BEHAVIOR OF GEOCELL REINFORCED SAND FOUNDATION SYSTEMS UNDER CYCLIC LOADING

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ABSTRACT

Geocell is an efficient type of reinforcement in the soil improvement problems as a result of the lateral confinement it provides for the infill soil. However, its applicability is not well considered in practice due to the lack of a standard design method. In this research, in order to study the monotonic and cyclic behavior of geocell reinforced sand, a reduced scale physical model of foundation on the reinforced soil is developed and pressure-settlement performance of the foundation system is evaluated. Geocells with various heights are made using a woven geotextile which are located in the optimum position in the dense sand bed and the strip foundation model is then situated on the surface of the reinforced soil. The footing is then subjected to a pre-specified static load followed by 1000 cycles of repeated loads with the frequency of 0.5 Hz. The results show that cyclic loading leads to substantial plastic settlement in each cycle which have a decreasing trend by increase in the load cycle number. Depending on the type of reinforcement and the amplitude of the cyclic load there would be footing instability after some load cycles i.e. ratcheting happens or a stable condition in which development of plastic settlement will be ceased by exerting the cyclic load i.e. plastic shakedown occurs. It is concluded that the cellular geotextile improves the performance of the footing much more than the planar geotextile with the same amount of reinforcement. Increasing height of geocell will also result in more improvement factors in reducing the permanent plastic settlements and the amplitude of the cyclic loading and its difference with the ultimate static bearing capacity of the footing makes a significant contribution on the behaviour of the reinforced sand foundations.

INTRODUCTION

In recent years using geosynthetics as soil reinforcements is a very common technique for soil improvement. One of the most effective types of geosynthetics are geocells which have been used as soil reinforcement for embankments, foundations, retaining walls and slopes. Since geocell has a three-dimensional geometry, it provides a great lateral confinement for the infill material without dependence on the friction or interlocking with the infill soil. When they are used under the foundations or embankments, the bearing capacity of subgrade increases and footing settlements decreases much more than the case of using the planar types of reinforcements like geotextiles and geogrids as s result of confinement and distribution of pressure to a wider area in the underlying soil.

Many researchers have performed laboratory tests to study the improvement effect of geocell reinforcements under foundations (e.g. Sitharam and Sireesh, 2005; Dash et al., 2007; Moghaddas Tafreshi and Dawson, 2010; Dash, 2012; Leschinsky and Ling, 2013) . Bathurst and Jarret (1988) undertook a series of large scale static tests to investigate load-deformation behavior of geocomposite mattresses constructed over a compressible peat subgrade. They concluded that the reinforced gravel bases showed significant load capacity improvement at large rut depths in comparison with similar thicknesses of unreinforced gravel bases.

The results of large scale triaxial tests on samples of geocell reinforced sand have shown that the shear strength of the geocell encased sand increases because of the induction of apparent cohesion in the sand due to confinement. However, the internal friction of the infill sand remains constant (Bathurst and Karpurapu, 1993). Madhavi Latha et al. (2009) proposed a nonlinear empirical equation to determine the stiffness of the infill sand in terms of modulus of the geocell material and stiffness of the unreinforced sand. They proposed a design method based on the equivalent properties of the geocell reinforced composite.

Recently Avesani Nato et al. (2013) proposed an analytical approach to predict the bearing capacity of geocell reinforced soil by considering different mechanisms of geocell i.e. the stress dispersion effect, membrane effect and confinement effect. However, this analytical method has still a lot of limitations and its applicability has not been approved by the other researchers. On the other hand most of the experimental works by the researchers are performed using geocells made from geogrids or the commercial geowebs.

