Experimental Study on Bearing Capacity of Geocell-Reinforced Bases

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ABSTRACT: Geocell, a three-dimensional interconnected geosynthetic made of polymer, has been used to improve base course properties by providing soil confinement to increase its stiffness and to reduce its permanent surface deformation. Research conducted in the past on geocell-reinforced base courses has shown apparent benefits over unreinforced ones. However, the use of geocell reinforcement for base courses on soft subgrade is limited due to lack of established design methods. In this study, laboratory tests were conducted to investigate the behavior of geocell-reinforced bases under static and repeated loading. Two base course materials, Kansas River sand and quarry waste, were used as infill materials. This study investigated the bearing capacity and stiffness improvement provided by geocell reinforcement and the effect of infill materials. This study also evaluated the permanent deformation and the percentage of elastic deformation of geocell-reinforced Kansas River sand and quarry waste compared with unreinforced bases. The test results show that the single geocell reinforcement can increase the bearing capacity, stiffness, and percent of elastic deformation for each cycle and reduce the permanent deformation.

1 INTRODUCTION

AASHTO (American Association of State Highway and Transportation Officials) reports approximately one-fifth of pavement failures occur due to insufficient structural strength. Inadequate bearing capacity of underlying weak subgrade and inefficient load transfer from the base course are two of the main reasons for pavement failures. This fact has led to research efforts to improve the state of pavement design practice and to develop sustainable pavement stabilization techniques. One of the options in this regard is the use of a suitable reinforcement to improve the overall structural strength and stiffness and to reduce the associated costs at the same time. During the last 40 years 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). Geosynthetic reinforcement has been reported to increase bearing capacity and reduce settlement, resulting in extended service life of pavements. Geogrids and geotextiles are commonly used as planar reinforcements at the subgrade-base interface or within the base course to increase the performance. Geocell, a three-dimensional interconnected honeycomb type of polymeric cells, is used within the base course. The majority of the research in the past has focused on planar reinforcements and developed design methods for these products (Giroud & Noiray 1981, Giroud and Han 2004, and Leng & Gabr 2006). For geocell reinforcement a significant gap between the applications and the theories has been identified outlining the need for further research to develop a reliable design method (Yuu et al. 2008).

The United States Army Corps of Engineers used the idea of cellular soil reinforcement for providing lateral confinement to improve the bearing capacity of poorly graded sand in 1970s (Webster 1979a). Earlier geocells, known as sand grids, were made up of paper soaked in phenolic water resistant resin. Metallic geocells, especially aluminum, were later chosen for better strength but they were costly and difficult to handle. The polymeric geocells currently in use eventually emerged as a suitable alternative. High-density polyethylene (HDPE) is the most common polymer used to make geocell. Pokharel et al. (2009a) reported an improved geocell product made of novel polymeric alloys. Geocell comes in varying shape, size, aspect ratio, height, and thickness.

This paper discusses the results of plate load tests conducted to evaluate the bearing capacity improvement for single geocell-reinforced sand and quarry waste. Laboratory tests for this research were carried out using a poorly-graded Kansas River sand and a quarry waste as the granular infill materials. A set of laboratory tests were conducted to study the influence of geocell reinforcement on the bearing capacity and stiffness as compared with unreinforced bases.

2 PAST STUDIES ON GEOCELL REINFORCEMENT

While geotextiles are mostly used for separation, drainage, and filtration, geogrids and geocells are mostly used for reinforcement by providing confinement. Lateral confinement, increased bearing capacity, and the tensioned membrane effect are the major geosynthetic reinforcement mechanisms (Giroud & Han 2004). Three-dimensional geocells can effectively provide lateral confinement to infill materials. In addition, the friction between the infill material and the geocell walls combine with the action of the reinforced base as a mattress to restrain the subgrade soil from moving upward outside the loaded area and provide the vertical confinement to the infill material and the subgrade. These mechanisms highlight the importance of geocell stiffness for the lateral and vertical confinement.

