Geocell-Reinforced Crushed Stone Base for Low-Volume Roads

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ABSTRACT

Crushed stone bases are widely used for low-volume roads. However, shear strength of the crushed stone materials can be vastly improved by confining the material in geocellular confinement systems or geocells. Geocells are 3-dimensional honeycomb-like structures. The objective of this study was to test a geocell design with crushed stone (AB-3) in-fill and a thin hot-mix asphalt (HMA) surface layer under real world traffic. A 50-mm HMA pavement test section over a 100-mm thick AB-3 geocell-reinforced base and a 300-mm thick unreinforced AB-3 base were constructed at the Civil Infrastructure System Laboratory (CISL) of Kansas State University (KSU). The sections were instrumented to measure the strains at the bottom of the HMA layer and stresses on top of the subgrade. The unreinforced section was loaded with 50,000 repetitions of an 80-kN single axle load. The reinforced section was loaded with 70,000 repetitions. The calculated and measured responses show, in the reinforced section, stresses on top of the subgrade exceeded the unconfined compressive strength of the soil. It is recommended that the geocell depth be increased along with the thickness of the HMA layer for paved low-volume roads.

Keywords: geocells – AB-3 – accelerated pavement testing (APT) – low volume roads
INTRODUCTION

Low volume roads make up approximately 80% of the world’s road structures. Use of crushed stone in these bases has been widespread. In Kansas, this crushed stone material is known as AB-3. The material has a dense gradation with a large percentage of fine material. Depending on the fine material present, the AB-3 can lack enough stability to withstand heavy traffic. An economical system is needed to increase the shear capacity of the AB-3 materials. Geocellular confinement systems, geocells, are three-dimensional honeycomb-like structures filled with an in-fill of an available material. Geocells can be used in AB-3 road bases to enhance the shear strength and in turn, trafficking ability of the geocell-reinforced bases.

Geocells can be made from different materials. Originally, geocells were made from high-density polyethylene (HDPE) strips 200 mm wide and approximately 1.2 mm thick. These strips were then ultrasonically welded together. The geocells were collapsed for shipment and then placed on the surface of the subsoil and propped open in an accordion fashion with an external stretcher assembly. An in-fill material was then placed in the geocells and compacted using a vibratory compactor (Koerner 1994). Although the configuration remained unchanged, there have been advancements in the materials used to manufacture geocells. The geocells used in this study are a NEOLOY™ polymeric alloy (nano-composite alloy of polyester/polyamide nano fibers, dispersed in a polyethylene matrix) or New Polymeric Alloy (NPA).

Due to its 3-D structure, geocells are mainly used for confinement applications more than any other planar geosynthetic reinforcement (Yuu et al. 2008). Dash et al. (2001, 2003, and 2004) and Sitharam et al. (2005) have demonstrated the use of Geocells for increasing bearing capacity and reduce settlement of soft soil foundations. Without proper testing, geocells will fail to gain acceptance as a viable low volume road building tool. Very little research has been done using geocells as base reinforcement in paved roads (Yuu et al. 2008).

In 2009, the University of Kansas (KU) and Kansas State University (KSU) did joint research on unpaved NPA geocell-reinforced bases over weak subgrade. Three different in-fill materials were used in the study: crushed stone, AB-3, Reclaimed Asphalt Pavement (RAP), and quarry waste (Pokharel et al. 2011 and Han et al. 2010). The study resulted in the following conclusions for NPA geocell-reinforced unpaved roads:

1. A 170-mm NPA geocell reinforced base can outperform a 300-mm crushed stone base (Pokharel et al. 2011);
2. RAP is the best performing in-fill material (Pokharel et al. 2011);
3. The NPA geocell increased the stress distribution angle (Pokharel et al. 2011; and
4. A thicker (50 mm to 75 mm) cover is needed to minimize the damage to the NPA geocells (Han et al. 2010).

This study was expected to extend those results to low-volume paved roads.

STUDY OBJECTIVE

The objective of this study was to test a NPA geocell design with AB-3 as the in-fill material and a thin hot-mix asphalt (HMA) overlay under real world traffic.

