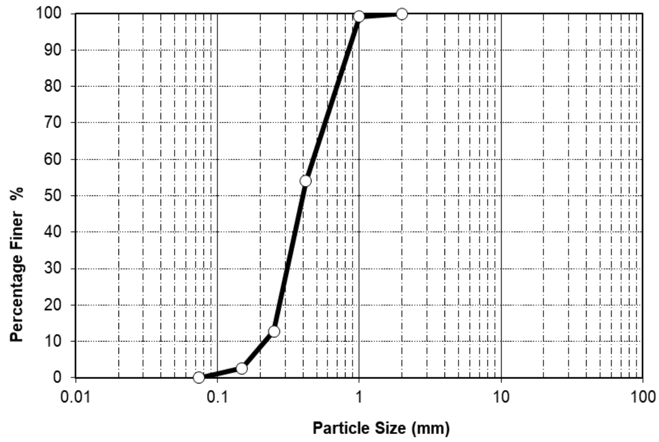


Fig. 3. Grain size distribution of sand

2.6. Preparation of the model tests

To obtain a homogeneous sand bed in the experimental study, fill sand was filled layer by layer in 50mm thickness into to the test box with same compaction procedure. The average unit weights of sand in the experimental studies were 15.30 and 16.30kN/m3. Corresponding relative densities of the sand samples were 35 and 65%, respectively. Pipe was placed to desired location in sand bed and uplift forced were applied with by means of an uplift rod. Investigated parameters were shown in Figure 3 and test program was shown in Table 2 in tabulated form. Tests were carried out for different embedment ratio and soil density in accordance with the program.

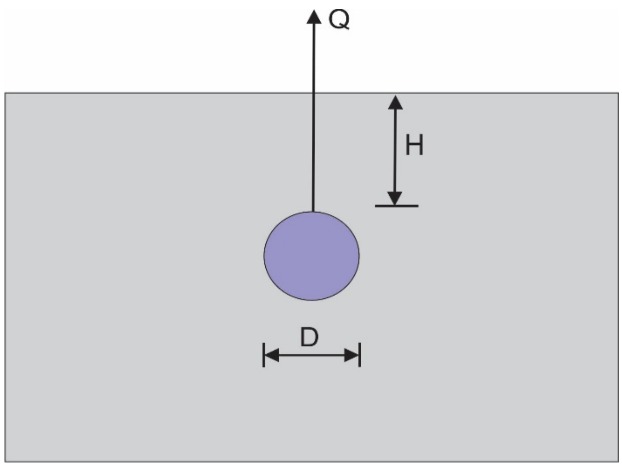


Fig. 3. Investigated parameters

Table 2. Test program

Test Name	Relative Density, Dr (%)	Embedment Ratio (H/D)
UPL1	35	1
UPL2	35	2
UPL3	35	3
UPL4	35	4
UPL5	35	5
UPL6	35	6
UPL7	35	7
UPL8	35	8
UPL9	85	1
UPL10	85	2
UPL11	85	3
UPL12	85	4
UPL13	85	5
UPL14	85	6
UPL15	85	7
UPL16	85	8

3. Experimental Results

In this section a total of 16 model test results are presented and the effects of different parameters are discussed. The uplift capacity of the pipe is represented using a non-dimensional factor, called breakout factor, Fq. This factor is defined as follows.

$$F_q = \frac{Q}{H \times \gamma \times A}$$

Q : Uplift capacity of pipe,

H : Embedment depth of pipe,

γ : Soil unit volume weight,

A : Pipe cross section area.

The ultimate uplift capacities for the model are determined from the load-displacement curves as the peaks, after which the pipe collapses and the load decreases.

In the model tests, the effects of the embedment ratio and soil density on the uplift capacity were investigated. The uplift capacity - displacement curve obtained for Dr = 35% and Dr = 65% densities are shown in Figure 4 and Figure 5, respectively. The test results are shown in Figure 6, transformed into a dimensionless breakout factor.