Tests on single geocell-reinforced bases have shown an increase in the resilient modulus from 16.5 to 17.9% for cohesive soils and 1.4 to 3.2% for granular soils (Mengelt et al. 2006). For a given mattress thickness and rut depth, geocell reinforcement has been reported to increase the bearing capacity by twofold (Bathurst & Jarrett 1989). Shimizu & Inui (1990) also reported increased bearing capacity by geocell reinforcement and the extent of the 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. (2009a) found that the behavior of geocell-reinforced sand depends on the initial shape and the elastic modulus and the embedment condition of the geocell. Geocell reinforcement has also been reported to provide good improvement in resistance to repeated loads (Rea & Mitchell 1978). Chang et al. (2008) found the dynamic modulus of subgrade reaction to increase after 100 cycles of loading in a geocell-reinforced sandy soil. Studies carried out by Pokharel et al. (2009b) on single geocell reinforcement found a stiffness improvement factor of 1.5 and bearing capacity improvement factor of 2.0 over the unreinforced case. Under repeated loading, geocell-reinforced granular base was found to reduce the plastic deformation and increase the percentage of elastic deformation to 95% of the total deformation at the end of 150 loading cycles (Pokharel et al. 2009b).

3 PROPERTIES OF BASE AND GEOCELL MATERIALS USED IN THE TESTS

In the present study, novel polymeric alloy geocells were used to reinforce two different base materials, Kansas River sand and quarry waste. The properties of the materials used for the tests are summarized below.

Kansas River sand used as the granular base for the tests is a poorly graded sub-rounded river sand with a mean particle size (d_{50}) of 2.6 mm. The other properties of this sand are: minimum void ratio = 0.354, maximum void ratio = 0.583, specific gravity = 2.65 at 20^{o}C, coefficient of curvature, C_c = 0.98, coefficient of uniformity, C_u = 2.73, friction angle = 41^{0}, γ_{min} =16.4 kN/m^3, and γ_{max} = 19.5 kN/m^3. The grain size distribution of this sand is presented in Figure 1.

The quarry waste used in the tests was brought from a local quarry site in Kansas. Quarry waste is a waste material produced during the production of aggregates and has not been well utilized. Geocell may provide a "green" solution to recycle quarry waste for roadway construction. The quarry waste used as the granular base for the tests has a mean particle size (d_{50}) of 1.2 mm. The other properties are: liquid limit = 20, plastic limit = 12, specific gravity = 2.76, 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. The grain size distribution curve for this material is shown in Figure 1 and the compaction curve is shown in Figure 2.

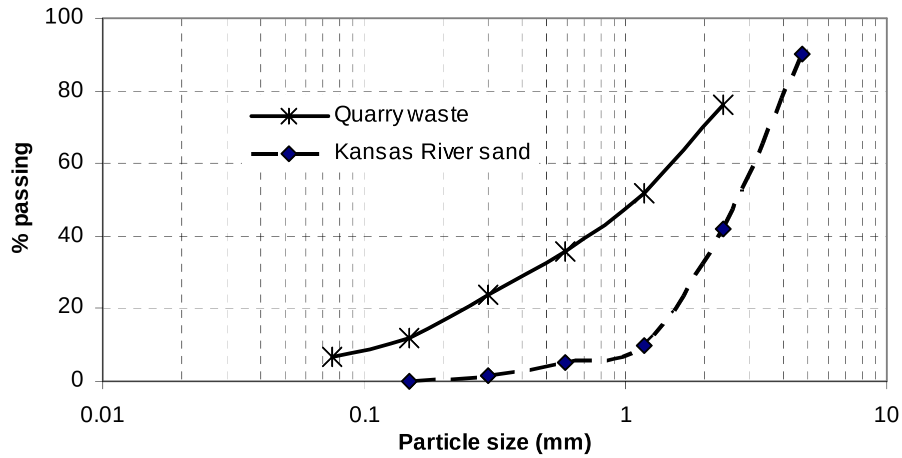

Figure 1. Grain size distribution curve of Kansas River sand (Han et al. 2008) and quarry waste