STUDY APPROACH
To achieve the study objective, pavement test sections were constructed at the Civil Infrastructure System Laboratory (CISL) of Kansas State University (KSU). The test sections consisted of a NPA geocell-reinforced AB-3 base and an unreinforced AB-3 base. The unreinforced section was loaded with 50,000 repetitions of an 80-kN single axle load while the reinforced section was loaded with 70,000 repetitions.

FACILITIES

CISL houses an accelerated pavement testing (APT) machine and three pits of approximately the same size, 6.1-m long, 4.9-m wide, and 1.8-m deep, for constructing test sections. The reaction frame of the APT machine covers a distance of 12.8 m and applies a load of 80-kN single axle load with air-bag suspension on dual tires. The wheel assembly is belt driven by a 20-HP electric motor, while the load is controlled by hydraulic pressure. The tire pressure used in this study was 552 kPa. The moving wheel has a frequency of 0.167 Hz (i.e. 6 sec/pass) at a speed of 11.3 km/hr (Lewis 2008). The machine is fitted with stepper motors to allow the machine to simulate traffic wander. For this test, the wander was setup with a truncated normal distribution between -150 mm and +150 mm. The distribution can be seen in Figure 1.

In this study, the pit was divided into two lanes (6.1 m long by 2.45 m wide). The subgrade for each lane was a clay (A-7-6) compacted to a CBR of about 6%. To separate the base and subgrade, a non-woven geotextile was used. The NPA geocell-reinforced base layer was constructed following recommendations from Pokharel et al. (2011) and Han et al (2010). The NPA geocells were laid out in a near circular pattern with 250 mm in the wheel direction (also the seam direction) and 210 mm in the transverse direction. Also, the optimum NPA geocell height found by Pokharel et al. and Han et al. was 75 mm. Thus, the height of the NPA geocells in this study was 75 mm. A cover of 25 mm of AB-3 was placed over the NPA geocells after they were filled with AB-3 and compacted. This cover thickness was lowered since an HMA wearing surface would be constructed. The control or unreinforced base layer was 300-mm layer of AB-3. Both lanes were covered with 50-mm HMA layer of a Superpave mixture with 12.5 mm Nominal Maximum Aggregate Size (NMAS).
MATERIALS PROPERTIES

NPA Geocells and Geotextile

The NPA geocells used in this study are NEOLOY™ polymeric alloy (nano-composite alloy of polyester/polyamide nano fibers, dispersed in polyethylene matrix) (Han et al. (2010)). The polymeric alloy has a similar flexibility at low temperatures as HDPE, along with an elastic behavior similar to engineering thermoplastics. The NPA geocells used in this study are made of materials with a tensile strength of 19.1 MPa and secant elastic modulus of 355 MPa at 2% strain. Han et al. (2010) performed the tensile test at a strain rate of 10%/minute at 23 °C. The NPA geocell had a wall thickness of 1.1mm and two perforations of 350 mm² each on one pallet of the NPA geocell. The geotextile used as a separator between the subgrade and base was a 3.5-oz. non-woven geotextile.

Subgrade

An AASHTO (American Association of State Highway and Transportation Officials) A-7-6 clay was used in subgrade construction. Han et al. (2010) found the optimum moisture content to be 21% with a maximum dry density of 1.61 g/cm³. An approximate California Bearing Ratio (CBR) of 6% was reached in the pits at a moisture content of 21%. Plastic Limit (PL), Liquid Limit (LL), and percent finer than 75 μm sieve tests were conducted at KSU and were found to be 22%, 43%, and 97.68%, respectively. The Plasticity Index was 21 (Bortz et al. 2011).

