3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,
28-30 June 2012, Near East University, Nicosia, North Cyprus

Laboratory investigation of the uplift behavior of belled piles in reinforced sand

S. Javadi
M.Sc student of Geotecnical Engineering, Civil Engineering Department, K.N. Toosi University of Technology, Tehran, Iran, sadrajavadi@sina.kntu.ac.ir

S.N. Moghaddas Tafreshi
Associate Professor,Civil Engineering Department, K.N. Toosi University of Technology, Tehran, Iran, nas_moghaddas@kntu.ac.ir

KEYWORDS: uplift load, Geocell-reinforcement, Geocell thickness, belled pile

ABSTRACT: Footings are frequently subjected to combination of permanently downward loads (weight of the structures) and upward loads (e.g. earthquake, wind tension cables for suspension bridges, marine structures such as floating platforms and tension leg platforms) which may result in pullout forces much greater than the weight of the structure itself. Hence anchors of large uplift capacity are required that is capable of resisting tensile force with the support of surrounding soil in which anchor is embedded. The pullout force may be carried out by the deep footings such as the piles/belled piles. In this paper, a series of laboratory, pilot scale tests were performed to evaluate the uplift performance of belled piles embedded in Geocell-reinforced sand. The effect of Geocell thickness on the uplift resistance of pile is studied. The results show that, with increase in the thickness of Geocell reinforcement over the bell of pile, the pullout resistance of the belled pile significantly increases and its upward displacement decreases as compared with the unreinforced one while the efficiency of the reinforcement decreases by increasing the thickness of Geocell.

1 INTRODUCTION

Footings require the special attention due to acting different types of loads. Among them, the combination of static load and upward load can play destructive role and leads to uplift load on footings. Static loads such as dead load of structure and dynamic loads like upward/downward loads due to earthquake, wind, and waves force are some examples that are of the high possibility to occur in one ordinary structure. Hence, footings may be alternatively subjected to uplift loading which leads tension force on the footings. In early decades, because of high efficiency and easy application of geosynthetics, soil reinforcement has been broadly developed in geotechnical engineering (e.g, Dash et al., 2001, 2007; Sireesh et al., 2009; Sanat et al., 2010; Moghaddas Tafreshi and Dawson, 2010a,b). Considering the reinforced foundations under pull out loads, show the lack of experimental studies on the uplift behaviour of footing. Ilamparuthi and Dickin (2001a,b) have investigated the behavior of pile embedded in Geogrid-reinforced soil under static pull out loads. They showed that the uplift resistance of Geogride-reinforced soil increases as compared with unreinforced soil. Considering the reinforced foundations under pull out loads, show the lack of experimental studies on the uplift behaviour of footing.

Hence, in this paper, in order to develop a better understanding of the Geocell reinforcement effect, a series of experimental tests were performed to evaluate the uplift behavior of belled piles located at Geocell-reinforced soil. The overall goal was to demonstrate the benefits of Geocell, with the detailed objective of this study being to compare the performance of Geocell reinforcement systems and unreinforced systems on the uplift resistance of single belled pile.

2 Testing Materials

The soil used in these tests was a granular soil of grains size between 0.07 and 25 mm and with a specific gravity, G_s of 2.65. It has a Coefficient of uniformity, Cu, of 13.86, Coefficient of curvature, Cc, of 1.20, Medium grain size, D50, of 1.40 mm. The maximum and minimum void ratio (e_{max} and e_{min}) of the sand were obtained as 0.66 and 0.36, respectively. According to the Unified Soil Classification System, the sand is classified as well graded sand with letter symbol SW. The relative density of soil was chosen 70% in all of the tests.

The Geocells used were made of a type of a planar geotextile thermo-welded to form a honeycomb structure with an open top and bottom – an innovative approach for use in ground stabilization. The type of geotextile used to form the Geocell is non-woven. The engineering properties of this geotextile as listed by manufacturer (DuPont de Nemours, Luxembourg) are: thickness 0.57 mm, mass per unit area 190 gr/m2, ultimate tensile strength 13.1 kN/m and effective opening size 0.08mm. Fig. 1 shows the isometric view of the Geocell used in the experiments.