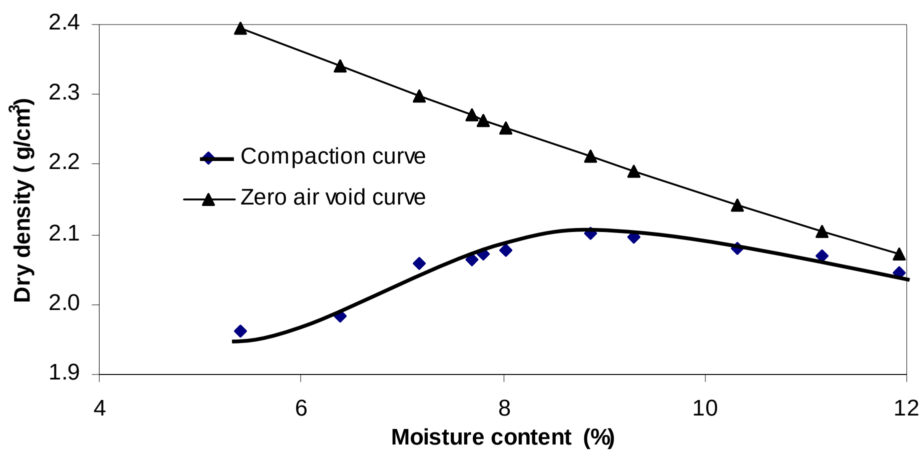

Figure 2. Compaction curve of quarry waste

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 geocell had a tensile strengths of 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 perforations were located at a distance of 16 cm center to center. The height of the geocell was 100 mm and the thickness of the geocell wall was 1.1 mm. 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. 2009a). The stress-strain curve of this geocell is shown in Figure 3.

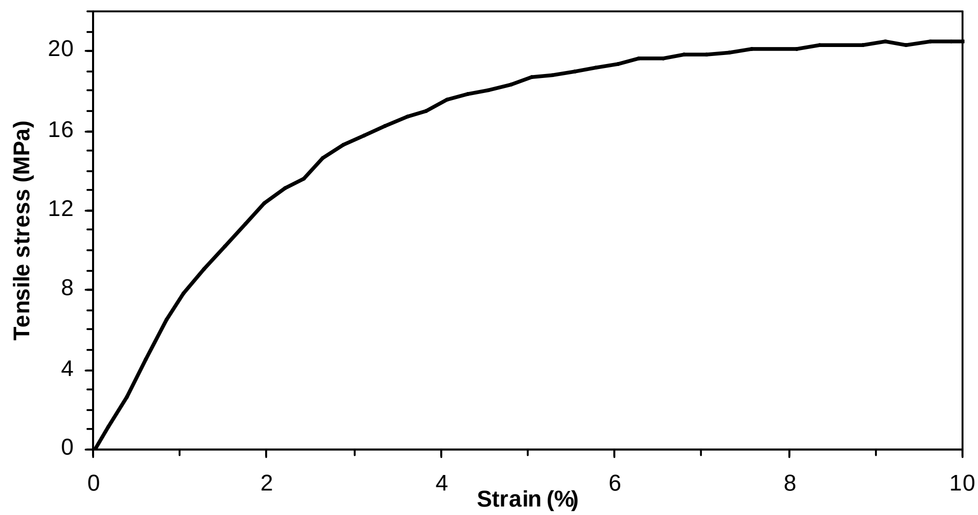

Figure 3. Tensile strength of geocell

4 TEST SETUP

Laboratory 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 has a 15.2 cm diameter air cylinder with a maximum air pressure of 2,100 kPa. The steel loading plate has the same diameter as the air cylinder. The details of the test setup are shown in Figure 4. The test box is square and has a plan area of 60.5 x 60.5 cm^2 with an adjustable depth. The geocell was placed at the center of the box and filled and embedded in the base material. The Kansas River sand was placed and compacted to 70% relative density in three layers, 5.0 cm thick for each of the first two layers and the top layer of 2.0 cm. For the quarry waste, 95% compaction was achieved at the optimum moisture content. For comparison purposes, unreinforced sand and quarry waste samples were prepared in a similar way and tested under static loading. For both base materials, static and repeated loading tests were conducted. The static tests were conducted on both reinforced and unreinforced sections by increasing the load in increment of 35 kPa. The repeated load tests were conducted only on the reinforced sections at an applied pressure of 345 kPa (corresponding to approximately 70% of the pressure at failure under the static loading) for the sand and 550 kPa for the quarry waste. The repeated load was applied at 1 cycle/minute for 150 cycles. The loading was selected based on the typical tire pressures for highway trucks and construction equipment ranging from 345 kPa to 550 kPa. Quarry waste can be used as the surface layer in an unpaved road so the loading 550 kPa was used. However, the Kansas River sand could only withstand a static load of approximately 500 kPa; therefore, a cyclic load of 345 kPa was chosen.

