A Summary of Research on Geocell-Reinforced Base Courses

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ABSTRACT

Geosynthetics have been widely used as construction materials for soil reinforcement since 1970s. In the past, most of the research on subgrade improvement and base reinforcement has been focused on planar geosynthtics, such as geogrid and woven geotextile. However, limited research has been done on three-dimensional geocell reinforcement of base courses. A series of static and cyclic plate loading tests, full-scale moving wheel tests, and numerical modeling were conducted by the research team at the University of Kansas on geocell-reinforced base courses with different infill materials (Kansas River sand, quarry waste, well-graded aggregate, and recycled asphalt pavement). This paper summarizes the main research findings from these studies addressing permanent, elastic, and creep deformations, stiffness, bearing capacity, and stress distribution, development of design methods for geocell-reinforced bases. These studies showed that geocell-reinforced base courses reduced the vertical stresses at the interface between subgrade and base course, reduced permanent and creep deformations, increased elastic deformation, stiffness, and bearing capacity of base courses.

INTRODUCTION

It has been a routine challenge how to optimally manage available natural and financial resources to construct high-quality roads and to minimize repair and maintenance costs. A sustainable option is to stabilize pavement structures by using some stabilization techniques that improve pavement structural strength, reduce repair and maintenance costs, and use on-site or recycled materials. Geosynthetic reinforcement has been one of the established stabilization techniques for subgrade improvement and base reinforcement for over 40 years [1, 2]. There are different types of geosynthetic products (e.g., geotextile, geogrid, geomembrane, geocell, geonet, geopipe, geofoam, geocomposite, etc.) available in the market. Woven geogrids and geotextiles are two planar geosynthetics commonly used at the interface between subgrade and base course or within the base course to improve the performance of a road. Geocell is a three-dimensional interconnected honeycomb type of geosynthetics used within the base course to confine unbound aggregates since 1970s [3].

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Rajagopal et al. [4] investigated the strength and stiffness behavior of granular soil confined in single and multiple geocells and found that the apparent cohesive strength of granular soil increased due to geocell confinement; however, geocell confinement had no effect on frictional strength of granular soil. Mandal and Gupta [5] conducted a series of static plate loading tests on geocell-reinforced sand and found that geocell increased the bearing capacity and reduced the settlement. Yuu et al. [6] conducted a comprehensive literature review and reported that theories and design methods for geocell were far behind for roadway applications because the mechanisms of geocell reinforcement were not well understood and there was not well developed design method.

The research team at the University of Kansas has conducted a series of studies on geocell-reinforced base courses since 2006. This paper provides a summary of research work and findings based on these studies for unpaved roads including static and cyclic plate loading tests, full-scale moving wheel tests, numerical modeling, and development of design method. The research work and findings on low-volume geocell-reinforced paved roads can be found in Achraya [7] and are not included in this paper. Geocells were used to reinforce a variety of base course materials, ranging from poorly-graded Kansas River sand (KR sand), well-graded AB-3 aggregate, quarry waste (QW), and recycled asphalt pavement (RAP). An artificial subgrade containing 75% KR sand and 25% Kaolin and an AASHTO A-7-6 clay were used as subgrade in cyclic plate loading tests and full-scale moving wheel tests, respectively. A 3.5 oz non-woven geotextile was placed at the interface between subgrade and base course as a separator for all the reinforced sections.

STATIC PLATE LOADING TESTS

A series of static plate loading tests were performed in medium-size test boxes (0.6 m x 0.6 m or 0.8 m x 0.8 m) to investigate vertical stress-displacement responses of unreinforced, single geocell-confined, and multi geocell-confined base courses with different infill materials (KR sand, QW, AB-3, and RAP). Creep deformations of RAP confined in single and multiple geocells were also investigated. The loading system had a 0.15 m diameter air cylinder with a maximum air pressure of 900 kPa as shown in **Figure 1**. The loading plate was 0.15 m in diameter. In these tests, base courses were placed inside a wooden box without any subgrade, which can also be considered as base course on firm subgrade. The objective of these tests was to evaluate the confinement effect of geocells on the behavior of granular fill independent of subgrade.

