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Effects of soil reinforcement on uplift resistance of buried pipeline

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ABSTRACT

Pipeline failure caused by low uplift resistance in soil is a serious environmental and economic issue. Hence, having access to higher uplift resistance of pipeline through soil reinforcement has received considerable attention. The objective of this study is to examine the effect of performing geogrid to increase the uplift resistance of buried pipelines. To examine the effect of burial depth, pipe diameter, length of geogrid layers and the number of geogrid layers on the peak uplift resistance (PUR) of loose sand, 33 small-scale tests were performed in the laboratory. Results of laboratory tests reveal that depth of burial and pipe diameter have a direct effect on the PUR results. The findings show that the number of geogrid layers does not have a remarkable influence on PUR values. While the residual PUR values are of interest, for the same length of geogrid, the use of two layers of geogrid instead of one is advantageous. To verify the experimental results, 33 experiments were back analyzed using "PLAXIS 3D TUNNEL" program. It was found that experimental and numerical results are in good agreement.

1. Introduction

In general, buried pipelines are commonly utilized to transport natural oil/gas, water, and other materials. In design of offshore pipeline, the maximum value of uplift resistance is an essential factor. The pipeline profile is pushed upward in the case of severe upheavals of backfill soil as well as pipeline's own weight. To provide adequate uplift resistance and consequently prevent pipe uplift, the depth of pipeline insertion and the soil cover should be selected properly. Many researches have been conducted on the uplift resistance of buried pipeline [1–6]. In this paper, the incorporation of geogrids in enhancement of uplift resistance of buried pipelines in loose sand is considered. In this regard, an experimental study consisting of 33 small scale uplift tests were conducted. Simultaneously, numerical analysis was conducted utilizing PLAXIS 3D TUNNEL for verification purpose.

2. Related works

Experimental, numerical and mathematical analysis have been widely used to investigate the uplift resistance of buried pipelines [7–17]. Among other researchers, the application of geogrid in enhancing the uplift capacity of buried pipelines in compacted moist cohesionless soils was investigated by Selvadurai [18]. It was found that a considerable increase in the uplift capacity of pipes is obtained utilizing geogrid, when peak loads are considered.

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In addition, it was reported that an enhancement of uplift capacity up to 250 percent is obtained when the ultimate capacity corresponding to the large pipe displacement is considered.

A series of centrifuge model tests was conducted by Thusyanthan et al. [19] at 30 g to investigate the upheaval buckling resistance of buried pipelines in clay. Vertical pipe displacement, excess pore pressure at the pipe invert and the resistance of soil cover were measured. In this regard, significant parameters including rock dump depth, pipe pullout rate, burial depth, and interval time between burial and commissioning was investigated. The tests results revealed that the burial depth is directly proportional to the uplift resistance. In addition, the effect of rock dump on uplift resistance is more noticeable compared to clay backfill for the rate of pullout in both slow and fast conditions. Based on the uplift factor given by Schaminee et al. [20], the effect of sand relative density on the uplift resistance was investigated by Bransby et al. [3]. A series of physical and centrifuge modeling tests were conducted in both dense and loose sands to measure the uplift resistance of buried offshore pipelines. An uplift factor of 0.5 was obtained in loose sand while this factor increased to 1 for dense sands. The upheaval bulking of buried pipelines in different type of soils was investigated by Ommundsen [21] utilizing experimental and numerical analysis. The results demonstrated that the uplift resistance of clay is much greater compared to sand and gravel.

A small-scale laboratory model test was conducted by Trautmann et al. [22] to measure the maximum uplift force of buried pipelines in dried sand. The maximum uplift force of buried pipelines a function of sand density and pipe depth was considered. Under plane strain condition, the results demonstrated that the uplift resistance of loose sand is considerably lower compared to the uplift resistance dense sands. The obtained results validated the analytical results of uplift resistance estimation presented by Vesic [8] and numerical results of uplift resistance estimation given by Row and Davis [23]. Similar small-scale laboratory model test was conducted by Choobbasti et al. [24] to investigate the influence of relative density of sand as well as burial depth on the uplift resistance of buried pipelines. Results indicated that more uplift resistance is obtained by increasing the burial depth of pipelines. However, sand relative density is more influential such that a 20% increase in sand unit weight has the same effect as a 40% increase of burial depth on uplift resistance of buried pipelines.

The influence of burial depth, backfill density and pipe diameter on the uplift resistance of cohesionless soils was investigated by Dickin [10] through a centrifuge model test. The results demonstrated that the effect of pipe diameter on uplift resistance is insignificant for pipes with diameter greater than 1 m. In addition, the roughness of the pipe is a non-influential parameter for embedment ratios larger than 3.5. However, this parameter is very effective on the uplift resistance at shallow depths. In comparison between dense and lose sands, higher uplift resistance for models in dense sands was obtained. A similar study was performed by White et al. [2] to investigate the pipe uplift mechanism in dry sand through centrifuge model tests. The results showed that the peak uplift resistance is strongly influenced by the relative density of sand.

3. Laboratory tests procedure

In this study, several small scale physical tests were performed to examine the uplift capacity of a pipeline section in loose sand. For this reason, the experimental system consisted of a rectangular test chamber as well as a pulling arm system connected to an AC motor to apply an uplift force to the pipe. The size of the test chamber used in this study is 600 mm, 200 mm and 400 mm for width, depth and height respectively. Two sides of the chamber as well as the base are constructed using steel plate 20 mm thick. The front side material of chamber is Plexiglas 20 mm thick. More details of the test equipment are shown in Fig. 1.

Three pipe sections 25 mm, 35 mm, and 45 mm in diameter and 150 mm in length were used to obtain the maximum uplift resistance. Different lengths of geogrid 200, 300 and 400 mm in length were also utilized in this study.

The small scale laboratory tests consisted of three distinct phases. In the first stage, measurements of the uplift capacity of the pipeline were carried out without the geogrid reinforcement. These tests were conducted for two different depths of embedment (100 mm and 150 mm).

In the first series of experiments, the pipe section along with the loading rods are first removed, and loose sand was poured as an initial layer into the chamber. Then the pipe sections were placed at different burial depths (100 mm and 150 mm). Consequently, the loading rods were connected to the loading platform. Since the loads were applied through an actuator system, the test was essentially set to be displacement controlled. By using a motor speed controller, the movement rate of the loading was controlled. In this study, the loading rate was set at 0.05 mm/s. In the pipe sides, two pieces of yonolit were used as a smooth material to minimize the skin friction between Plexiglas and pipe.

The second stage of experiment was carried out with incorporation of one layer geogrid with lengths of

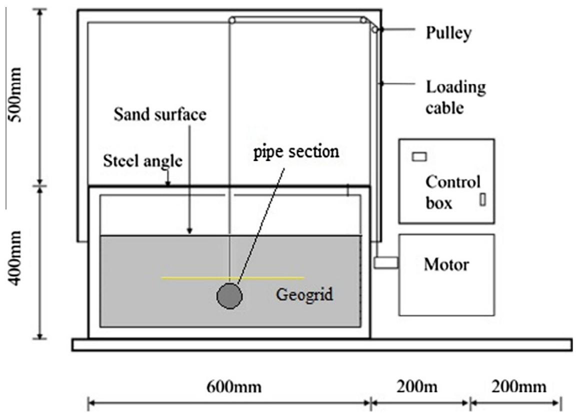

Fig. 1. Schematic view of pullout test.