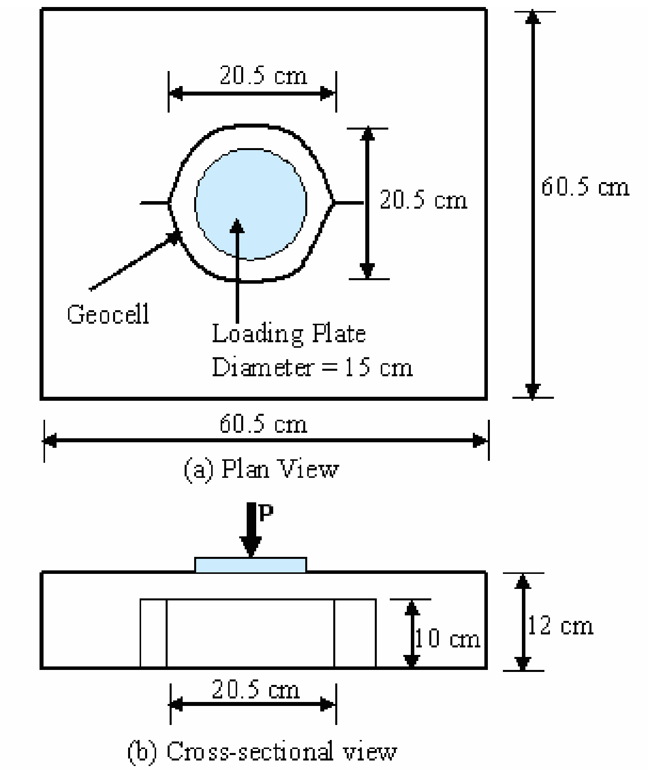

Figure 4. Test setup

5 RESULTS AND DISCUSSIONS

Benefits of geocell reinforcements on the Kansas River sand and the quarry waste were investigated in this study. The details on the geocell-reinforced Kansas River sand are also discussed in Pokharel et al. (2009a, b). For comparison purposes, the main results of the geocell-reinforced Kansas River sand are presented here as well along with those for the geocell-reinforced quarry waste.

To study the effectiveness of single geocell reinforcement in two types of base materials, one specific type of geocell made from novel polymeric alloy was used in this study.

As shown in Figure 5, under static loading the improvement factors for the geocell-reinforced Kansas River sand over the unreinforced base are 1.75 in terms of ultimate bearing capacity and 1.5 in terms of stiffness. The improvement factor of the stiffness is defined as the ratio of the slope of the initial portion of the load-displacement curve for the reinforced base to that for the unreinforced base. Improvement was also observed for the geocell-reinforced quarry waste; however, the degree of improvement was not as significant as that for the geocell-reinforced Kansas River sand. Since the quarry waste has a significant fines content, it has apparent cohesion after compaction. However, one of the contributions of geocell is to provide apparent cohesion to granular material; therefore, the cohesion existing in the base material minimizes the benefit of the geocell for lateral confinement under static loading. However, the loss of the moisture in the base would minimize the apparent cohesion and it is expected that the benefit of the geocell would become more significant at such a condition. Due to the limited capacity of the load frame, the tests for the quarry waste were carried out to the maximum static pressure of 900 kPa only. The improvement provided by the geocell is expected to be more evident at failure pressure.