Pokharel [8] and Thakur et al. [9] investigated vertical stress-displacement responses of 0.12 m thick geocell-reinforced KR sand, QW, and RAP bases, in which the height of geocells was 0.10 m and there was 0.02 m fill cover. Details of these three infill materials and geocell can be found in Pokharel [8] and Thakur et al. [9]. Static loads were applied through a rigid metal plate on unreinforced and geocell-reinforced bases in increments by adjusting air pressure in the air cylinder. The deformation of the base course corresponding to each load at every five-minute interval was recorded until failure of the test section. The applied vertical stress versus displacement curves for unreinforced and geocell-reinforced bases are shown in **Figure 2**. It was found that RAP and QW bases did not fail up to the vertical stresses of 586 and 892 kPa, respectively and showed linear vertical stress-displacement behavior. However, unreinforced, single gecell-reinforced, and multiple geocell-reinforced KR sand bases failed at 248, 482, and 792 kPa, respectively. Therefore, the geocell confinement of the KR sand significantly increased the bearing capacity of the KR sand. The test results also showed that the geocell significantly increased the stiffness of KR sand and RAP bases; however, limited improvement was observed for geocell-reinforced QW. The vertical stress-displacement responses can be further analyzed in terms of a stiffness improvement factor. The stiffness improvement factor is the ratio of the slope of the initial portion of the vertical stress-displacement curve for the geocell-confined base to that of the unreinforced base. The improvement factors for the geocell-reinforced bases over corresponding unreinforced bases ranged from 1.2 to 2.0 in terms of stiffness for KR sand and RAP bases and 1.9 to 3.2 in terms of bearing capacity for KR sand. Among three infill materials, the QW bases had the highest stiffness followed by KR sand and RAP bases.

Figure 1. Static plate loading test

Thakur et al. [9] conducted creep tests by applying a sustained vertical stress of 276 kPa or 552 kPa on unreinforced, single geocell-reinforced, and multiple geocell-reinforced RAP bases for about 7 to 10 days to investigate the confinement and vertical stress effects on the creep deformations of the RAP. The displacement with time was monitored during each test. The axial creep strains were calculated from the measured displacements. The axial creep strain versus time curves are plotted in **Figure 3** to demonstrate the influence of the geocell confinement and applied vertical stress on the creep behavior of the RAP. The test results showed that the amount and rate of creep deformation decreased with an increase in the degree of confinement (from unreinforced, single geocell to multi-geocell) and a decrease in the applied vertical stress.

