Large-Scale Experimental Studies to Evaluate the Resilient Modulus of Geocell-Reinforced Reclaimed Asphalt Pavement Bases

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ABSTRACT

Resilient modulus is considered as one of the key parameters for the flexible pavement design. However, determination of the resilient modulus of the geocell-reinforced base material is not achievable using conventional resilient modulus laboratory testing, due to constraint of larger size of geocell than traditional soil specimens. Geocell is a three-dimensional, polymeric, honeycomb-like structure of cells interconnected at joints. The cell walls keep the encapsulated material from being pushed away from the applied load and offer an all-around confinement by virtue of its three-dimensional nature. In this study, a series of large-scale repeated load tests were performed to analyze the behavior of geocell-reinforced reclaimed asphalt pavement (RAP) bases. The performance of the geocell-reinforced RAP base was analyzed in terms of resilient behavior of the reinforced testbed under repeated loading. The results show that a 10-cm high-density polyethylene (HDPE) geocell layer increased the resilient modulus of the base layer to approximately three times of that for the unreinforced case.

INTRODUCTION

2017 ASCE report card (ASCE 2017) on civil infrastructure assigned grade ‘D’ for America’s roads and this rating necessitates the adoption of more sustainable and resilient approaches in design and construction of transport infrastructures such as highway embankments and pavements. Reclaimed asphalt pavement (RAP) material has been considered as one of the sustainable options in the pavement industry. Increased use of RAP as a percentage of the total asphalt mix can significantly reduce greenhouse gas emissions by eliminating the significant fuel consumption required to acquire and process raw materials for the virgin mix (NAPA 2009). However, 100% unbounded RAP cannot be used as the base layer due to its low shear strength and high permanent deformation under cyclic loading (Taha 1999, McGarrah 2007 and Kazmee et al. 2009). This necessitates the adoption of a chemical or mechanical stabilizer for improving the performance of the RAP material.
Several studies have been performed to evaluate the effectiveness of stabilized RAP in terms of resilient modulus. Repeated load triaxial tests performed by Gnanendran and Woodburn (2003) on lime treated RAP material exhibited nearly 30% improvement in terms of resilient modulus. Potturi (2006) used cement and cement-fiber to stabilize RAP aggregates and demonstrated the effectiveness of cement in improving the performance of RAP material. Li et al. (2007) and Wen et al. (2011) conducted repeated load triaxial tests (RLTTs) on fly ash treated RAP specimens and concluded that the resilient modulus of RAP increased with increase in the percentage of fly ash. The RLTTs on untreated and cement treated RAP by Puppala et al. (2011, 2018) evaluated the effectiveness of moderate cement treatment in enhancing resilient characteristics of RAP aggregates.

Limited literature is available on the resilient behavior of mechanically stabilized RAP materials, specifically, geocell-reinforced RAP material due to its significantly large specimen size. However, the effectiveness of geocell in reducing permanent deformation of RAP material under repeated loading has been confirmed by various studies, such as Han et al. (2011), Pokharel et al. (2011), and Thakur et al. (2012). The studies by Dash et al. (2007), and Zhang et al. (2010) verified the additional lateral confinement and widening of stress distribution angle due to the presence of geocell reinforcement. Moreover, the field tests on geocell-reinforced pavement confirmed the effectiveness of geocell reinforcement in improving the strength and stiffness properties of the base layer (Al-Qadi and Hughes 2000, Emersleben and Meyer 2008, 2010).

The main objective of this study is to address the effectiveness of geocell-reinforced RAP base layer in terms of resilient modulus to aid in the designing of geocell-reinforced pavement bases. A series of large-scale repeated loading tests were performed on HDPE geocell-reinforced RAP base layer to quantify the structural support provided by geocell foundations. Resilient modulus of unreinforced and geocell-reinforced RAP base layers with respect to the number of load cycles was computed analytically and compared. Parametric studies are also performed to evaluate the effect of height, the location of loading, and gradation of RAP in the resilient behavior of geocell-reinforced RAP base.

**EXPERIMENTAL STUDY**

**Test Materials**

*Geocell and Geosynthetic Membrane*

High-density polyethylene (HDPE) geocell was used as the reinforcement to impart confinement to the RAP material. The 10-cm geocell mattress used in this study is shown in Fig. 1. The properties of HDPE geocell including cell size, cell depth, polymer density, and seam peel strength are shown in Table 1. A geosynthetic membrane was used at the interface of the subgrade and base layer as a separator to prevent mixing of RAP material with the clay subgrade.
Reclaimed Asphaltic Pavement Material
Two different RAP materials were used in this study namely R1 and R2, which were obtained from the Texas Department of Transportation (TxDOT) stockpiles in Arlington, Texas and Grandview, Texas, respectively. A series of laboratory tests were performed to characterize both the RAP materials including sieve analysis (ASTM D1241 2014), compaction (Tex-113 E 2011), specific gravity (ASTM D854 2014), unconfined compression strength test (ASTM D2166 2016), and resilient modulus test (NCHRP 01-28A 2004). From the test results, it was observed that R2 contained finer particles than R1.

