Repeated Load Response of Square Footings on Geocell Reinforced Soil: Comparing Use of Single and Multiple Layered Geocells

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SUMMARY:
Reinforced soil has been used successfully in a wide variety of geotechnical applications, some of which have been tested the boundaries of current understanding of the functioning of the geosynthetic–soil composite systems. However, the use of geocells for base reinforcement is hindered by the existing gap between applications and theories. This paper describes a series of different laboratory, pilot scale tests to evaluate the effect of geocell reinforcement on bearning capacity and settlement of footing under static and repeated loads. In general, the extra strength was observed due to geocell-reinforcement which is to be dependent on the number of the geocell layers and thickness of geocell used to reinforce the soil. The results show that the efficiency of reinforcement in reducing the footing settlement and in increasing the bearing capacity was increased by increasing the mass of reinforcement (more layers) in the soil. Also, the results indicate that, for the same mass of geocell material used in the reinforced soil bed, layered geocell reinforcement system behaves more effectively than those obtained for one layer of reinforcement to improve the behavior of footing (increasing bearing capacity and decreasing settlement of soil).

Keywords: Geocell reinforcement; Pilot scale test, Footing settlement, Bearing capacity

1. INTRODUCTION

Soils are periodically subjected to cyclic shear stresses in situ in many circumstances such as earthquakes, wind forces in high buildings, pile construction, traffic loads and machine vibrations. Foundations under repeated loads are, therefore, of interest where loads are dynamic in nature due to the action of earthquakes or moving parts of a machine installed on a foundation. These dynamic loads are applied repetitively over a very large number of loading cycles. The investigation and design of footings under dynamic loadings still remains a challenging task for the geotechnical engineer.

Both theoretical and experimental studies of the dynamic bearing capacity of shallow foundations have been reported by several researchers to understand the load–settlement relationship of footings and also the relationship between footing settlement and the number of load cycles (Cunny and Sloan, 1961; Raymond and Komos, 1978; Das and Shin, 1994). In recent decades, due to its economy, ease of construction and ability to improve the visual appearance, reinforced soil has been widely exploited in geotechnical engineering applications. In the case of reinforced footings under repeated loads, only a few relevant studies have been found and these concentrated on planar-reinforced applications (Das and Shin, 1994; Shin et al., 2002; Dash et al., 2004; Moghaddas Tafreshi & Khalaj, 2011; Sireesh et al., 2005; Moghaddas Tafreshi & Dawson, 2010). Indeed, the lack of understanding about this composite material can lead to undesired and unexpected in situ deformations and settlements, which can in turn cause damage to adjacent infrastructure. In this paper, an experimental study was conducted to study the behavior of Soil-Geocell under repeated loading to simulate the machine foundations loads. A series of tests on the single and double layers of geocell was performed to evaluate the role of different factors on the soil-geocell behavior such as number of geocell layers and intensity of load cycles.

2. TESTING EQUIPMENTS

The testing apparatus is consisted of three main parts include the loading system, the testing tank and the data acquisition system. The testing tank is a rigid steel box accommodates the soil, reinforcement and loading surface which is shown in Figure 1. The front face has been consisted of a plexy glass of 20 mm thickness to allow the visual observations of the soil-reinforcement system, as well as the photo scanning. According to the preliminary tests, the measured deflection of the side faces of the tank proved to be negligible and in the ranges to satisfy the rigidity of the system. Soil used in tests is prepared in zone A and zone B (Figure 1) to simulate the natural soil and the replaced soil-geocell, respectively.