Base Course

AB-3

AB-3 is a well-graded base material that is used in a variety of low-volume road applications. Figure 2 shows the gradation for AB-3 as specified by the Kansas Department of Transportation (KDOT). The AB-3 material used in this study was the same as the one used in previous studies (Pokharel et al. 2011 and Han et al. 2010). Pokharel et al. (2011) found a mean particle size of (d₅₀) of 4.4 mm, a coefficient of curvature of 1.55, and a coefficient of uniformity of 21. The optimum moisture content of 10.2 % would produce a CBR of 45%. The maximum dry density was determined to be 2.13 g/cm³. The AB-3 was compacted at a moisture content of 9.2% in the control lane and to about 9% in the NPA geocell lane.
Hot Mix Asphalt

A 50-mm HMA layer was placed over the base layer. The HMA was produced and laid by a local asphalt contractor as seen in Figure 3. A Superpave mixture with 12.5 mm NMAS and fine gradation, known as SM-12.5A in KDOT, was used. The aggregate blend consisted of 26% 19-mm rock, 17% 9.5-mm chips, 20% manufactured sand, and 17% concrete sand. A PG 70-28 binder was used. The in-place density was 92% (2.25) of theoretical maximum specific gravity. The mixture air void content at N_{design} was 4.04%. The final cross section of the lanes is shown in Figure 4.
INSTRUMENTATION

The lanes were instrumented with pressure cells on top of the subgrade and two strain gages at the bottom of the HMA layer. Thermocouples in the HMA layer were also placed. The NPA geocells were instrumented with five strain gages per lane. The instrumentation layout can be seen in Figure 5.

The pressure cells were Geokon Model 3500 pressure cells. The H-Bar strain gages consisted of Texas Measurements PML-60-2L gages epoxied to 2 aluminum pieces as suggested by Lewis (2008). The thermocouples used were a Type T. The strain gages placed on the NPA geocells were Vishay C2A-06-250LW-120. During placement of the HMA layer, some of the H-Bar gages were damaged.
RESULTS

Rut Depths

The test lanes were subjected to the moving wheel test. The rut depths were measured in two different ways. First, a profile was taken with a transverse profiler (Lewis 2008). The profiler is a 4.27-m long piece of aluminum tubing with a 5-cm² cross section. A Chicago Dial Indicator digital gage is mounted to a movable slide on the beam. The gage produces a digital output and sends data to a spreadsheet. Three fixed reference points, at every 1.5 m of lane length, were placed on the HMA on outside of the lanes. Measurements were taken every 12.5 mm. The second method of measuring rut depths was using a sight level and measuring stick. The elevation of the wheel path was taken every 305 mm. These measurements were compared to a set reference point inside of the CISL building. Typical profiles for each lane can be seen in Figures 6 through 9.

As seen in the figures the lane in the reinforced lane deteriorated quickly. After only 10,000 passes, the transverse profile showed an average rut depth of 12.5 mm. The failure rut depth for this study was set at 12.5 mm. The average longitudinal depression depth was 10.77. The unreinforced section fared better with transverse rut depth and longitudinal depression depths of 5.69 and 0.91 mm, respectively. A summary of the ruts depths with the applied number of load cycles can be seen in Table 1. The unreinforced lane received 70,000 passes while the NPA geocell-reinforced section AB-3 received only 50,000 passes due to scheduling of a 38-mm overlay.

![Figure 6. NPA geocell reinforced AB3 lane typical transverse profile](image-url)
Figure 7. NPA geocell reinforced AB-3 lane longitudinal profile

Figure 8. Unreinforced AB3 lane typical transverse profile
Table 1. Average rutting depth

<table>
<thead>
<tr>
<th>Cycles (in thousands)</th>
<th>Average Rut Depth (mm)</th>
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<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Unreinforced AB3 - Longitudinal</td>
<td>0.91</td>
</tr>
<tr>
<td>Unreinforced AB3-Transverse</td>
<td>5.69</td>
</tr>
<tr>
<td>Reinforced AB3 - Longitudinal</td>
<td>10.77</td>
</tr>
<tr>
<td>Reinforced AB3-Tansverse</td>
<td>12.54</td>
</tr>
</tbody>
</table>

**Vertical Stresses**

Pressure cells were placed above the subgrade and just below the geotextile. The pressure was recorded for a full wander (676 passes) each time. The top 50 peak pressures were averaged and presented in Figure 10. The pressure on the subgrade in the NPA geocell-reinforced AB-3 lane (GC AB3) was well above the unreinforced AB-3 (UR AB3) lane. It is to be noted that the stress at in the NPA geocell reinforced lane surpassed unconfined compressive strength of 105 kPa of the subgrade soil.
FWD Testing and Data Analysis