Clay Subgrade
The low plasticity clay, obtained from a site in Grandview, Texas, was used as the subgrade material for this study. The liquid limit and plasticity index (ASTM D4318 2017) of the clay subgrade was determined to be 42.1% and 17.1%, respectively. The maximum dry density of subgrade was 1963 kg/m³ corresponding to an OMC of 11.5% from modified Proctor test (ASTM D1557 2012).

Table 1: Properties of the Geocell reinforcement (source: Geo Products LLC)

<table>
<thead>
<tr>
<th>Material properties</th>
<th>Values</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Expanded cell size (cm)</td>
<td>$32 \times 29$</td>
<td>-</td>
</tr>
<tr>
<td>Nominal Expanded cell area (cm$^2$)</td>
<td>460</td>
<td>-</td>
</tr>
<tr>
<td>Cell depth (cm)</td>
<td>10.16</td>
<td>-</td>
</tr>
<tr>
<td>Seam Peel strength (N)</td>
<td>1423.43</td>
<td>-</td>
</tr>
<tr>
<td>Polymer Density (kg/m$^3$)</td>
<td>935.5 - 964.3</td>
<td>ASTM D-1505</td>
</tr>
<tr>
<td>Carbon black content (% minimum by weight)</td>
<td>1.5</td>
<td>ASTM D-1603</td>
</tr>
<tr>
<td>Nominal sheet thickness after texturing (mil)</td>
<td>60 -5%,+10%</td>
<td>ASTM D-5199</td>
</tr>
</tbody>
</table>
Large Scale Laboratory Test

Large-scale repeated load tests were conducted on a steel tank of dimensions 1.83 m × 1.83 m × 0.76 m as shown in Fig. 2. The clay subgrade was compacted at 95% maximum dry density (MDD) maintaining the water content at optimum moisture content (OMC). The subgrade was placed in three equal lifts by compacting each lift using a vibratory compactor. A geotextile was used as a separator between geocell-reinforced RAP layer and subgrade. RAP material was placed inside geocell pockets in three equal lifts by compacting each cell individually for each lift using a vibratory compactor.

A circular steel plate of 15.2 cm diameter and 1.3 cm thickness was used to simulate tire contact area. Repeated load tests were performed on the testbed by placing the circular steel plate at the center of the actuator against the reaction frame to avoid eccentric loading. A seating load of 55 kPa was applied initially and then the load was increased to a maximum of 550 kPa. A haversine load of 0.2 Hz frequency was used for simulating the traffic load. Each test was performed on the unreinforced and geocell-reinforced testbed for 1000 load cycles. Repeatability of tests was ensured by performing two trials for each parametric study. Two vertical LVDTs were installed on the top of the loading plate to record the total surface deformation under cyclic loading. The axial load applied and the corresponding displacement at the surface was measured using a data acquisition system. The stresses and strains developed at the surface were calculated by analyzing this data. A typical stress strain plot from the repeated load laboratory test is shown in Figure 3. The details of the experimental setup used are provided by Saladhi (2017).

Figure 2. Large-scale repeated load testing facility.
RESULTS AND DISCUSSIONS

Resilient Modulus ($M_r$)

Resilient modulus is the fundamental material property to characterize pavement base materials. It is the key design parameter in AASHTO 1993 and MEPDG flexible pavement design. Resilient modulus is primarily a measure to determine the stiffness of a material and can be defined as the ratio of cyclic stress to the recoverable strain.

To evaluate the resilient modulus, stresses developed at the mid-height of each layer was calculated. For unreinforced case, a stress dispersion angle of 26° was used based on the conventional 2 Vertical to 1 Horizontal method and for the geocell-reinforced case, a stress distribution angle of 30° based on Thakur et al. (2012) was used. The variation of resilient modulus of the subgrade with change in moisture content was also considered, as the compacted subgrade had a slight variation in moisture content from the target values.

The resilient modulus of the entire testbed is given by,

$$M_r = \frac{\sigma_a}{\varepsilon_a}$$

where $\sigma_a$ is the deviatoric stress applied to the sample and $\varepsilon_{axial}$ is the axial elastic strain developed due to the applied $\sigma_a$.

