Behavior of Geocell-Reinforced Granular Bases under Static and Repeated Loads

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ABSTRACT

Geosynthetics have been used for base reinforcement since 1970s. Numerous research has already been carried out for planar geosynthetic reinforcement but limited research has been conducted for three-dimensional geocell reinforcement. Literature review has also demonstrated a significant gap between the applications and theories of geocell reinforcement outlining the need for more research. This study was to investigate the behavior of reinforced bases using a single geocell under static and repeated loads on a loading plate. The experimental results show that the single geocell could increase the stiffness by approximately 50% and the maximum load by 100% as compared with those of the unreinforced base. The repeated test shows that the geocell-reinforced base had the percentage of elastic deformation increase with the number of cycles of the repeated load up to 95%.

INTRODUCTION

Geosynthetics have been used for subgrade improvement and base reinforcement since 1970s (Webster, 1979). Tingle and Jersey (2007) categorically pointed out the problems associated with maintaining low-volume unpaved roads with minimal funding and identified geosynthetic reinforcement as a possible means to deal with this condition. Use of geosynthetics as soil reinforcement has been reported to increase the overall stiffness and bearing capacity of the geosynthetic-soil composite. Geosynthetics are also found helpful in reducing settlement and rutting depth. For a given design condition, these improvements lead to a reduced amount of aggregate material and/or extending of the service life. Planar reinforcement, such as geogrid and geotextile, has been widely used in unpaved roads with established design methods (for example, Giroud and Noiray, 1981; Giroud and Han, 2004). Geogrid interacts with the granular base to mainly provide confinement in two dimensions and the geotextile mainly provides separation between base course and subgrade. Geocell, due to its three-dimensional configuration, is ideal for soil confinement. The idea of geocell was first introduced by the United States Army Corps of Engineers to provide lateral confinement to beach sand during 1970s (Webster, 1979). Different materials of geocell have been used in the field and/or research, such as metallic, polymeric, and paper cells. However, the commercial geocells currently available are composed of polymeric materials (most commonly high-density polyethylene (HDPE)). The polymeric cells are welded together to produce an interconnected honeycomb type of structure that provides lateral confinement, a tensioned membrane effect, and stress distribution to a wider area (Zhou and Wen, 2008). The majority of the research so far has focused on planar reinforcement for subgrade improvement and base reinforcement. Yuu et al. (2008) identified a significant gap between the applications and the theories for geocell reinforcement outlining the need for further research.

To understand the behavior of geocell-reinforced bases under static and repeated loads, plate load tests were carried out on reinforced granular bases using a single geocell and compared with an unreinforced base. This paper discusses the results of these plate load tests. A novel polymeric alloy type of geocell and poorly-graded Kansas River sand as the base material were used for these tests.

REINFORCEMENT MECHANISMS

For roadway applications, geotextiles have been mostly used for separation, drainage, and filtration and woven geotextiles are sometimes used for reinforcement as a tensioned membrane. Geogrids and geocells have been mostly used for reinforcement by providing confinement to base courses and subgrade. Lateral confinement, increased bearing capacity, and the tensioned membrane effect have been identified as the major geosynthetic reinforcement mechanisms (Giroud and Han, 2004). Geogrids provide lateral confinement through the interlocking between geogrid apertures and aggregates. Giroud and Han (2004) developed a design method for geogrid-reinforced unpaved roads considering the interlocking effect by the geogrid in-plane stiffness, the increased bearing capacity, the stress distribution, the relative stiffness of base to subgrade, the subgrade strength properties, and other traffic related factors.

In geocell-reinforced bases, three-dimensional geocells can effectively provide lateral confinement to infill materials. In addition, the friction between the infill material and the geocell wall and the action of the geocell-reinforced base as a mattress to restrain the subgrade soil from moving upward outside the loaded area provide the vertical confinement to the infill material and the subgrade. Therefore, the stiffness of geocell is important for the lateral and vertical confinement.

Mhaiskar and Mandal (1996) indicated that at a given height and a width to height ratio, the elastic modulus of the geocell was more important than the seam strength. Tests on single geocell-reinforced bases showed an increase in the resilient modulus: 16.5 to 17.9% for cohesive soils and 1.4 to 3.2% for granular soils (Mengelt et al., 2006).

