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Tough cell

Geosynthetic reinforcement shows strong promise

An estimated 80% of all roads in the world are unpaved. According to an AASTHO report, approximately 20% of pavements fail due to insufficient structural strength.

Nowadays, it is challenging to optimally manage available natural and financial resources on construction of new roads and repair, maintenance and rehabilitation of existing roads. A sustainable option to overcome this problem is to develop an innovative pavement stabilization technique with a suitable reinforcement alternative that improves the overall structural strength, reduces operational costs, minimizes maintenance requirements and uses on-site or recycled materials.

In the past four decades, planar geosynthetic reinforcement (geotextile and geogrid) has been used to improve the performance of roadways by subgrade improvement and base reinforcement. Geocell, a three-dimensional interconnected honeycomb polymeric cell, is another type of geosynthetic reinforcement that is ideal for soil confinement. The concept of lateral confinement by cellular structures dates back to the 1970s. The U.S. Army Corps of Engineers developed this idea for providing lateral confinement to poorly graded sand to improve its bearing capacity. For easy transportation, most geocell products have a foldable three-dimensional geometry and are often honeycomb-shaped after being unfolded. The use of geocell, especially for roadway applications, however, is limited by a lack of understanding of mechanisms and influencing factors for geocell reinforcement and an established design method.

Research on exploring geocell reinforcement for roadway applications has been ongoing at the University of Kansas in cooperation with other research institutes. The objectives of this comprehensive research are to understand the mechanisms and influencing factors of geocell reinforcement, evaluate its effectiveness in improving roadway performance and develop design methods for roadway applications. This research includes laboratory box tests, accelerated moving wheel tests, field demonstration and development of design methods.

A variety of base materials have been investigated, ranging from poorly graded beach silty sand and Kansas river sand, well-graded aggregate, quarry waste and recycled asphalt pavement. Simplified and mechanistic-empirical design methods for geocell-reinforced unpaved roads were developed.

High-density, novel ideas

Two types of geocell materials were used in this research: high-density polyethylene (HDPE) and novel polymeric alloy (NPA). The NPA geocell is made of a nanocomposite alloy of polyester/polyamide nanofibers dispersed in a polyethylene matrix. The NPA is characterized by flexibility at low temperatures similar to HDPE with elastic behavior similar to engineering thermoplastic. The NPA geocells have a lower thermal expansion coefficient and higher tensile stiffness and strength than HDPE geocells. The geocells had the cell size of 205 mm x 235 mm when they were expanded to a nearly circular shape. The heights of the geocells used in this research were 75 mm, 100 mm and 150 mm. The HDPE geocell had a tensile strength of 12.5 MPa, while the NPA geocell had tensile strengths ranging from 19.1 to 21.3 MPa.

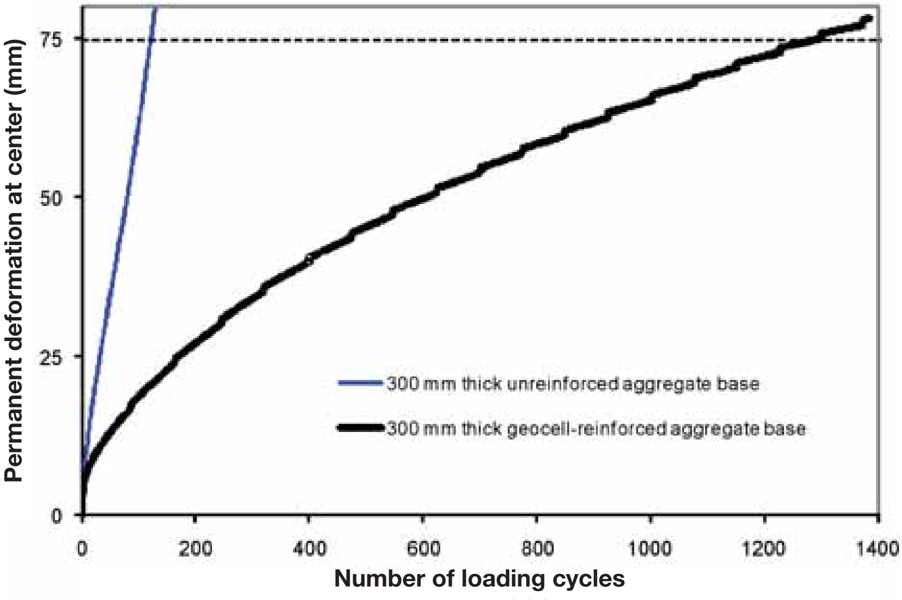
Placed in a box

A series of static and repeated plate loading tests were conducted on both unreinforced and NPA geocell-reinforced base courses with different infill materials (Kansas River sand, quarry waste and well-graded aggregate) and geocell arrangements in medium-sized test boxes (600 mm x 600 mm or 800 mm x 800 mm) with a loading apparatus at the University of Kansas. Under static loading, six key influencing factors on the behavior of geocell-reinforced bases were investigated, including the placement shape of the geocell, the type of the geocell material, the embedment of the geocell, the thickness of the reinforced section, the quality of the infill material and the multicell reinforcement. The benefit of NPA geocell reinforcement in reducing the creep deformation of recycled asphalt pavement also was evaluated. The repeated loading tests investigated the effect of infill material on the performance of geocell-reinforced bases. The key findings from these tests are summarized below:

- The geocell placed in a circular shape had higher stiffness and bearing capacity than the geocell placed in an elliptical shape;
- NPA geocell reinforcement increased the stiffness of the granular base course by up to two times and the bearing capacity by up to 2.5 times as compared with the unreinforced base course. The geocell with a higher elastic modulus material produced greater improvement;
- Under repeated loading, NPA geocell reinforcement significantly reduced the permanent deformation of the granular base. The percentage of elastic deformation to the total deformation under each loading cycle was higher in the case of a stronger infill material as compared with a weaker fill material; and
- NPA geocell reinforcement reduced the creep deformation of the recycled asphalt pavement by approximately 40%. It is recommended that a noncreep cover material should be used above the geocell.