Total elastic strain ($\varepsilon_t$) developed in the testbed will be equal to the sum of elastic strains developed in the individual layers.

$$\varepsilon_t = \varepsilon_{GR} + \varepsilon_S$$

$$\varepsilon_t = \left(\frac{\sigma_1}{M_r}\right)_{GR} + \left(\frac{\sigma_1}{M_r}\right)_{S}$$
where $\varepsilon_{GR}$ and $\varepsilon_S$ are the elastic strains developed on geocell-reinforced RAP layer and subgrade, respectively and $(\sigma_1)_{GR}$ is the axial stress transferred to the geocell-reinforced RAP base and $(\sigma_1)_S$ is the axial stress transferred to the subgrade. The resilient modulus of the geocell reinforced RAP layer is given by,

$$M_{rGR} = \frac{\sigma_{1GR}}{\varepsilon_t (\frac{\sigma_1}{M_r})_S}$$

The variation of resilient modulus with number of load cycles for unreinforced and geocell-reinforced RAP layer is shown in Figure 4. Resilient modulus of geocell-reinforced RAP base is approximately three times that of the unreinforced RAP base after 1000 load cycles. The resilient modulus of geocell-reinforced RAP base showed a significant increase till 600 cycles and finally reached almost a constant value of 325 MPa. The exponential increase in the resilient modulus of reinforced RAP material during initial phase might be due to the lateral confinement offered by the cellular structure of geocell reinforcement and the rearrangement of particles under initial loading. This resulted in a compact arrangement thereby increasing the particular interlocking and stiffness of the material. The initial increase in stiffness is equivalent to the pre-conditioning cycles applied to a traditional repeated-load triaxial test, where 500 to 1000 cycles are applied prior to initiating the actual loading sequences. Similar observations were made by Banerjee (2017) and Banerjee et al. (2018) for various subgrade soils.

![Figure 4. Variation of resilient modulus with number of load cycles.](image)

**Parametric Studies**

Parametric studies were performed on the geocell-reinforced RAP base layer under repeated loading by varying the height, gradation of RAP, and location of loading. The performance of the system was evaluated based on the improvement in the resilient modulus of geocell-reinforced RAP layer.
**Geocell Height**

Geocell reinforcement with two different heights, 10 cm, and 15 cm, were used for the study. The resilient modulus variation with number of load cycles for the unreinforced and geocell-reinforced case is shown in Figure 5. It can be observed that the resilient modulus of reinforced RAP increased with an increase in the height of geocell reinforcement. With the increase in height of geocell, the applied load was transferred to a larger area resulting in the improvement in overall performance of the RAP layer. A similar type of observation was also made by Thakur et al. (2012).

**Gradation of RAP**

To evaluate the effect of gradation on the strength and stiffness behavior of the testbed, repeated load tests were performed on two different RAP materials, GR1 and GR2 (G shows geocell reinforced) from different locations in Texas. GR2 contained more amount of finer particles than the GR1. The results obtained were plotted and is shown in Figure 6. It can be observed that the gradation of the RAP layer has a significant effect on the resilient modulus of the geocell reinforced RAP layer. GR1 with the coarser RAP particles showed substantial improvement compared to GR2. This may be due to the development of particle interlocking through the apertures of the geocell reinforcement which will tend to reduce with increase in fineness of the material.

![Figure 5. Variation of resilient modulus with the height of geocell.](image)
Location of Geocell

The location of the loading can influence the behavior of the geocell reinforced RAP material. The load can be applied by placing loading plate either on the center of geocell (‘a’ in Figure 7) or on the joint of geocell (‘b’ in Figure 7). Laboratory testing was performed on both the cases and the results were plotted as shown in Figure 7. It can be observed that the testbed with loading on joint performed better than the loading on the center case. The slight improvement of about 7% in resilient modulus was due to the presence of weld on the joint which enabled the reinforced testbed to sustain the higher load.
CONCLUSION

Large-scale repeated load tests were conducted on unreinforced and geocell reinforced RAP bases to evaluate the strength and stiffness behavior of geocell reinforcement in terms of resilient modulus. It was observed that the 10-cm HDPE geocell increased the resilient modulus of the RAP base to approximately three times of that of the unreinforced case. This is primarily due to the additional lateral confinement offered by the cellular structure of the geocell reinforcement under repeated loading. Apart from the confining effect, the increase in stress distribution angle due to the lateral distribution of stresses through the interconnected geocell pockets resulted in higher resilient modulus. Parametric studies were performed to study the effect of height, the gradation of RAP, and location of loading on the resilient behavior of reinforced RAP. The study showed that the height and gradation of loading has a significant influence on the resilient modulus of geocell-reinforced RAP base. This study is limited to large-scale laboratory testing and further requires field implementation of geocell reinforced RAP bases under real-time traffic loading to study the long-term behavior and influence of actual traffic loading.

REFERENCES