For roadway applications, the behavior of the base under repeated loading is more important than that under static loading. The results of the geocell-reinforced Kansas River sand under repeated loading are presented in the paper by Pokharel et al. (2009b). Similar test results for unreinforced and geocell-reinforced quarry waste are presented in Figure 6. The displacement at a load of 0kPa is the permanent deformation of the base course. The difference in the displacements between 0 and 552kPa is the elastic deformation. Figure 6 shows that the single geocell reduced the permanent deformation of the quarry waste base by a factor of approximately 1.5 compared to the unreinforced section.

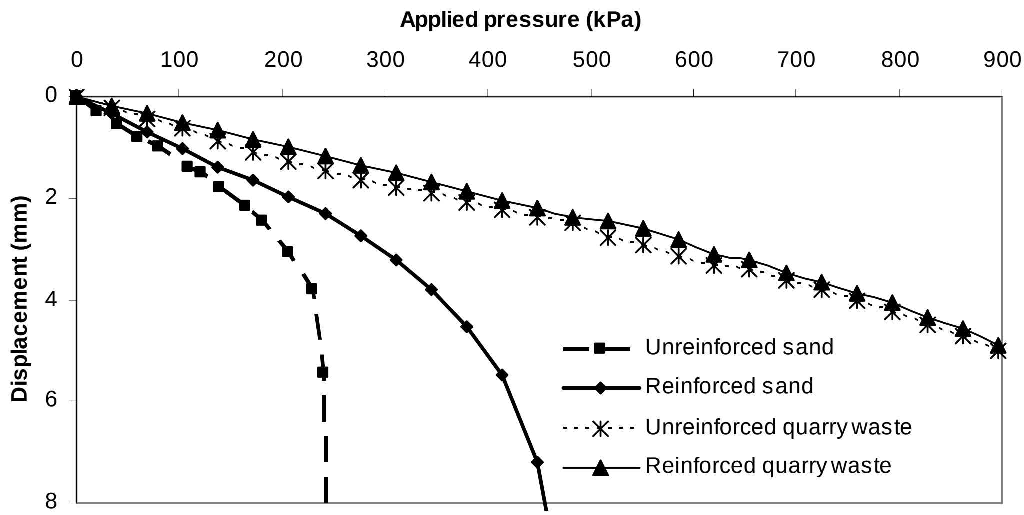

Figure 5. Pressure-displacement curves for unreinforced and geocell-reinforced bases under static loading

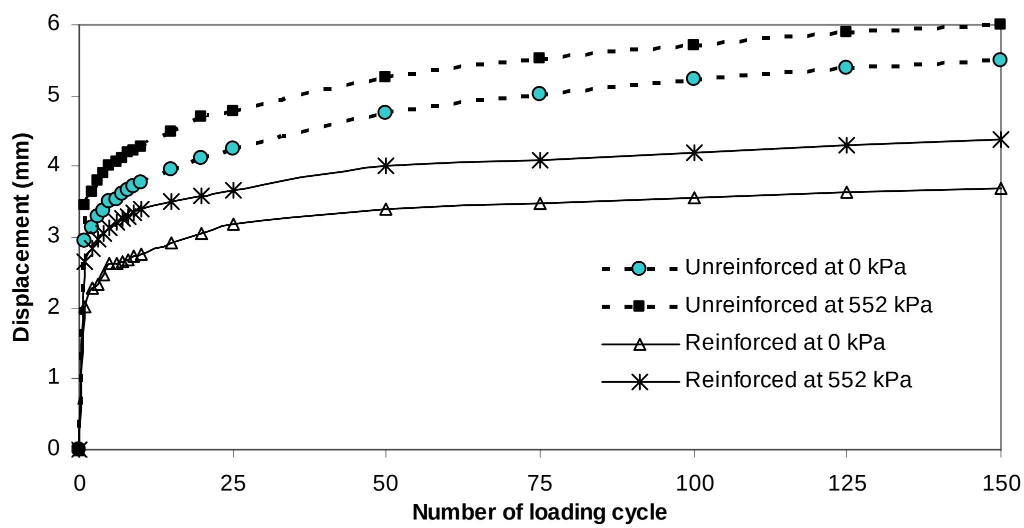

Figure 6. Displacement versus number of loading cycles for quarry waste base under repeated loading