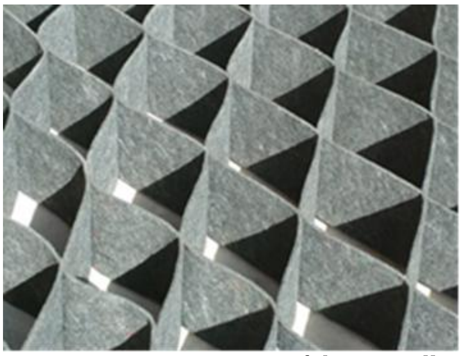

Figure 1. Isometric view of the Geocell.

3 Testing Apparatus and Instrumentations

A physical model test was conducted in a test bed-loading frame consisting of the testing tank, the loading system and the data acquisition system. The testing system consists of three substantial parts of the loading system, testing tank and the data acquisition system. The general arrangement of the testing system is shown in Fig. 2. Loading system includes a hydraulic cylinder can produce two-way pressure on the model-belled pile (It is able to run upwards and downwards pressure on the head of pile). The testing tank is designed as a rigid box, 650 mm in length and width, and 650 mm in height, encompassing the soil, Geocell, and model-belled pile (see Fig. 2). Data acquisition system is to automatically read and record both the load and the displacement. An S-shaped load cell with an accuracy of ±0.01% and a full-scale capacity of 15 kN was placed between the loading shaft and the pile head to precisely measure the pattern of the applied load. A Linear variable differential transducer (LVDT) with accuracies of 0.01% over their full range (100 mm) were placed on the pile model to measure the displacement of the pile during loading. To ensure accurate readings, all of the devices were calibrated prior to each series of tests.

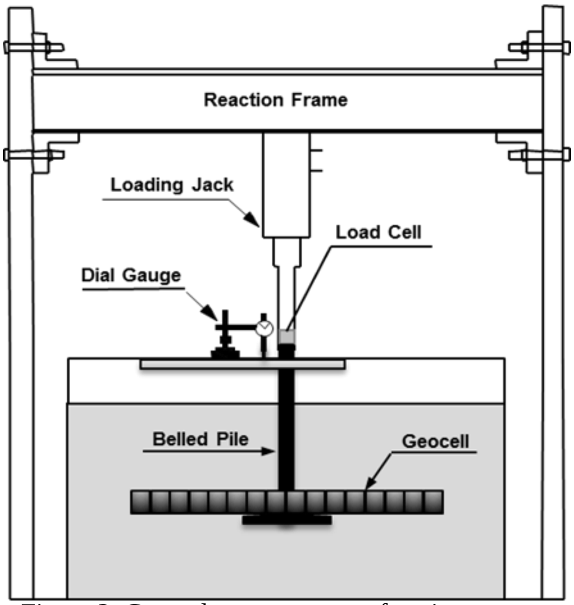

Figure 2. General arrangements of testing system.

4 Preparation of Model Test

The schematic layout of the trench, which contains the soil, belled pile and Geocell over the belled pile is shown in Fig. 3. To prepare the soil in the testing tank, the compaction method is used. The compaction energy produces by means of hydraulic cylinder, which applies constant pressure on a wooden stiff plate (690 mm × 690 mm in plan dimensions). The dimensions of the wooden plate was 10 mm less than the dimensions of the tank, so a 5 mm wide gap was provided on each side of the tank to prevent contact between the wooden plate and the sides of the tank. The wooden plate is approximately fitted on the soil surface so all the energy will transfer uniformly to bed. Before compaction the soil layers in the tank, compaction system was calibrated at different compaction energy (i.e. using the uniform pressure applied on the wooden plate) and number of compaction repetitions for the soil layers of 100 mm in thickness. Table 1 shows the calibration of compaction procedure.