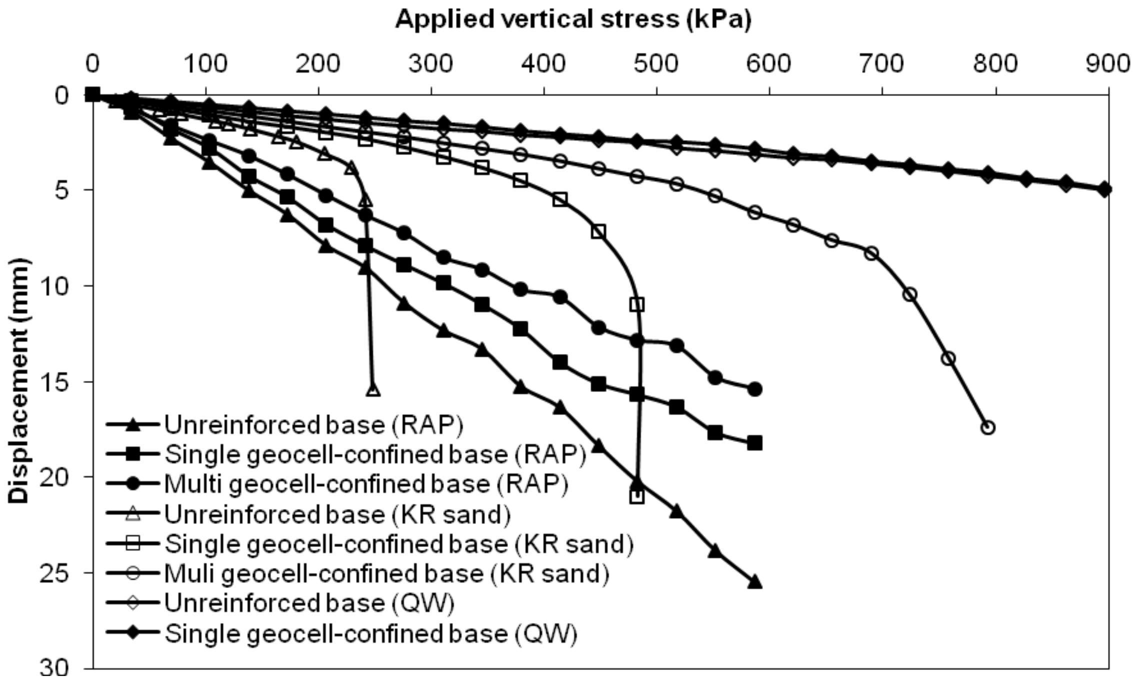

Figure 2. Vertical stress-displacement curves for the static plate load tests

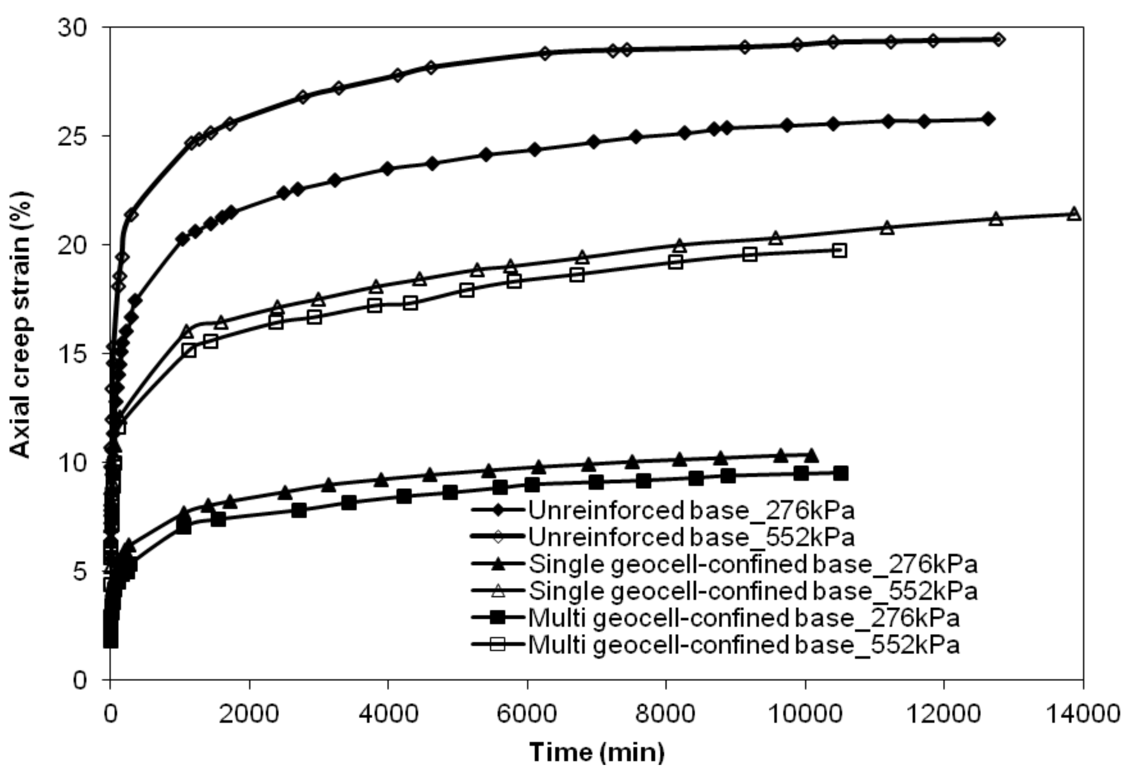

Figure 3. Creep Behavior of geocell-reinforced RAP bases (modified from Thakur et al. [10])