Bathurst and Jarrett (1989) reported a stiffer geocell for a given mattress thickness and a designed rut depth could increase load bearing capacity by a factor of two. Shimizu and Inui (1990) found that the geocell could increase bearing capacity and the extent of increase correlated to the horizontal stiffness of the cell material. Inclusion of geocell in the granular bases could increase both the bearing capacity and the elastic modulus of the base by providing confinement to the infill material (Han et al., 2008). Pokharel et al. (2009) found that the behavior of geocell-reinforced sand depended on the initial shape and the elastic modulus of the geocell. Geocell reinforcement has also been reported to provide good improvement on resistance to repeated loads (Rea and Mitchell, 1978). Chang et al. (2008) found the dynamic modulus of subgrade reaction increased after 100 cycles of loading in a geocell-reinforced sandy soil.

PROPERTIES OF BASE AND GEOCELL MATERIALS USED IN THE TESTS

Kansas River sand was used as the granular base for the tests. Kansas River sand is poorly-graded and has a minimum void ratio of 0.354, a maximum void ratio of 0.583, and a specific gravity of 2.65 at 20°C. The mean grain size (d_{50}) of this sand was 2.6 mm.

The geocell used for the tests was made of novel polymeric alloy, which is characterized by flexibility at low temperatures similar to HDPE and elastic behavior similar to engineering thermoplastic. The geocells had tensile strengths 23.27 N/mm. The elastic modulus of the geocell at 2% strain was 620 MPa. The 2% strain was chosen because the measured strains in geosynthetics in the field were typically within this range. The geocell used in this study had two perforations of 100 mm^2 each on both pallets. The height and thickness of the geocell were 100mm and 1.1 mm, respectively. A single geocell was laid out in a near circular shape with a diameter of 205 mm. The selection of this shape was based on the earlier study by the authors (Pokharel et al., 2009). The stress-strain curve of this geocell is shown in FIG. 1.

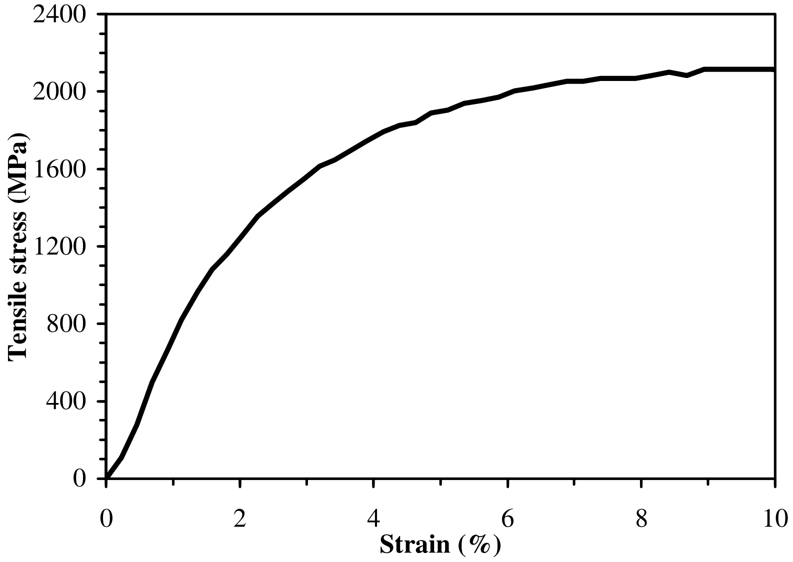

FIG. 1 Tensile strength of geocell

TEST PROCEDURE

Plate load tests were conducted in a loading apparatus designed and fabricated at Department of Civil, Environmental, and Architectural Engineering at the University of Kansas. The loading system had a 150 mm diameter air cylinder with a maximum air pressure of 2100 kPa and a 150 mm diameter loading plate. The test box was 605 mm by 605 mm square in plan. Tests were conducted to verify that single geocell within this box would not have any boundary effect. Single geocells with a height of 100mm were used for both static and repeated load tests. The geocell was placed in the center of the box at a near circular shape and infilled and embedded in the sand compacted to 70% relative density. Compaction was done in three layers, 50 mm each for the first two layers and 20mm for the top layer. For comparison purposes, unreinforced sand was also prepared in a similar way and tested under static loading until failure. For the geocell reinforced sand, both static and repeated loading tests were conducted. The static test was conducted by increasing the load until the geocell-reinforced sand failed. The repeated load test was only conducted on the reinforced sand at an applied pressure of 345 kPa (corresponding to approximately 70% of the pressure at failure under the static loading). Due to the low ultimate bearing capacity of the unreinforced sand, a repeated load test at the same pressure was impossible. The repeated load was applied at 1 cycle/minute for 150 cycles.