For comparison purposes, the percentage of elastic deformation of the geocell-reinforced Kansas River sand and quarry waste and the unreinforced quarry waste sections are shown in Figure 7. The percentage of elastic deformation is defined as the percentage of the elastic deformation to the total deformation at each cycle. Figure 7 shows that for the Kansas River sand, it took 10 cycles to reach 80% or more of elastic deformation and the elastic deformation exceeded 95% of the total deformation for each cycle at the end of 150 loading cycles. For the unreinforced quarry waste section, it took 10 cycles to reach 90% elastic deformation and it reached 99% of the total deformation at the end of 150 cycles. For the reinforced quarry waste section, however, it took less than 10 cycles to reach 90% or more elastic deformation and the percent of elastic deformation almost reached 100% of the total deformation for each cycle at 50 loading cycles. Figure 7 does not include a curve for unreinforced Kansas River sand because it failed before reaching the maximum pressure (345 kPa) in the first loading cycle. This comparison shows that the Kansas River sand had a smaller percentage of elastic deformation compared to the unreinforced and reinforced quarry waste due to its poor gradation, sub-rounded particles, and lack of apparent cohesion. Figure 7 also shows that the reinforced quarry waste had a higher percentage of elastic deformation than that of the unreinforced quarry waste due to the contribution of the geocell.

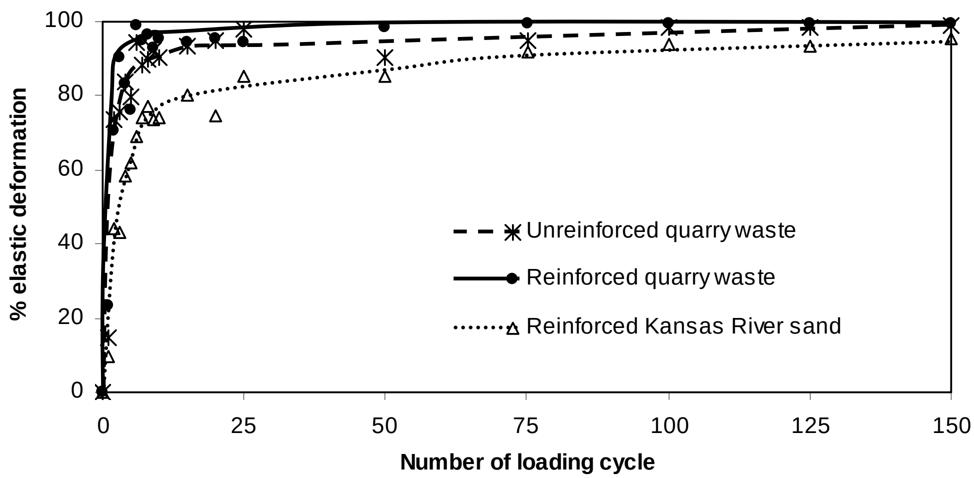

Figure 7. Percent of elastic deformation under repeated loading

6 CONCLUSIONS

This paper presents the results of experimental work conducted to investigate the behavior of geocell-reinforced bases under static and repeated loading. Both static and repeated plate loading tests were performed on a single geocell embedded in Kansas River sand and quarry waste bases to provide the confinement. The following conclusions can be drawn for this study:

1. Geocell reinforcement improved the bearing capacity and the stiffness of the Kansas River sand by improvement factors of 1.75 and 1.5, respectively, under static loading. However, geocell reinforcement had a minor effect on the stiffness of the quarry waste under static loading due to the existence of apparent cohesion.
2. The single geocell reduced the permanent deformation of the quarry waste base by a factor of approximately 1.5 compared to the unreinforced base
3. The Kansas River sand had a lower percentage of elastic deformation compared with the unreinforced and reinforced quarry waste due to its poor gradation, sub-rounded particles, and no apparent cohesion. The reinforced quarry waste had a higher percentage of elastic deformation than the unreinforced quarry waste due to the contribution of the geocell.

The above conclusions were obtained based on the test on geocell made of novel polymeric alloy. Geocells made of other materials may have different behavior and should be evaluated by testing.

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