Effect of infill material on the performance of geocell-reinforced bases

Han, J., Pokharel, S.K., and Parsons, R.L.
Civil, Environmental, and Architectural Engineering Department, the University of Kansas, Lawrence, KS66044, USA
Leshchinsky, D.
Department of Civil and Environmental Engineering, the University of Delaware, Newark, DE1971, USA
Halahmi, I.
PRS Mediterranean Ltd., Europe-Israel Tower, 2 Weizmann St., Tel-Aviv 64239, Israel

Keywords: geocell, geosynthetic reinforcement, base course, plate load test

ABSTRACT: Geocell, due to its three-dimensional structure, can effectively provide lateral confinement to infill material to increase the stiffness and bearing capacity of base courses and to reduce their permanent deformations under repeated loading. However, limited studies have so far been done to investigate the effect of infill material on the performance of geocell-reinforced bases. In this study, three different infill materials, poorly-graded Kansas River sand, quarry waste (QW), and well-graded AB-3 aggregate, were used. The performance of different infill materials in terms of bearing capacity, stiffness, permanent deformation, and percentage elastic deformation of the geocell-reinforced bases was studied in the experiment study. The test results show that the benefit of the geocell in the bearing capacity and stiffness of the reinforced base under static loading was more evident when a weaker infill material was used. However, the benefit of stronger infill materials became more evident under repeated loading. Under the same magnitude of repeated loading, permanent deformations of reinforced bases were significantly reduced and the percent of elastic deformations were significantly increased for all infill materials as compared with those of unreinforced bases.

1 INTRODUCTION

Insufficient structural strength of the pavement is one of the major causes of pavement failure. Weak subgrade bearing capacity and inefficient load transfer from the base course to the subgrade further aggravate this situation. Tingle and Jersey (2007) reported that the low-volume road managers use their limited resources for repair, maintenance, and rehabilitation. Development of sustainable pavement stabilization techniques has therefore become a challenge against the time for pavement designers. Reinforcement of base courses with geosynthetic material that can improve the overall structural strength and stiffness and reduce the overall cost has been looked upon as a suitable choice in this context. Since its inception almost 40 years ago geosynthetic reinforcement has greatly helped to improve the performance of both paved and unpaved roads and become one of the established techniques for base course reinforcement (Giroud & Han 2004).

Cellular soil reinforcement for poorly graded sand was used by the United States Army Corps of Engineers in 1970s (Webster 1979a). Evolution of geocells follows the sand grids made up of paper, metallic, and polymeric geocells in the chronological order. The metallic geocells had better strength but were costly and difficult to handle so, the polymeric geocells eventually emerged as a suitable alternative. High-density polyethylene (HDPE) is the most common polymer used to make polymeric geocells.

Geocells are factory-made 3-dimensional forms of geosynthetic materials with interconnected cells, which are filled with soil to form a reinforced mass. They have been successfully used worldwide to reinforce soft foundations for structures, road bases, slopes, and walls. Confinement to limit lateral displacement, formation of stiff mattress for wider load distribution, and contribution of tensile strength to soils are key benefits of geocells.

There is a significant gap between the applications and the theories of application of geocell reinforcement (Yuu et al. 2008) which outlines the need to develop a reliable design method. Recently conducted studies on single geocell-reinforced granular base courses suggest that geocell reinforcement increase the bearing capacity and stiffness of the soil-geosynthetic composite, and reduce the permanent deformation under static and repeated loading (Pokharel et. al. 2009a, b, and c). Under repeated loading, geocell-reinforced granular bases reduced the plastic deformation and increased the percentage of elastic deformation (Pokharel et al. 2009b).

This paper discusses the results of plate load tests conducted to evaluate the effect of granular infill material on single geocell-reinforced bases using sand, quarry waste (QW), and AB-3 aggregate. Laboratory tests were conducted to study the influence of geocell reinforcement on the bearing capacity, stiffness, and permanent deformation.

2 MATERIALS

The stress-strain curve of the Novel polymeric alloy (Neoloy) geocells used in this study is shown in Figure 1. Neoloy geocells characterized by flexibility at low temperatures similar to HDPE and elastic behavior similar to engineering thermoplastic were used for this research. The ultimate tensile strength of the geocell strips was 23.27 N/mm and the elastic modulus of the geocell strips at 2% strain was 620 MPa. The height of the geocell was 100 mm and the thickness was 1.1 mm.