RESULTS AND DISCUSSIONS

Figure 2 presents the pressure-displacement curves of the unreinforced sand under static loading and the geocell-reinforced sand under static and repeated loading. It is shown that the unreinforced sand under static loading failed at 230 kPa while the single geocell-reinforced sand under static loading failed at 480 kPa. Therefore, the maximum load was increased by approximately 100% from the unreinforced to reinforced sand under static loading. The stiffness of the unreinforced and reinforced sands can be determined based on the slopes of the linear portions of the pressure-displacement curves. As shown in FIG. 2, the stiffness of the reinforced sand is approximately 1.5 times that of the unreinforced sand.

For the repeated loading, approximately 70% (345 kPa) of the failure load was applied on the geocell-reinforced sand. The first loading up to a load of 345 kPa was applied in the same manner as that in the static loading to verify the repeatability of the test results. The comparison clearly shows a reasonable repeatability.

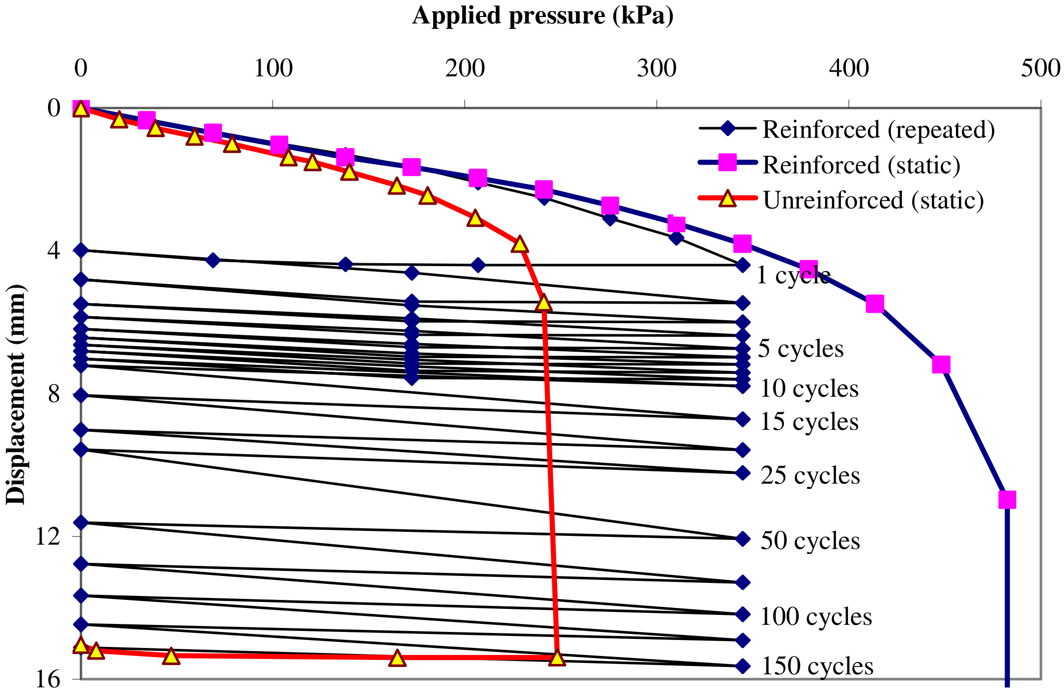

FIG. 2 Pressure-displacement curves under static and repeated loading

From the repeated loading test, the cumulative displacements at the applied pressures of 0 and 345kPa were measured and presented in FIG. 3. The cumulative displacement at 0kPa is the permanent deformation (also called plastic deformation). In the roadway applications, the permanent deformation is often reflected as a rut depth by a loaded wheel. The difference of the displacements at 0 and 345kPa is the elastic deformation, which is also plotted in FIG. 3. In other words, the total displacement is equal to the plastic deformation plus the elastic deformation. The percent of elastic deformation was calculated by dividing the elastic displacement to the total displacement induced by each load cycle. FIGURE 4 shows that the percent of elastic deformation increased with the number of the load cycle. It is shown that the initial loading had a low percent of elastic deformation, in other words, it had a high percent of plastic deformation. However, the percent of elastic deformation increased rapidly with the loading cycle and became relatively stable (80% or more) after 10 cycles. The elastic deformation after 150 cycles was 95.2% of the total deformation. The high percent of elastic deformation is beneficial to the service life of the road. FIGURE 4 also shows that it took approximately 150 cycles to reach a displacement (15mm), which corresponds to 10% the diameter of the loading plate. However, the same displacement was reached in one cycle for the unreinforced sand at 67% magnitude of the repeated load.

The above results and discussion have demonstrated the clear benefits of geocell reinforcement in terms of increased stiffness, increased bearing capacity, and reduced plastic deformation. It is expected that the geocell-reinforced sand can perform much better than the unreinforced base under traffic loading.