Cyclic plate loading tests with a plate diameter of 0.3 m were performed in a large-scale testing box (2.2 m x 2 m x 2 m high) equipped with a servo hydraulic MTS loading system at the University of Kansas. The load actuator has a 245-kN capacity. A cyclic load at the maximum magnitude of 40 kN (corresponding to a loading pressure of 550 kPa) was applied at a frequency of

Large-scale plate loading test in the geotechnical test box. The repeated loading tests investigated the effect of infill material on the performance of geocell-reinforced bases.



Comparison of permanent deformation with loading cycles between unreinforced and NPA geocell-reinforced aggregate road sections.

0.77 Hz on geocell-reinforced bases over weak subgrade.

Earth-pressure cells were placed at the interface between subgrade and base to measure the transferred stresses at the interface while strain gauges were placed on the geocell to measure the strains during cyclic loading. A number of unreinforced and geocell-reinforced Kansas River sand, aggregate and recycled asphalt pavement base sections over weak subgrade of 2% CBR were tested. The thicknesses of base courses were 150, 230 and 300 mm.

The geocell-reinforced aggregate road section, which consisted of two layers of 100-mm-high NPA geocell with a 50-mm-thick fill cover between and above the geocell, had approximately 10 times more loading cycles at the permanent deformation of 75 mm as compared with the unreinforced section. Similar observations were observed in other test sections, but the degree of improvement depended on the geocell height and the infill material and density.

The key findings from these cyclic tests are summarized below:

- The geocell reinforcement improved the life of the unpaved road sections by increasing the number of loading cycles. The degree of improvement depended on the geocell height and the infill material and density;
- The geocell reinforcement increased the stress distribution angle, reduced the stresses transferred to the subgrade and slowed down the rate of base-course deterioration;
- Strain measurements on the NPA geocell confirmed the beam effect on the geocell-reinforced base;
- The calculated resilient moduli showed that the base courses in all the test sections deteriorated under cyclic loading, but the rate of deterioration was significantly reduced by NPA geocell reinforcement; and
- The density of the infill material is important for the performance of geocell-reinforced bases.

Wheels down

Full-scale moving wheel tests on unreinforced and geocell-reinforced unpaved road sections over weak or intermediate subgrade were conducted using the accelerated pavement testing (APT) facility at Kansas State University. The test pit of the APT facility was 6.1 meters long, 4.9 meters wide and 1.8 meters deep. The APT machine had a full-scale 80-kN single axle with dual tires with the tire pressure of 550 kPa. The wheels were run at a speed of 11.3 km/hr within the test pit. A total of 16 test sections were evaluated, including seven recycled asphalt pavement sections, four well-graded aggregate sections, four Kansas River sand sections and one quarry waste section. The key findings from these moving wheel tests are summarized below:

- NPA geocell section showed that the the required base thickness could be reduced to achieve the same performance of the unpaved roads over weak subgrade. The NPA geocell-reinforced Kansas River sand exhibited the largest improvement over the unreinforced section;
- Geocell reinforcement improved the life of the unpaved road sections, increased the stress distribution angle and reduced the vertical stress transferred to the subgrade as compared with the unreinforced control section;

Accelerated pavement testing of unpaved road sections at Kansas State University.

- Geocell reinforcement reduced the maximum vertical stress at the interface between base and subgrade as compared with that in the the unreinforced section;
- A 50- to 75-mm-thick fill cover is necessary to minimize the damage to the geocell during trafficking; and
- The density of the infill material is crucial to the benefit of geocell reinforcement.

Led by Prof. David White from Iowa State University, a field demonstration on the NPA geocell-reinforced unpaved road was conducted in May 2011 near the under-construction highway 9B in Jacksonville, Fla. The data from this field demo are under review and analysis; however, the initial observations and data showed the effectiveness of NPA geocell reinforcement to confine and strengthen the silty sand found in Florida.

Positive reinforcement

Theoretical studies were conducted in this research to evaluate the behavior of geocell-reinforced bases and develop design methods for geocell-reinforced bases over unstable and stable subgrade. A simplified design method was developed for geocell-reinforced unpaved roads over weak subgrade while a mechanistic-empirical method was developed for geocell-reinforced unpaved roads over stable subgrade. These design methods have been calibrated and verified based on NPA geocell reinforcement. Similar procedures may be adopted to calibrate and verify the design methods with other geocell products.

The laboratory experimental studies, full-scale moving wheel tests and field demonstration in this comprehensive research have demonstrated clear benefits of NPA geocell reinforcement in terms of increased stiffness and bearing capacity, wider stress distribution and reduced permanent deformation, which all contribute to prolonged roadway life. The field demonstration has shown NPA geocell as a viable option to reinforce silty sand in roadway construction. The design methods developed in this research can help engineers design geocells for future roadway applications.

Acknowledgements

This research was funded by the Transportation Research Institute of the University of Kansas, PRS Mediterranean Inc. of Israel, the Mid-America Transportation Center and the Geosynthetic Institute under the fellowship program for Dr. Xiaoming Yang. Their financial support is greatly appreciated. During this research, we received great cooperation, guidance, support and/or assistance from the following individuals: Prof. Dov Leshchinsky, Prof. Robert Parsons, Prof. Mustaque Hossain, Prof. David White, Dr. Robert Honea, Mr. Oded Erez, Mr. Izhar Halahmi and Dr. Ofer Keif. R&B

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