The investigation of the behavior of geocell reinforced sand foundation systems under cyclic loading is not well considered in the literature and only few reserachers have performed cyclic laboratory tests (e.g. Moghaddas Tafreshi and Dawson, 2012) which do not include many aspects of the cyclic response of the reinforced foundations. In this research series of experimental tests are conducted on a reduced scale physical model of a foundation on the geocell-reinforced sand. A woven geotextile is used to make geocell with different heights. The footing is subjected to a pre-specified static load followed by 1000 cycles of repeated loads with the frequency of 0.5 Hz and the performance of the geocell reinforced soil under cyclic loading is discussed.

LABORATORY MODEL

A physical model is developed to study the stress-settlement behavior of footings on reinforced sand. Main parts of the laboratory apparatus are:

● Footing model: A rectangular cube made of aluminum with B=50 mm in width and L=340 mm in length is used to represent a strip footing. The height of the footing model is also high enough so as to be considered a rigid footing. The bottom of the footing is made rough by means of sticking sand paper to represent the existing conditions in real foundations.

● Soil container: The length of the soil container is 800 mm (16B) to be sure that boundaries don't influence the results and failure wedges don't reach the side walls in the unreinforced and reinforced tests. The width of the container should be equal to the length of the footing in order to have the plane strain conditions. However, it is considered 342 mm to avoid any contact between the footing and side walls. The height of the container is 560 mm which is large enough (more than 10B) to eliminate the effect of bottom boundary on the result.

● Raining system: The sand sample in this research is prepared using the air-pluviation technique to have homogenous sand in the sample. The height and rate of raining are considered in a way that the desired relative density is acquired.

● Loading equipments: Loading is provided by a pneumatic cylinder attached to a compressed air tank. It is able to exert uniform loading with time in the pressure-controlled condition. The capacity of the loading system is sufficient to reach the ultimate bearing capacity of the foundation in all tests.

● Data acquisition: In the tests, loading and settlement of the footing are measured by a loadcell and a LVDT. They are connected to a data logger which is able to record the measurements of the instrumentations.

MATERIALS

A) SAND

The soil used in the experimental tests is a silica sand with rough and angular grains. Physical properties of the sand are presented in Table 1. Grain size analysis shows that all of the sand grains passes sieve number 8 and remain on sieve number 30. Therefore, sand used in this research is considered poorly-graded sand (SP) according to ASTM D 422 soil classification. All of the experimental tests in this research are conducted on sand with relative density of 72 % which is categorized as dense sand and corresponds to density equal to 16.1 kN/m^3.

Table 1. Physical properties of soil

Description	Value
Medium grain size, D_{50} (mm)	1.54
Specific gravity, G_s	2.67
Maximum void ratio, e_{max}	0.878
Minimum void ratio, e_{min}	0.575
Moisture content, ω (%)	0
Relative density, D_r (%)	72
Friction angle, φ (degrees)	38

B) REINFORCEMENT

In this research a geotexile is used in the cellular shape for reinforcing the sand. It is usually called geocell in practice. Table 2 shows the engineering properties of the geotextile used in the tests.

Table 2. The engineering properties of the reinforcement materials used in the tests

Description	Value
Type of cellular reinforcement	Woven Geotextile
Material	Polyester
Thickness, t (mm)	0.81
Ultimate Tensile Strength (kN/m)	21.8
Secant Modulus at 2% strain, J (kN/m)	275
Secant Modulus at 5% strain, J (kN/m)	72
Elongation at failure (%)	25.0

To produce a cellular geotextile, the strips of the geotextiles are stitched in the place of joints with care so that it is garaunteed not to have any damage in the joints for loads less than the ultimate tensile strength of the geotextile material. The photo of this hand-made geocell is presented in Figure 4. As it can be seen, the pockets are in diamond shape with diameters equal to d. The height of geocell is designated by h and the width of geocell is named b. It should be noted that the length of the geocell reinforcement is considered approximately equal to the width of soil tank for the sake of plane strain conditions.