CYCLIC PLATE LOADING TESTS

Pokharel [8] and Thakur et al. [9, 10] conducted a series of cyclic plate loading tests on unreinforced and geocell-reinforced KR sand, AB-3 aggregate, and RAP bases over weak subgrade in a large-size box (2.2 x 2 x 2 m high) equipped with a servo hydraulic MTS loading system as shown in **Figure 4**. The loading plate had a diameter of 0.3 m and the load actuator had a capacity of 245 kN. The cyclic load with a peak force of 40 kN and a trough force of 0.5 kN at a wave frequency of 0.77 Hz was applied on geocell-reinforced bases over weak subgrade (target CBR = 2%). A mixture containing 75% KR sand and 25% kaolin was used as subgrade. Earth pressure cells were placed at the interface between subgrade and base to measure transferred vertical stresses at the interface. The strain gages were installed at the geocell wall to measure the induced strains. The thicknesses of base courses were 0.15 m, 0.23 m, and 0.23 m. Geocell improved the performance of bases by reducing the permanent deformation, reducing the vertical stress at the interface of base and subgrade, and increasing the elasticity of RAP bases. The strain measurements showed that the geocell-reinforced bases behaved as a slab. The degree of improvement depended on the geocell height, infill materials, and density. For a demonstration purpose, the improvement in the permanent deformation of a geocell-reinforced base over an unreinforced base with the same base material and thickness is shown in **Figure 5**. It is shown that at the permanent deformation of 75 mm, the ratio of the loading cycles for the reinforced section to that for the unreinforced section was approximately 10.

Figure 4. Cyclic plate loading test

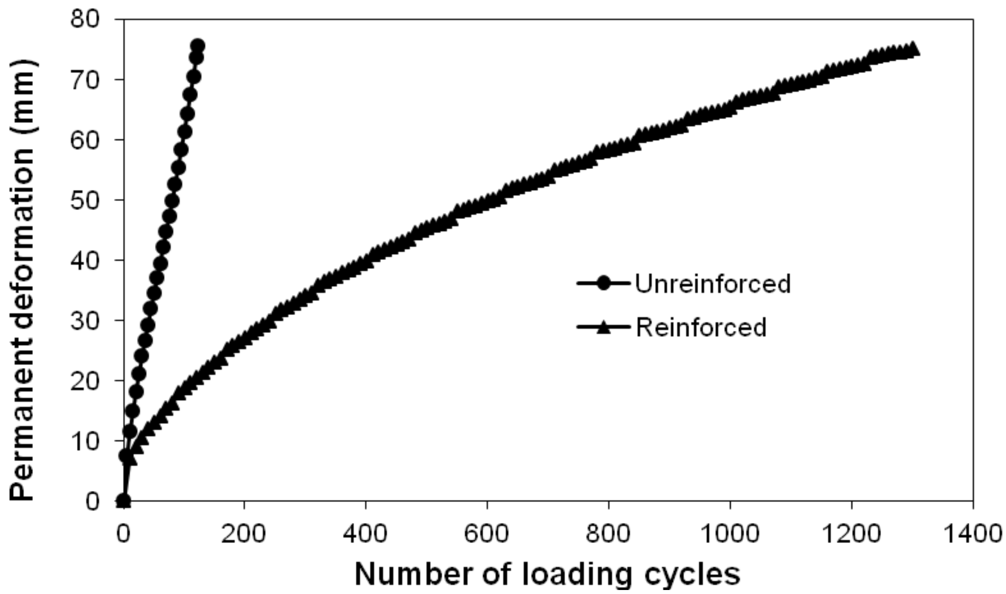

Figure 5. Permanent deformation versus the number of loading cycles (0.30 m thick AB-3 base)