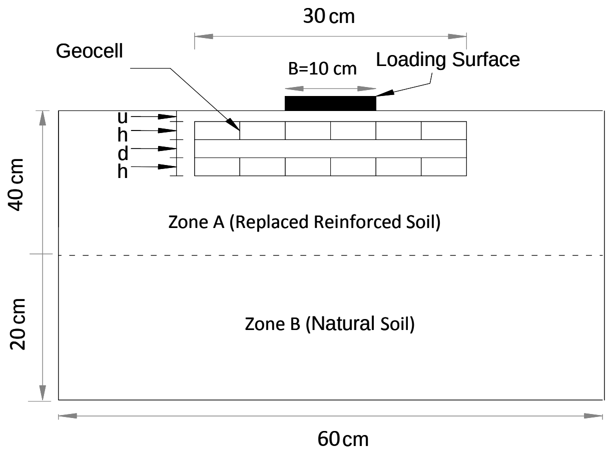

Figure 1. The schematic layout of the trench

To prepare the soil in both zones, the compaction method is used. According to table 1, the system was calibrated with different compaction energy to achieve desire relative density. The compaction energy produces by means of pneumatic cylinder, which applies constant pressure on a wooden stiff plate (600 mm * 600 mm). The wooden plate is fitted to the soil surface so all the energy will transfer to soil uniformly. A special data acquisition system was developed by which stress and settlement could be read and recorded automatically. The system was able to read the data from channels simultaneously. An S-shape load cell was also used and placed in the loading shaft to measure the pattern of the applied loads on the trench surface accurately. Two LVDTs were placed on the loading surface (a rigid steel plate of 100 mm length, 100 mm width and 20 mm thickness) to measure the settlement of soil surface during the repeated loads. Readers should refer to the paper of (Moghaddas Tafreshi and Khalaj, 2011) for more details of loading system and data acquisition system and also for the general view of testing equipment (Moghaddas Tafreshi and Khalaj, 2011).

Table 1. Compaction Calibration

Piston Force (kg)	1200	1200	1200	900	900	900	720	720	720
Number of impact	3	2	1	3	2	1	3	2	1
$\gamma_{d(\frac{gr}{cm^3})}$	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
Dr(%)	84	67	49	76	63	40	71	58	40

3. TESTING MATERIALS

The soil used in both Zone A and Zone B was a granular soil of grains size between 0.07 and 25 mm, D_{50}=1.65 mm, C_c=0.77, C_u=10.90 and G_s=2.60. This sand is classified as SP in unified soil classification system. The maximum and minimum porosities of this soil were obtained 0.91 and 0.65, respectively. The relative density of soil in zone A and B were selected 63% and 84%, respectively. Geocells used as reinforcement was made of a type of non-woven geotextile – an innovative approach for use in ground stabilization. When the geocell filled with soil or other mineral material, it provides an ideal surface for construction projects such as pavement, road, foundations, slopes, driveways and so on. The pocket size of the geocell kept constant of 50 mm). It was used at heights (h) of 25 and 50 mm in the testing program. Figure 2 shows an isometric view of the geocell used in the investigations. The engineering properties of this geotextile, as listed by the manufacture, are presented in Table 2.

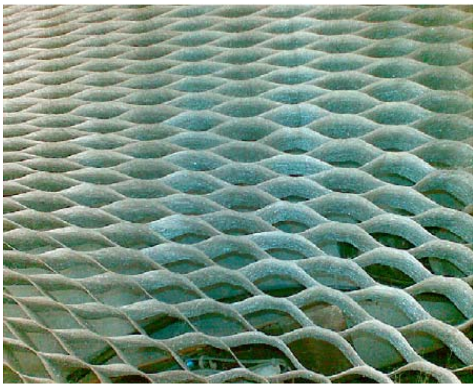

Figure 2. Isometric view of the geocell

Table 2. The engineering properties of the geotextile used in the tests.

Description	Value
Type of geotextile	Non-woven polymer
Type of polymer	100% polypropylene
Area weight (g/m2)	190
Thickness under 2 kN/m2 (mm)	0.57
Thickness under 200 kN/m2 (mm)	0.47
Tensile strength (kN/m)	13.1
Strength at 5% (kN/m)	5.7

4. PREPARATION OF MODEL TEST

Prior to start compaction in zone A, the soil in zone B was compacted with pneumatic system describe is section 2. The soil in zone A was compacted in layers of 25 mm in thickness. According to the test type, each geocell-reinforced layer were placed carefully and compacted separately. Soil mixture placed either between the two geocell layers or inside the pocket of geocell. The surface of the soil was then leveled and the steel plate of 100 mm length, 100 mm width and 20 mm thickness (as a model of loading surface) was centered in the testing tank. A load cell was placed in the loading shaft to record the applied loads and two LVDTs were placed on the footing model accurately to measure the settlement of soil surface during the repeated loads. In order to simulate the interlocking and friction of loading surface model and soil, the base of the model footing was made rough by cementing a thin layer of sand to it with epoxy glue. It should be noted that in all tests the first layer of reinforcement was placed at u/B=0.15.