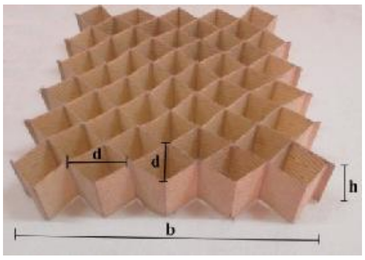

Figure 1. Photographic view of geocell reinforcement

TEST PROCEDURE

In all of the experimental tests footing width is considered equal to B=50 mm and the distance between bottom of footing and top of reinforcement is u=5 mm (u/B= 0.1). This value is shown to be the optimum value of u/B for the geocell reinforced soil (Moghaddas Tafreshi and Dawson, 2010). The schematic conditions of the tests as well as the designations used in this study are presented in Figure 2.

The tests are typically performed by using geocell with h/B=0.5, d/B=1 and b/B=1 and the sand density for both the subgrade and the geocell infill soil is considered dense. For the tests with purpose of investigating the effect of geocell height, other geocell heights (h/B=0.25 and h/B=1) are also considered in the test schedule. Moreover, to compare the behaviour of cellular geotextile and planar geotextile, a test with two layers of geotextile completely equivalent to the geocell with h/B=1 (in terms of the value of the reinforcement) is performed. They are located in the distance of 0.35B from the bottom of the footing and their vertical distance is also 0.35B. These values are reported to be the optimum values for the best performance of the geotextile (Moghaddas Tafreshi and Dawson, 2010). The footing is loaded monotonically to a pre-defined static pressure of q_{stat}=50 kPa (the pressure increment is 1 kPa/s) and then cyclic load with the amplitude of q_{cyc}=75 kPa are applied for at least 1000 cycles of loading and unloading with the frequency of 0.5 Hz.

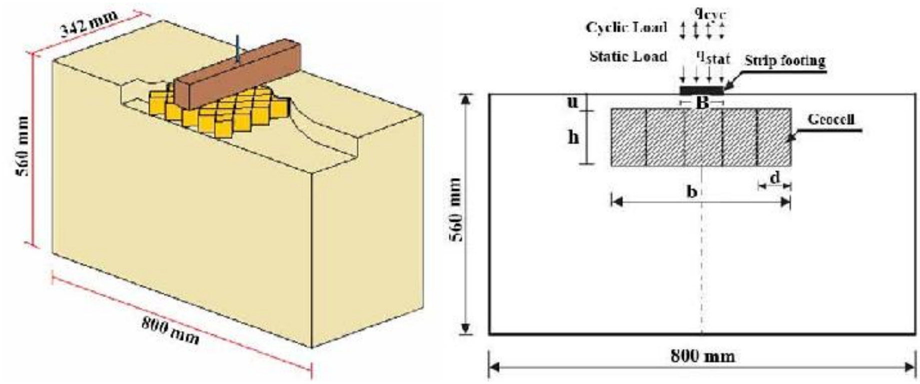

Figure 2. Geometry of the geocell reinforced foundation bed

RESULTS AND DISCUSSION

Figure 3 and Figure 4 show the pressure-settlement behaviour of the unreinforced soil, soil reinforced with planar geotextile and geocells with different heights. It is obvious that geocell performs much better in terms of both bearing capacity and settlement under static loading and the geocell with more height improves the static bahavior substantially.