FULL-SCALE MOVING WHEEL TESTS

Pokharel [8] and Yang [11] conducted a series of full-scale moving wheel tests on unreinforced and geocell-reinforced KR sand, AB-3 aggregate, QW, and RAP bases over weak or immediate subgrade (target CBR 3 or 5%) using the accelerated pavement testing (APT) facility at Kansas State University as shown in **Figure 6**. The test pit of the APT facility was 6.1 m long, 4.9 m wide, and 1.8 m deep. The APT machine consisted of a full-scale 80 kN single axle with dual tires with tire pressure of 550 kPa. An AASHTO classified A-7-6 soil was used as subgrade. A non-woven geotextile was placed at the interface between subgrade and base in case of geocell-reinforced bases. The strain gages were installed on the geocell walls to measure induced strains. The thicknesses of the base courses were 0.17 m, 0.23 m, 0.25 m, and 0.30 m. They concluded that the geocell reduced the rut depth and vertical stresses transferred to the subgrade by distributing the load over a wider area. It was also reported that a sufficient cover of 0.05 to 0.075 m thick was necessary to minimize damage to the geocell during trafficking. For a demonstration purpose, the reduction in the vertical stresses transferred to the subgrade for the geocell-reinforced base over the unreinforced base is shown in **Figure 7.** It is shown that the vertical stress at the interface in the reinforced section was approximately half of that in the unreinforced section.

Figure 6. Moving wheel test (from Pokharel [8])

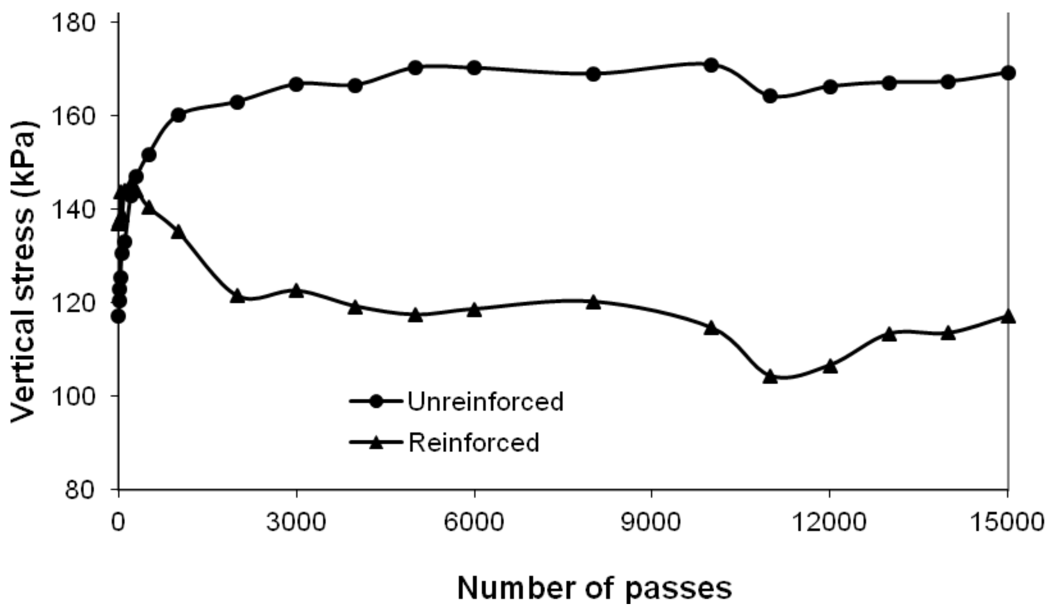

Figure 7. Vertical stresses at the interface of subgrade and base versus the number of passes (0.25 m thick RAP base)