In order to prepare the model test, the relative density of soil was selected 70%. This relative density was produced using constant pressure of 18 kPa and three compaction repetitions on the wooden plate (see Table 1, the marked column). To ensure that the calibration system produces the proper relative density, the soil density was measured for several tests, and the maximum difference in the soil density was around 2%-3%.

The unreinforced soil beneath the belled pile, with thickness of 300 mm, was compacted in three layers of 100 mm in thickness. Then the belled pile was located in the center of tank on soil surface. The model belled pile consists of a 350 mm cylindrical rod with diameter of 20 mm and a bell with 80 mm diameter and 20 mm thickness.

The Geocell layer were placed above the bell of pile and then the soil inside the opening of Geocell and unreinforced soil above the Geocell-reinforced layer was compacted in layers of 100 mm in thickness until the specified level of soil achieves. An indicator plate was placed between load cell and pile as shown in Fig. 2. LVDT was set on the indicator plate to record the settlement data and load cell was placed between the loading shaft and the pile head to record the applied loads. In all tests, the belled pile is subjected to a static pull out force at a rate of 1.0 kPa per second.

Table 1. Compaction Calibration

Applies pressure (kPa)	**30**	**30**	**30**	**22**	**22**	**22**	**18**	**18**	**18**
number of compaction repetitions	3	2	1	3	2	1	3	2	1
γ_d (kN/m3)	1.54	1.50	1.46	1.52	1.49	1.44	1.51	1.48	1.44
E	0.69	0.73	0.78	0.71	0.74	0.81	0.72	0.76	0.81
D_r (%)	84	67	49	76	63	40	71	58	40

5 Test Parameters and Testing Program

The geometry of the test configurations for the Geocell reinforcement considered in these investigations is shown in Fig. 2. Also, the details of the tests are given in Table 2. In the case of the reinforced bed, test series 2 was conducted by varying the thickness of Geocell (H). It should be noted that many of the tests described in Table 1 were repeated carefully at least twice to examine the performance of the apparatus, the accuracy of the measurements, the repeatability of the system, reliability of the results and finally to verify the consistency of the test data. The results obtained depicted a close match between results of the two or three trial tests with maximum differences in results of around 8%. This difference was considered to be small and is acceptable in geotechnical engineering applications (Moghaddas Tafreshi and Dawson, 2010a,b).

Table 3. Probability of exceeding 25 mm settlement in the field

Test Series	Type of reinforcement	Thickness of Geocell, H (cm)	Width of Geocell, b (cm)	No. of Tests	Purpose of the tests
1	Unreinforced	--------	--------	1+2*	To quantify the improvements due to reinforcements
2	Geocell Reinforced	2.5, 5, 7.5, 10	40	4+5*	To study the effect of the Geocell thickness, H

*the tests which were performed two or three times to verify the repeatability of the test data

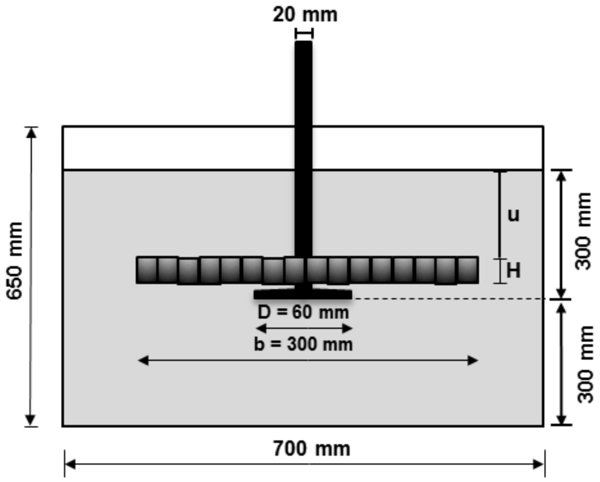

Figure 3. Geometry of the belled pile and Geocell reinforced foundation bed.