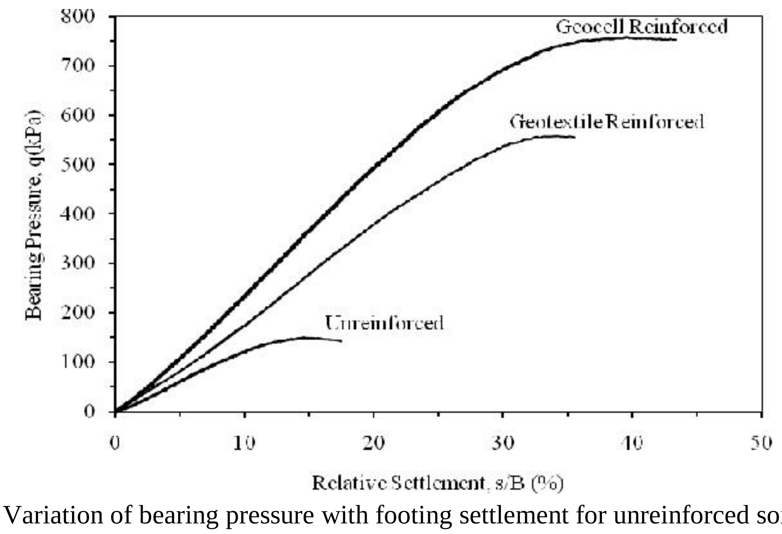

Figure 3. Variation of bearing pressure with footing settlement for unreinforced soil and soil reinforced with planar and cellular geotextile

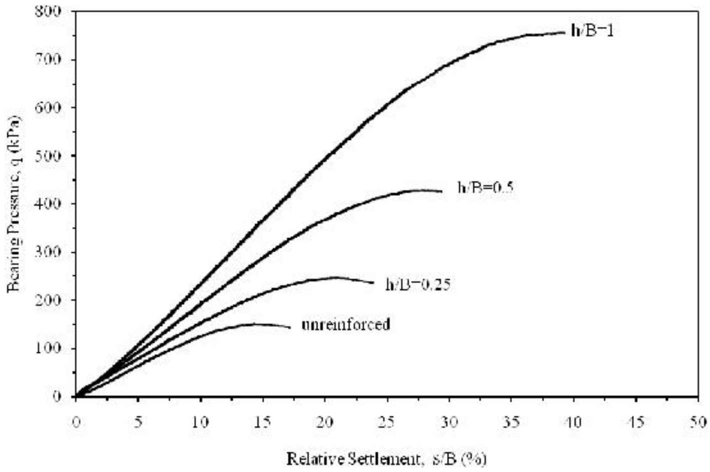

Figure 4. Variation of bearing pressure with footing settlement for geocells of different heights

Figure 5 shows the variation of bearing pressure and footing settlement with time in the reinforced sand test with static stress of 50 kPa (one third of the ultimate bearing capacity of the unreinforced sand) and cyclic stress of 75 kPa (half of the ultimate bearing capacity of the unreinforced sand). The loading frequency is considered f=0.5 Hz. The height of the geocell used in this test is h/B=0.5 (h=25 mm). It should be noted that only some of the primary cycles are shown in Figure 6. According to Figure 6 in the first cycle of loading a large settlement occurs which just a small portion of that settlement is resilient and most of the settlement in this cycle is plastic and irrecoverable. During the other loading cycles the incremental plastic settlement tends to decrease. This can also be seen in Figure 7 which shows the hysteresis pressure-settlement curve.