5. TESTING PROGRAM

Twenty-nine tests in different series were planned and carried out in this research. According to table 3, the tests were scheduled to find out the effect of the embedded depth of the first geocell layer (u), the number of geocell layers (N) and performance of a composite material (geocell-soil) on the behaviour of foundation bed. All these variable parameters used to describe the tests are expressed in non-dimensional form with respect to loading surface width (B) as u/B and d/B. The value of b/B was kept constant 3.2 based on the recommendation of the other researchers (Moghaddas Tafreshi and Dawson, 2010). It should be noted that many of the tests 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 10%. This difference was considered to be small and is subsequently neglected. It demonstrates that the procedure and technique adopted can produce repeatable tests within the bounds that may be expected from geotechnical testing apparatuses.

Table 3. Tests Schedule

Test Series	Type of test	N	h/B	u/B	d/B	No. of Tests
1	Static	1	0.25	0.10, 0.15, 0.20	--	3+3*
2		2	0.25	0.15	0.15, 0.25, 0.35	3+3*
3		2	0.25 0.5	0.15	0.25	2+2*
4		0, 1, 2	0.25	0.15	--	3
5	Repeated	0, 1, 2	0.25	0.15	0.25	3+4*
6		1	0.5	0.15	0.25	1+2*

* Repeated tests

Figure 3 shows the typical time history of applied load on the soil surface. As can be seen, the soil surface is subjected to an incremental increasing repeated load having an minimum amplitude of 2 kg/cm2 and maximum amplitude of 9 kg/cm2. A trapezoidal load cycles with a frequency of 0.25 Hz would be continued until it reach 15 cycles or, alternatively, excessive settlement and unstable behavior is observed.

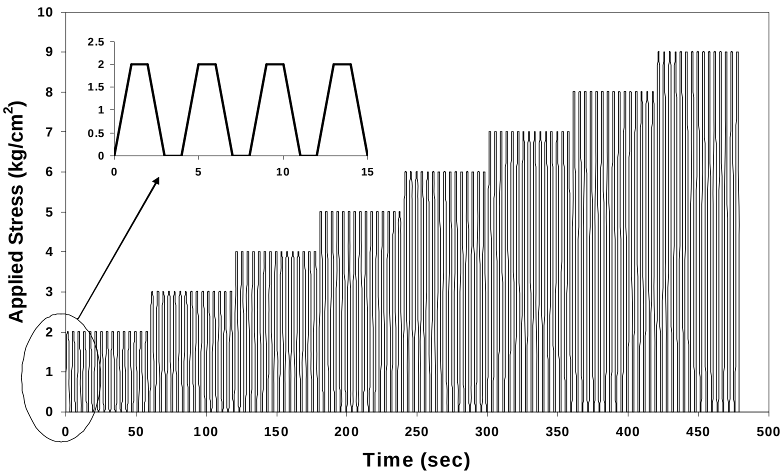

Figure 3. Typical history of repeated load on surface soil

6. RESULTS AND DISCUSSION

In this section, the tests results of the laboratory model are presented with a discussion highlighting the effects of the different parameters. The presentation of all the result figures would have made the paper lengthy, so only a selection to illustrate the observed trends is presented.

6.1. Static Tests

In order to obtain the optimum value of cover over the reinforcements (ratio u/B) and the optimum space between layers (ratio d/B), the increase in ratio of bearing capacity of reinforced to unreinforced soil due to reinforcement under static loading was selected as an assessment criterion. The performance improvement due to the provision of reinforcement is represented using a non-dimensional improvement factor, q_{rein}/q_{unrein}, which compares the bearing capacity of reinforced soil to that of the unreinforced at the same settlement (Figure 4 and 5). From these figures, it was clearly found that the optimum values of u/B and d/B is approximately around 0.15 and 0.25 respectively. So in all the other tests, the u/B and d/B ratio would be fixed 0.15 (u=15 mm) and 0.25 (25 mm), respectively. The variation of q_{rein}/q_{unrein} with settlement is shown in Figure 6 to evaluate the effect of geocell layers. From this figure, it is clear with increase the number of geocell layers the bearing capacity of foundation bed increases. Also the performance of two layers of geocell is better compared with one layer of geocell at the same mass of geocell reinforcement. The bearing capacity ratio for N=2 (h/B=0.25) is approximately twice the bearing capacity ratio with N=1 (h/B=0.5) while the mass of geocell is the same.