6 Result

Fig. 4 presents the uplift strength-upward displacement behaviour of the belled pile located at unreinforced and Geocell-reinforced beds for four thickness of the Geocell; H (H=2.5, 5, 7.5 and 10 cm). In the reinforced tests, the value of b/D was used around 5 (b=30 cm). From this figure, it may be clearly observed that, with increasing the mass of reinforcement (increase in the height of the Geocell reinforcement; H), both stiffness and uplift strength (uplift strength at a specific displacement) considerably increase. Also, it shows clear evidence of failure at around 15-18 mm of upward displacement of in all the graphs, irrespective of the Geocell mass. In the case of the unreinforced soil bed and low mass of Geocell (H=2.5 cm), it is apparent that the uplift capacity failure has taken place at an upward displacement equal to 15 mm. For these two tests, beyond a displacement of 15-18 mm there is a reduction in the slope of the strength-displacement curve. At this range of settlement, heave of the fill surface starts. It is attributable to that the soil-reinforcement composite material breaking locally in the region above and around the bell of pile, because of high deformation induced by the large upward displacement. This leads to a reduction in the load carrying capacity of the pile indicated by the softening in the slope of the strength-upward displacement responses (Fig. 4). For the moderately and heavily reinforced cases (H=5, 7.5 and 10 cm), beyond a displacement of about 20 mm the slope and uplift strength of curves remains almost constant while the upward displacement continuously increases.

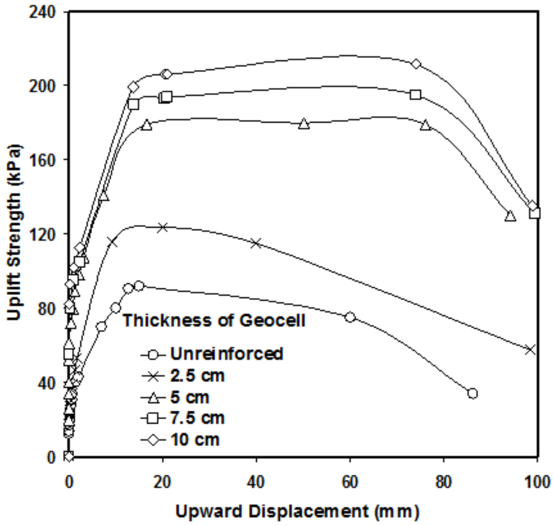

Figure 4. Variation of uplift strength with upward displacement of belled pile for the Geocell.

The variation of the uplift strength with thickness of Geocell (H) for different values of upward displacement of 4%, 8%, 12%, 16%, and 20% are shown in Fig. 5. Generally, from this figure, it is of interest to note that the uplift strength value increases with increase in upward displacement of pile, irrespective of the thickness of Geocell reinforcement (H). This indicates that the reinforcing efficacy increases with increase in upward displacement. This means that the internal confinement provided by the soil reinforcement increases with increase in the imposed upward displacement level on the reinforced system. Likewise, it can be seen that the values of uplift strength increase steadily with increase in the thickness of the Geocell (H/B). The reason is that more reinforcement considerably increases the stiffness of the reinforced sand bed compared to the unreinforced sand. The rate of enhancement in load carrying capacity of the belled pile can also be seen to reduce and can be anticipated that the improvement rates would be vanished with increase in the height of the Geocell (H).