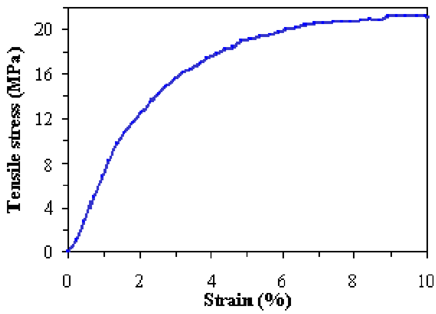

Figure 1. Tensile stress-strain curve of geocell

In the present study, three different base materials, Kansas River sand, quarry waste (QW), and AB-3 aggregate base material were used as infill material. Kansas River sand is locally available sand in Lawrence area in Kansas, USA. QW is the waste material produced during aggregate production in quarries. The QW and AB-3 used in the tests were brought from a local quarry site in Kansas. The grain size distribution curves of these infill materials are shown in Figure 2.

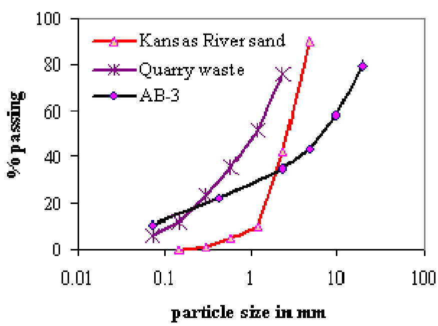

Figure 2. Particle size distributions of infill materials

Kansas River sand is a poorly graded subrounded river sand having a mean particle size (d_{50}) = 2.6 mm, minimum void ratio = 0.354, maximum void ratio = 0.583, specific gravity = 2.65 at 20°C, coefficient of curvature, C_c = 0.98, coefficient of uniformity, C_u = 2.73, friction angle = 41^0, minimum density γ_{min} =16.4 kN/m^3, and maximum density γ_{max} = 19.5 kN/m^3. QW used for the tests had a mean particle size (d_{50}) = 1.2 mm, liquid limit = 20, plastic limit = 12, specific gravity = 2.76 at 20°C, optimum moisture content = 9%, coefficient of curvature (C_c) = 0.77, coefficient of uniformity (C_u) = 12, California bearing ratio (CBR) = 57% at 7% moisture content and 38% at the optimum moisture content. AB-3 used for the tests is a well graded base material widely used in pavement applications in Kansas having a mean particle size (d_{50}) = 7.0 mm, liquid limit = 20, plastic limit = 13, specific gravity = 2.69 at 20°C, optimum moisture content = 10%, California bearing ratio (CBR) = 75% at 7.1% moisture content and 46% at the optimum moisture content.

3 TEST SETUP

Plate load tests were conducted in a medium-scale loading apparatus designed and fabricated at the geotechnical laboratory at the Department of Civil, Environmental, and Architectural Engineering at the University of Kansas. The loading system had a 15.2 cm loading plate and the square test box had a plan area of 60.5 x 60.5 cm^2. The reinforced section was 12 cm thick (including the 2 cm cover) over a firm bottom. The infill materials were compacted in three layers; the bottom two layers of 5 cm each and the cover of 2 cm. The sand was compacted to 70% relative density while the QW and AB-3 were compacted to 95% maximum dry density on the dry side. The repeated load tests were conducted on the reinforced Kansas River sand section at 345 kPa pressure and 550 kPa for the reinforced and unreinforced WQ and AB-3. The loading rate was 1 cycle/minute for 150 cycles. Selection of the loading magnitude was based on the typical tire pressures for highway trucks and construction equipment ranging from 345 kPa to 550 kPa. As reinforcement a single geocell was laid out in a near circular shape with a diameter of 20.5 cm. The selection of this shape was based on the earlier study conducted by the authors (Pokharel et al. 2009a).

4 RESULTS AND DISCUSSIONS

Figure 3 presents the pressure-deformation curves of the unreinforced Kansas River sand and the geocell-reinforced sand under repeated loading. It is shown that the unreinforced sand section failed at 230 kPa while the single geocell-reinforced sand under repeated loading of 345 kPa needed 150 cycles to reach the same level of deformation. The stiffness of the unreinforced and reinforced sands at the first loading cycle can be determined based on the slopes of the linear portions of the pressure-displacement curves. As shown in Figure 3, the stiffness of the reinforced sand is approximately 1.5 times that of the unreinforced sand.