6.2. Repeated Load Tests

Figure 7 shows the trend of surface settlement with the time (or number of load cycles) under loading and unloading for all repeated load tests with different foundation beds. This figure shows that the rate of change of peak settlement and residual settlement reduces as the number of cycles increases, and that a small reduction in amplitude (i.e. the difference between these two settlements) is also apparent. Often, the variation of settlement becomes stable after number cycles. This stabilizing response indicates that the early process of reorientation of particles, causing local fill stiffening, ceases relative rapidly and the system then reaches the ‘‘plastic shakedown’’ condition defined by Werkmeister et al. (2005), in which subsequent deformation is fully recovered in each cycle. The hysteresis loop of footing settlement, shown in Figure 8, is derived from the same tests. It is clear that a steady response condition was achieved with the load-settlement path forming a closed hysteresis loop. The hysteresis curve also shows that there is an increase in the slope of the repeated pressure-settlement curve with an increase in the number of load–unload cycles. This corresponds to a reduction in the rate of change of peak settlement with number of load applications which, together, are indicative of a hardening of the reinforced system (Figures 8 and 9). Although the pattern of response just described is applicable to most of the test, in the cases of the unreinforced soil under repeated load (Figure 8), excessive settlement and consequently unstable behavior is observed. This behavior is attributable to rupture zones developing under the strong cyclic loads locally in the region under and around load surface. Figures 8-9 illustrate a great benefit of using geocell-reinforcement in reduction of settlement of foundation bed compared with unreinforced foundation bed. Also for both situations of soil mixture (inside or between geocell layers), the settlement of soil surface decreases. Also the performance of two layers of geocell is better compared with one layer of geocell at the same mass of geocell reinforcement. The settlement for N=1 (h/B=0.5) is approximately 30% more than the settlement with N=2 (h/B=0.25) while the mass of geocell is the same.

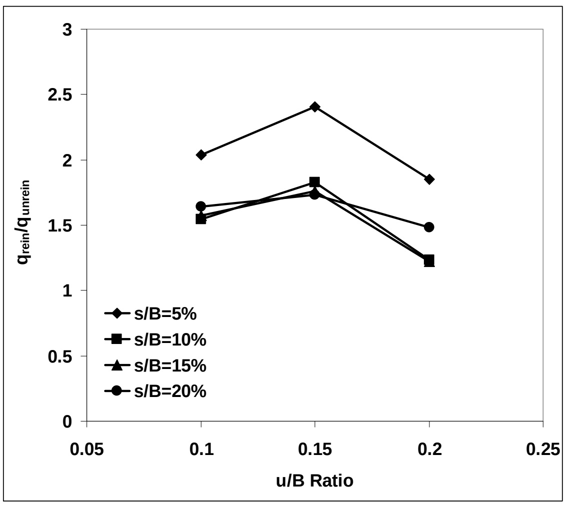

Figure 4. Variation of q_{rein}/q_{unrein} with u/B ratio at different settlement levels

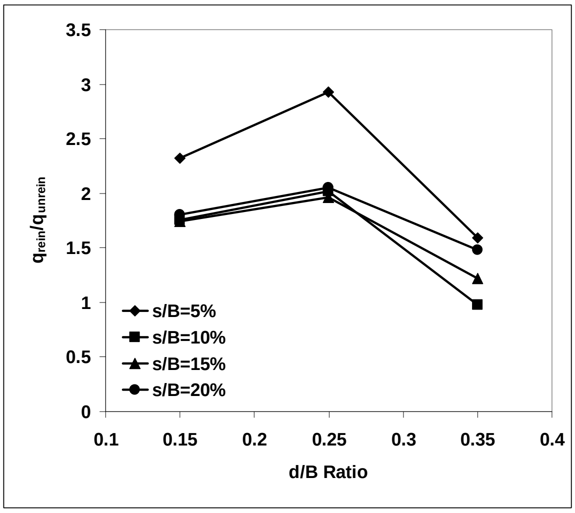

Figure 5. Variation of q_{rein}/q_{unrein} with d/B ratio at different settlement levels

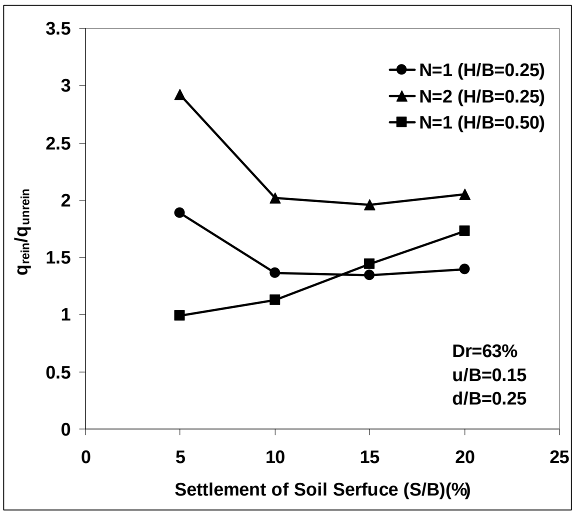

Figure 6. Variation of q_{rein}/q_{unrein} with S/B ratio at different geocell height (h/B = 0.25 and 0.5)