According to the results, it is seen that the uplift capacity of the pipe increases with the increase of the embedment ratio. The uplift capacity obtained at the same embedment ratio on dense sand is considerably higher than in the case of loose sand condition.

At the same embedment ratio, the uplift capacity of the buried pipe in dense sand condition is 3.5-4 times more than loose sand condition. The results obtained show that the soil properties and embedment ratio of the pipe are important parameters affecting pipe design.

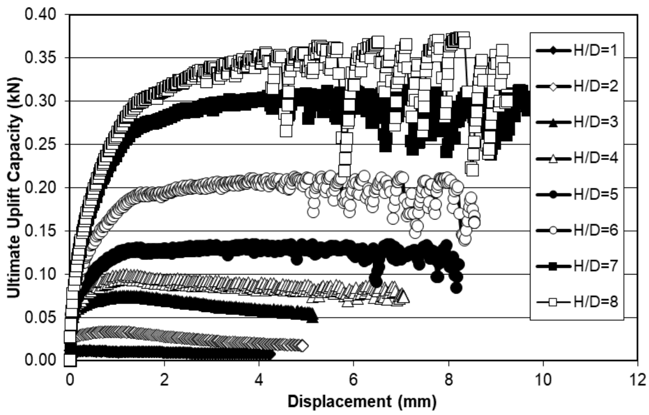


Fig. 4. Variations of uplift capacity with displacement for model tests (Dr=35%)

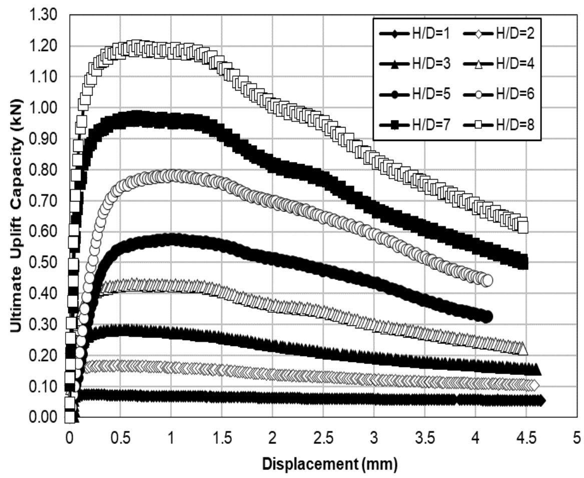


Fig. 5. Variations of uplift capacity with displacement for model tests (Dr=65%)

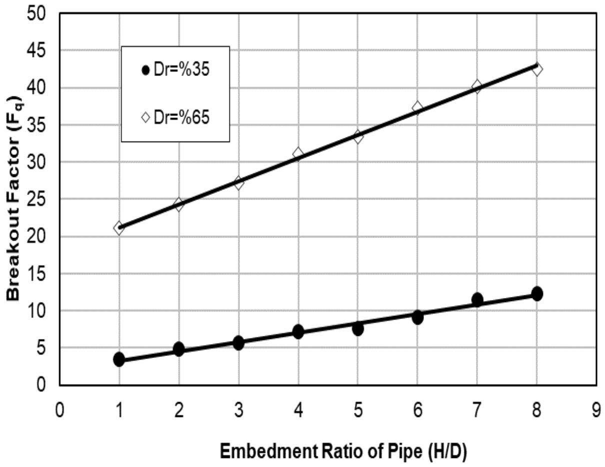


Fig. 6. Variations of breakout factor with embedment ratio of pipe

4. Conclusion

The conclusions from this study are:

1. The uplift capacity of the pipe increases with the increase of the embedment ratio.
2. The uplift capacity obtained at the same embedment ratio on dense sand is considerably higher than in the case of loose sand condition. At the same embedment ratio, the uplift capacity of the buried pipe in dense sand condition is 3.5-4 times more than loose sand condition.
3. The uplift capacity on pipes in sand is strongly influenced by embedment ratio of pipe and density of sand.

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