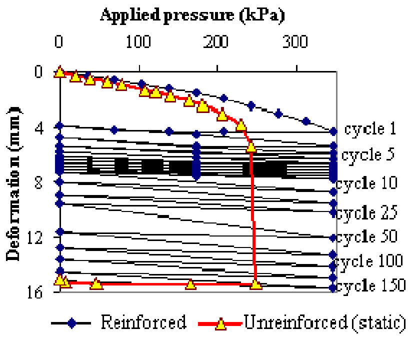

Figure 3. Deformations of Bases with Kansas River sand

Figures 4 and 5 present the cumulative deformations of reinforced and unreinforced QW and AB-3 bases, respectively under repeated loading. The curves show the cumulative deformations at each cycle for the maximum load (552 kPa) and the minimum load (0 kPa). The difference in these two values gives the elastic deformation at each cycle. Figures 4 and 5 clearly indicate the benefits of the single geocell reinforcement in terms of permanent deformation. The permanent deformations for the bases with the inclusion of a single geocell are found to be reduced by a factor of 1.50 for the QW base and 1.33 for the AB-3 base, respectively.

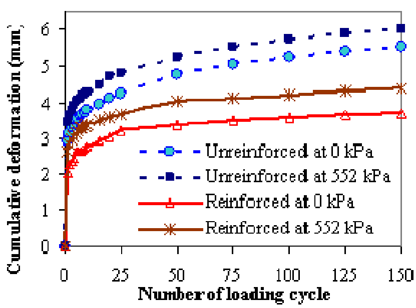

Figure 4. Deformations of Bases with QW

Figure 6 presents the elastic deformation as a percentage of total deformation for all three materials; reinforced sand and both reinforced and unreinforced QW and AB-3. The percent of elastic deformation was calculated by dividing the elastic deformation to the total deformation induced by each load cycle. The cumulative deformation at 0 kPa is the permanent deformation or the plastic deformation. In pavement design, the permanent deformation is referred to as the rut depth induced by a loaded wheel.

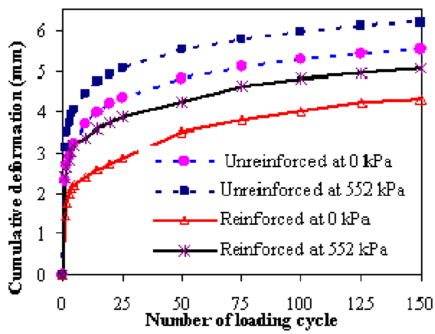

Figure 5. Deformations of Bases with AB-3

Figure 6 shows that the percent of elastic deformation for all the infill materials increased with the number of the loading cycle. At the initial loading cycles the plastic deformation was more pronounced, however, at around 10 cycles, the percent of elastic deformation increased rapidly with the loading cycle and became relatively stable. For the single geocell-reinforced Kansas River sand it was more than 80% elastic deformation after 10 cycles and more than 95% elastic deformation in case of QW and AB-3 at the same cycles. The percent of elastic deformation after 150 cycles was 95.2% of the total deformation for reinforced sand and more than 99% for the reinforced QW and the reinforced AB-3. The high percent of elastic deformation is desirable for longer service life of the pavement section. In case of unreinforced QW and AB-3, the percent of elastic deformation after 10 cycles was 90% and at the end of 150 cycles was more than 95% and 99%, respectively.

The results and discussion so far have demonstrated the clear benefits of geocell reinforcement in terms of reduced permanent deformation, increased stiffness and bearing capacity, and increased percent of elastic deformation. Therefore, the geocell-reinforced base irrespective of the granular infill material can be expected to perform much better than the unreinforced base under wheel loading.

The results further reinforce the previous laboratory and numerical studies under static loading that geocells can significantly increase bearing capacity and reduce settlements (Han et al. 2007). The results of this study establish the desirable benefits of geocell reinforcement under repeated loading as well.