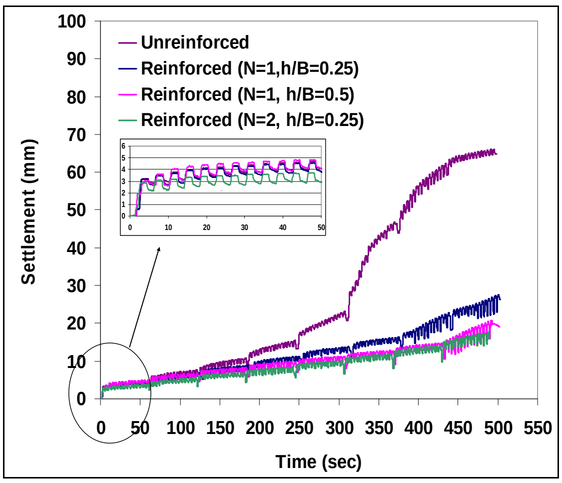

Figure 7. Variation of settlement with time

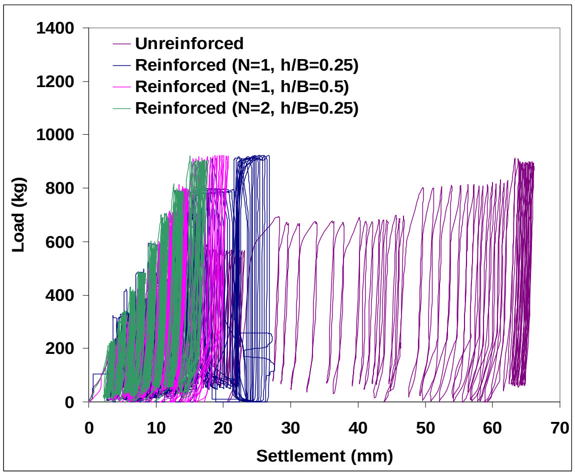

Figure 8. Hysteresis curve during repeated load

7. SUMMERY AND CONCLUSIONS

A series of laboratory test have been carried out on the model of shallow footing which is a representative of railway, road, and machine foundation resting on geocell reinforced soil. Geocell was used as reinforcement element. Two parameters were selected to identify their influence, bearing capacity and settlement of the whole system. It was found that the geocell-reinforcement increases the bearing capacity and decreases and the settlement of the foundation bed. From the static test results, it was clearly found that the optimum values of u/B and h/B is approximately around 0.15 and 0.25 respectively. Also the bearing capacity ratio of two layered reinforced soil (N=2, h/B=0.25) is approximately twice the bearing capacity ratio with of one layered reinforced soil (N=1, h/B=0.5) while the mass of geocell is the same. The repeated load test results show that the rate of change in peak settlement and residual settlement reduces as the number of cycles increases. Also as the number of geocell layers increase, the settlement of the foundation decreased. Furthermore, the performance of the geo-composite material increase when the number of reinforced layer increase in the same mass. For example, the settlement for N=1 (h/B=0.5) is approximately 30% more than the settlement with N=2 (h/B=0.25) while the mass of geocell is the same.

Qualitatively, this study has provided insight into the basic mechanism responsible for the behaviour of footings under repeated loads, such as earthquakes, traffic loads and machine vibrations, supported on geocell reinforced sand beds. In studies on large- and small-scale tests of the behaviour of granular layers with geogrid reinforcement, Adams and Collin (1997) and Milligan et al. (1986) showed that the general mechanisms and behaviour observed in the small model tests could be reproduced at large-scale. For these reasons, the general trends obtained here are expected to be similar at full-size. Nevertheless, it would be wise, in future tests, to assess larger scale model foundations at various conditions. For example, different footings (in size, shape and depth) and different characteristics (especially stiffness) and pocket sizes of the geocell should be studied to validate the present findings and to determine the existence of a scale effect, if any.

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