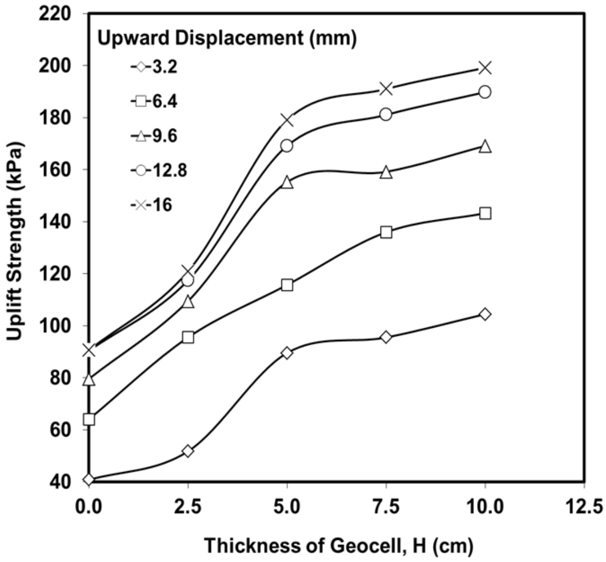

Figure 5. Variation of the uplift strength with thickness of Geocell (H) for different values of upward displacement of 4%, 8%, 12%, 16%, and 20%.

Fig. 6 shows the variation of the upward displacement with thickness of Geocell (H) for different values of uplift strength of 40, 80, 120, and 160 kPa. The missing values in Fig. 6 indicate that the failure occurred before the tensile resistance of 120 kPa (for unreinforced), and the tensile resistance of 160 kPa (for Geocell reinforcement with H=2.5 cm) were achieved. This figure indicates that the upward displacement decreases with increase in the thickness of Geocell reinforcement (H), irrespective of uplift strength. On the other hand, the reinforcing efficacy of Geocell in decreasing the upward displacement reduces with increase in the thickness of Geocell.

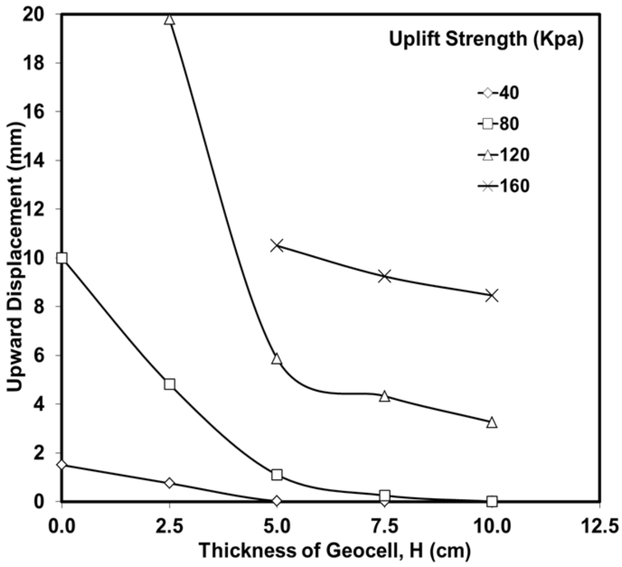

Figure 6. Variation of the upward displacement with thickness of Geocell (H) for different values of uplift strength.

7 Conclusion

In this research, laboratory model tests results were used to investigate the potential benefits of geocell reinforcement in increasing the uplift strength and in decreasing the upward displacement of a belled pile subjected to a monotonically tensile force. Based on the results obtained, the following conclusions can be extracted:

(1) Provision of the Geocell reinforcement in reinforcing the soil over the bell of pile significantly increases the uplift strength capacity and reduces the upward displacement of belled pile.

(2) Overall, when the thickness of Geocell reinforcement (H) increases, the uplift strength capacity of belled pile increases and the upward displacement of belled pile decreases.

(3) The rate of reduction in upward displacement and the rate of enhancement in the uplift load carrying capacity of the belled pile can also be seen to reduce with increase in the value of Geocell thickness.

(4) For the amounts of upward displacement that are tolerated in practical applications, improvements in uplift load capacity greater than 120% can be achieved with the application of Geocell reinforcement.

Although, the results presented herein provide encouragement for the application of Geocell-reinforcement to increase the performance of belled pile, the results of this study may be somewhat different to full-scale belled pile behaviour in the field while the general trend may be similar.

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