DEVELOPMENT OF DESIGN METHOD

Yang [11] developed three-dimensional numerical models to simulate the behavior of geocell-reinforced bases under static and repeated loadings. A non-linear elastoplastic model was used to model infill soil whereas a linear elastic plate model was used to model geocells for geocell-reinforced soil under static loadings. In addition, a mechanistic-empirical model was developed for geocell-reinforced soil under repeated loadings with some modifications in the stress-dependent response model of the current mechanistic-empirical pavement design guide (MEPDG) to consider the three-dimensional constitutive equation of tangent resilient modulus, the compaction-induced initial horizontal stress in the soil, and the residual stress increase due to the accumulated permanent deformation of geocell with the number of load passes. A parametric study was also performed based on the calibrated numerical models to investigate the effects of the following factors: (i) thickness of the geocell-reinforced layer, (ii) geocell modulus, (iii) subgrade stiffness and strength, (iv) interface shear modulus, and (v) infill material modulus. Yang [11] concluded that the developed numerical model well simulated the experimental results from the geocell-reinforced bases. For a demonstration purpose, **Figure 8** shows the comparison of measured and model-predicted rut depths versus the number of wheel passes for the geocell-reinforced bases.

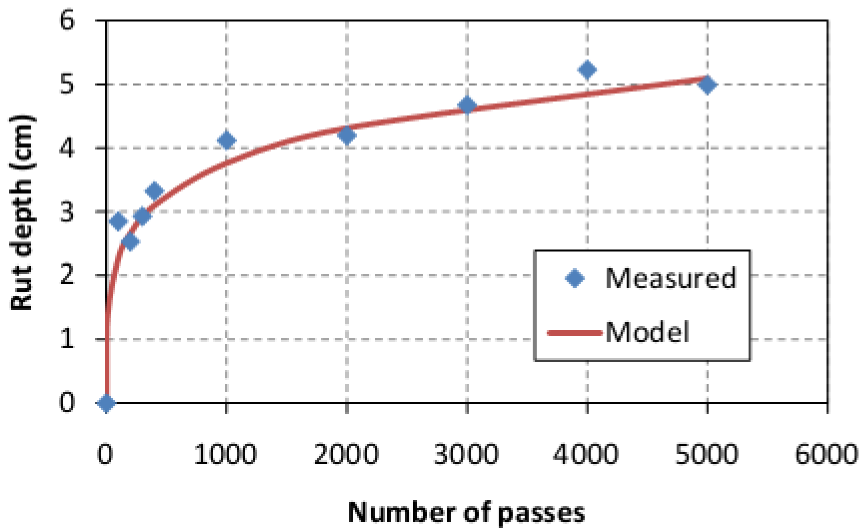

Figure 8. Measured and model-predicted rut depth versus number of passes (from Yang [11])

Pokharel [8] developed a simplified design method for geocell-reinforced unpaved roads by modifying the method developed by Giroud and Han [1, 2]. A modulus improvement factor (I_f) proposed by Han et al. [12] was included to account for the modulus increase of the base course by geocell confinement. The maximum limit of the modulus ratio was set to 7.6 for geocell-reinforced unpaved roads. The factor (k') depending on the geocell reinforcement was introduced and calibrated based on large-scale laboratory cyclic plate loading tests and full-scale moving wheel tests on geocell-reinforced granular bases over weak subgrdae. The design formula was verified by the test data.

CONCLUSIONS

The following conclusions can be made from the summary presented in this paper:

1) Geocell increased the bearing capacity and stiffness of granular bases. The degree of improvement depended on the type of infill material and the degree of geocell confinement.
2) Geocell reduced the creep deformation of RAP bases. The amount and rate of creep deformation of the RAP bases decreased with an increase in the degree of geocell confinement and a decrease in the applied vertical stress.
3) Geocell improved the performance of the bases by reducing the permanent deformation, reducing the vertical stress at the interface of base and subgrade, and increasing the elasticity of RAP bases. The degree of improvement depended on the type of infill materials and the degree of geocell confinement.
4) Geocell reduced the required thickness of the base course to achieve the same performance of the unpaved road over weak subgrade.
5) The design methods were proposed to design geocell-reinforced unpaved roads. More research is needed to validate these design methods.

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