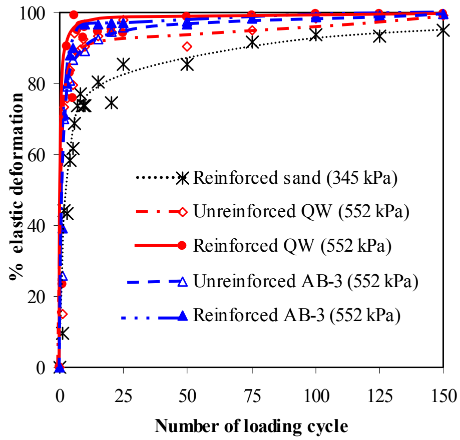

Figure 6. Percent of elastic deformation

5 CONCLUSION

This paper presents the results of the experiment conducted to investigate the effect of infill material on the performance of geocell-reinforced granular bases. The reinforced and unreinforced base courses with different infill materials were tested under repeated loading. Following conclusions can be drawn from this experimental study.

- Geocell reinforcement significantly reduced the permanent deformation after 150 cycles of loading irrespective of whether the infill material was weak or strong.
- In case of Kansas River sand the permanent deformation of the reinforced section after 150 loading cycle at 345 kPa was equal to the permanent deformation of the unreinforced section at the first cycle of 230 kPa loading.
- In case of QW the permanent deformation after 150 loading cycles on the unreinforced section was 1.50 times that on the reinforced section. This factor in case of AB-3 was 1.33.
- Single geocell reinforcement reduced the plastic deformation in all the cases but the percent of elastic deformation was higher in case of stronger infill materials (QW and AB-3) compared to the weaker material (sand). The improvement compared to the unreinforced case was more evident at the initial loading cycles.
- In case of geocell-reinforced sand 80% of the total deformation was elastic after just 10 cycles and it reached above 95% after 150 loading cycles. In case of geocell-reinforced QW and AB-3 the elastic deformation after 10 cycles was above 95% and reached more than 99% after150 cycles. This favorable behavior can be credited to the contribution of geocell.

This study was conducted on one type of geocell. The performance of other types of geocell may be different and should be investigated accordingly.

ACKNOWLEDGEMENTS

This research was funded jointly by the University of Kansas, Transportation Research Institute from Grant #DT0S59-06-G-00047, provided by the US Department of Transportation – Research and Innovative Technology Administration and PRS Mediterranean, Inc. in Israel. This support is greatly appreciated.

REFERENCES

Giroud, J.P. and Han, J. 2004. Design Method for Geogrid-Reinforced Unpaved Roads. I. Development of Design Method. *ASCE Journal of Geotechnical and Geoenvironmental Engineering*, Vol.130(8), pp. 775-786.

Han, J., Yang, X.M., Leshchinsky, D., Parsons, R.L., and Rosen, A. 2007. Evaluation of geocell-reinforced bases. *TRB 87th Annual Meeting* January 13–17, 2008, Washington, D.C.

Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., & Halahmi, I. 2009a. Experimental evaluation of influence factors for single geocell-reinforced sand. *TRB 88th Annual Meeting, January 11 to 15*, Washington, DC.

Pokharel, S.K., Han, J., Leshchinsky, D., Parsons, R.L., & Halahmi, I. 2009b. Behavior of geocell-reinforced granular bases under static and repeated loads. *International Foundation Congress & Equipment Expo 2009*, March 15-19, 2009, Orlando, Florida.

Pokharel, S.K., Han, J., Parsons, R.L., Qian, Y., Leshchinsky, D., & Halahmi, I. 2009c. Experimental Study on Bearing Capacity of Geocell-Reinforced Bases. *8th international conference on Bearing Capacity of Roads, Railways and Airfields*, June 29 - July 2, 2009, Champaign, Illinois.

Tingle, J.S. and Jersey, S. R. 2007. Empirical Design Methods for Geosynthetic-Reinforced Low-Volume Roads, *Journal of the Transportation Research Board*. No. 1989, 2, 91-101.

Webster, S.L. 1979. Investigation of Beach Sand Trafficability Enhancement Using Sand-Grid Confinement and Membrane Reinforcement Concepts, *Report GL-79-20 (1). U.S. Army Engineer Waterways Experiment Station*, Vicksburg, MS.

Yuu, J., Han, J., Rosen, A., Parsons, R.L. and Leshchinsky, D. 2008. Technical Review of Geocell-Reinforced Base Courses over Weak Subgrade. *GeoAmericas, Cancun, Mexico*. March 2 - 5, 2008.