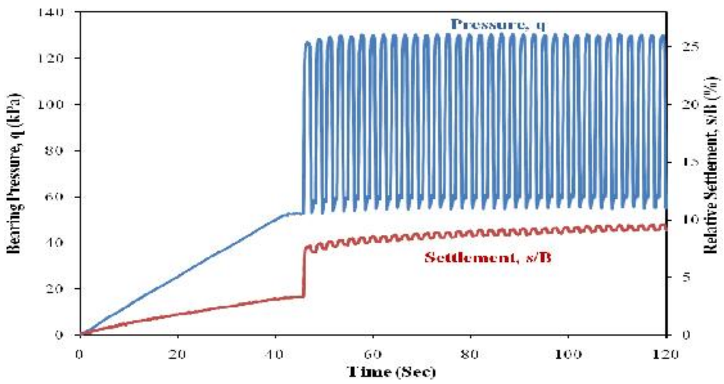

Figure 5. Variation of bearing pressure and footing settlement with time

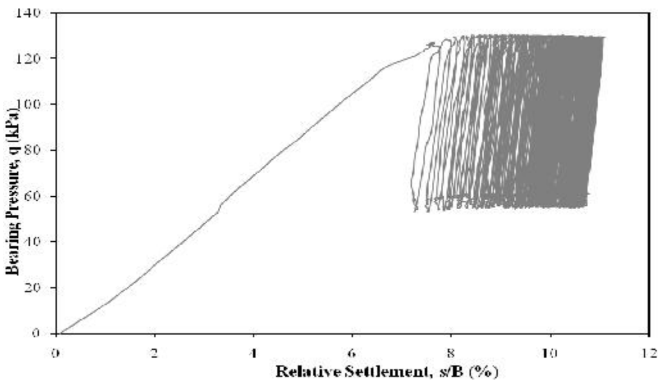

Figure 6. Hysteresis curve of bearing pressure vs. footing settlement under cyclic loading

Figure 7 demonstrates the variation of plastic settlement with increasing load cycles. In the case of the unreinforced soil, after about 120 cycles the accumulated plastic settlements will be so great that it leads to an unstable condition called ratcheting. However, for the reinforced cases the trend of increasing the plastic settlement is much less than the unreinforced soil and it seems that they tend to reach a stable condition after some more cycles. This condition is called plastic shakedown in which there would not be any plastic settlement with continuation of the loading and unloading cycles.

Figure 7 also shows that the efficiency of the cellular reinforcement in decreasing plastic settlement is higher than the planar reinforcement. It can be attributed to lateral confinement developed in cellular reinforcement due to its three dimensional structure while in the planar reinforcement, the reinforcing action depends only on the frictional resistance between the reinforcement and the surrounding soil.

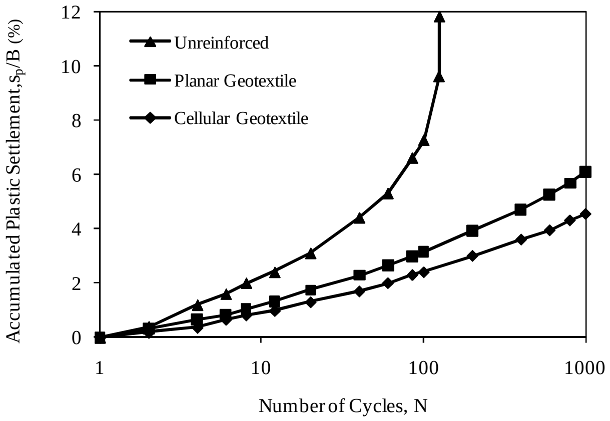

Figure 7. Variation of cyclic plastic settlement with load cycles

Figure 8 shows the variation of plastic settlements with load cycles for different heights of geocell. It is completely evident that the geocell with higher height is able to improve the performance of sand foundation better. It is due to higher amounts of confinement and hoop stresses which is developed in geocells with more height ratio. Figure 9 also shows this behavior improvement in different load cycle numbers.

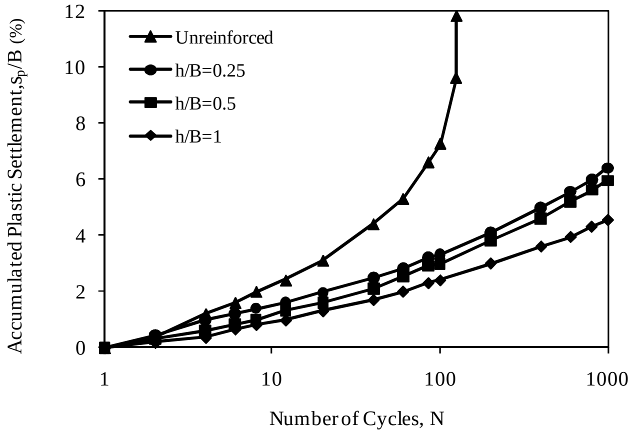

Figure 8. Variation of cyclic plastic settlement with load cycles for geocells with different heights