After paving, KDOT conducted Falling Weight Deflectometer (FWD) tests on the pavement. During FWD testing, seven sensors were used at offset locations of 0, 203, 305, 457, 610, and 914 mm. From the FWD results, the modulus of each layer was backcalculated using the software package EVERCALC from the Washington State Department of Transportation. To minimize the root mean square (RMS) error, deflection from only first four sensors were used in the backcalculation. These sensors were used to take into account the shallow subgrade (the CISL APT pits are underlain by a 230-mm Reinforced Concrete slab) and the effects of the concrete walls of the pits. The layer moduli were used in the KENPAVE software in the KENLAYER program for computing strain at the bottom of HMA layer and stress at the top of the subgrade. KENLAYER provides solution for an elastic multilayer system under a circular loaded area. These calculated responses were compared with the measured responses under the moving wheel load. Tables 2 and 3 list these responses. As can be seen in Table 2, the unreinforced AB-3 lane had much lower pressure on the subgrade in both cases. This is attributed to the unreinforced AB-3 base being four times thicker than the NPA geocell reinforced base.

Table 2. KENLAYER Comparison of Pressure on Subgrade

<table>
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<tr>
<th></th>
<th>Unreinforced AB-3</th>
<th>Geocell Reinforced AB-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure on Subgrade (kPa)</td>
<td>58.32</td>
<td>132.01</td>
</tr>
<tr>
<td>MEASURED (kPa)</td>
<td>41.76</td>
<td>124.94</td>
</tr>
<tr>
<td>% Difference</td>
<td>-28.40%</td>
<td>-5.36%</td>
</tr>
</tbody>
</table>
Strain at the bottom of the HMA layer

The strain at the bottom of the HMA layer was measured with the H-Bar strain gages. Table 3 lists both calculated and measured strains. The lower than expected strain in the reinforced AB-3 lane could be attributed to the beam effect of NPA geocells described by Pokharel et al. (2011) and Han et al. (2010). The base layer and HMA layer acted like a beam and could move together, reducing the strain at the interface.

Table 3. KENLAYER Comparison of Strain at the Bottom of HMA Layer

<table>
<thead>
<tr>
<th></th>
<th>Unreinforced AB-</th>
<th>Geocell Reinforced AB-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strain (Below HMA)</td>
<td>Strain (Below HMA)</td>
</tr>
<tr>
<td>KENLAYER</td>
<td>-0.000363</td>
<td>-0.000902</td>
</tr>
<tr>
<td>MEASURED</td>
<td>-0.000369</td>
<td>-0.000273</td>
</tr>
<tr>
<td>% Difference</td>
<td>-1.62%</td>
<td>69.75%</td>
</tr>
</tbody>
</table>

Using KENLAYER, a comparable unreinforced section was determined based on similar responses. The equivalent unreinforced layer would be approximately 200 mm. The pressure on the subgrade would be approximately the same as the smaller reinforced section. Using the knowledge gained from this study, a new design and construction was completed. The new NPA geocell-reinforced design consisted of 100 mm of HMA over a 100 mm NPA geocell with 50 mm of cover.

CONCLUSIONS

In this study, a polymeric alloy NPA geocell reinforced base with AB-3 as in fill materials and one unreinforced AB-3 base course were studied in an accelerated pavement testing. The following conclusions can be drawn from this study.

1. A 25-mm cover over the NPA geocells is too thin due to the irregularities in the heights of NPA geocells and subgrade. A 50-mm cover over the NPA geocells would ensure a better compaction over the NPA geocells and would also make construction easier.
2. A 75-mm thick NPA geocell reinforced base layer approaches the maximum capacity of the NPA geocells. A 100-mm thick NPA geocell would enhance the load-bearing capacity of the base layer.
3. The subgrade must be protected in order to ensure better performance of the paved road. The applied subgrade stress should be less than the unconfined compressive strength of the soil.
4. A HMA layer of 50 mm is too thin for the wheel load. The minimum thickness for the HMA layer is recommended to be 100 mm.

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REFERENCES