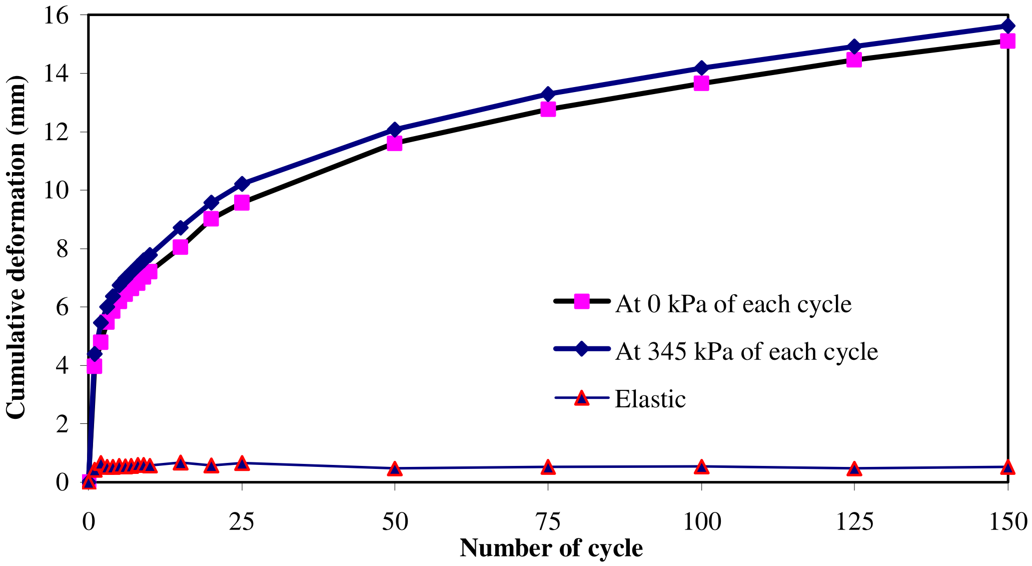

FIG. 3 Cumulative total and elastic deformation under repeated loading

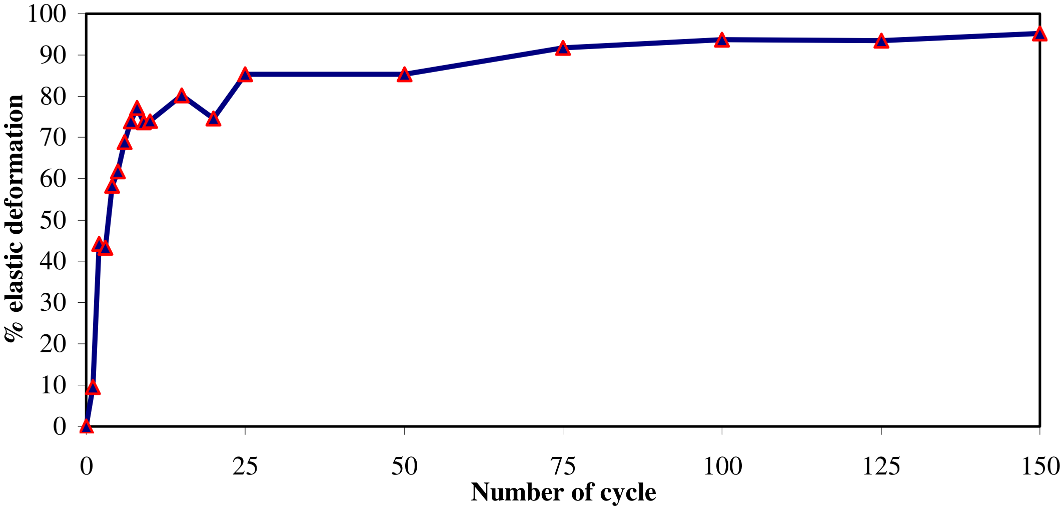

FIG. 4 Percent of elastic deformation under repeated loading

CONCLUSIONS

This paper presents the results of experimental work conducted to investigate the behavior of geocell-reinforced sand under static and repeated loading. Both static and repeated plate loading tests data were obtained. A single geocell was embedded in the base material to provide the confinement. Following conclusions can be drawn for this study:

1) Single geocell reinforcement improved the stiffness of the reinforced sand by a factor of 1.5 compared to the unreinforced sand.
2) Single geocell reinforcement increased the maximum load by two times from that of the unreinforced sand.
3) Single geocell reinforcement reduced plastic deformation and increased percent of elastic deformation under repeated loading. It only took 10 cycles to reach 80% or more of elastic deformation. The elastic deformation reached above 95% of the total deformation at the end of 150 loading cycles. This favorable behavior can be credited to the contribution of geocell.

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