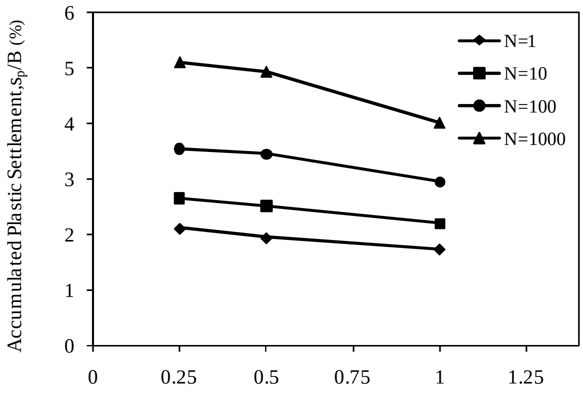

Figure 9. Variation of cyclic plastic settlement with geocell height

Figure 10 shows the variation of plastic settlements with load cycles for the cases of different cyclic load amplitude when the soil is reinforced by geocell with h/B=0.5. It shows that by increasing the cyclic load amplitude the plastic settlements increases. Figure 11 also shows that the variation of plastic settlement and cyclic load amplitude can be considered almost linear. However, the slope of this line inceases dramatically with the load cycle number.

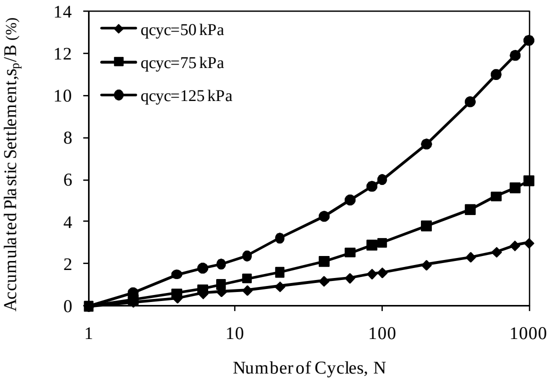

Figure 10. Variation of cyclic plastic settlement with load cycles for different cyclic load amplitude

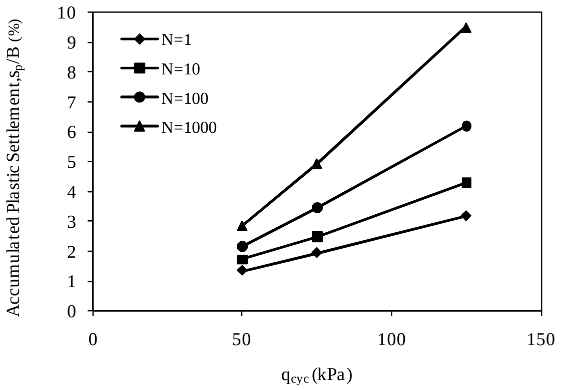

Figure 11. Variation of cyclic plastic settlement with level of cyclic load amplitude

CONCLUSIONS

In this research, laboratory model tests are used to investigate the potential benefits of reinforcing sand foundation with geocell. Cyclic loads are applied to the strip footing which was added to a pre-defined static load. The results of this study include:

1) The rate of footing settlement decreases significantly as the number of loading cycles increases and depending on the amplitude of the cyclic load and the reinforcement, there would be footing instability after some load cycles i.e. ratcheting happens or a stable condition in which development of plastic settlement will be ceased by exerting the cyclic load i.e. plastic shakedown occurs.
2) For a given amplitude of the cyclic load, geocell improves the performance much better than the planar geotextile.
3) If the height of the geocell increases, the amount of accumulated permanent settlements decreases.
4) By increasing the amplitude of the cyclic load, the permanent plastic settlement of the footing increases substantially. Its influence is highly dependent on the level of total static and cyclic load and the difference with the static bearing capacity.

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