Large-scale studies to evaluate the resilient modulus of geocell-reinforced RAP bases

By Anu M. George, Aritra Banerjee, Tom Taylor and Anand J. Puppala

The 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 et al. 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 (M_r). Repeated load triaxial tests performed by Gnanendran and Woodburn (2003) on lime-treated RAP material exhibited nearly 30% improvement in terms of M_r. 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 and Wu (2011) conducted repeated load triaxial tests (RLTTs) on fly ash-treated RAP specimens and concluded that the M_r of RAP increased with an expansion 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

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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 M_r to aid in the designing of geocell-reinforced pavement bases. A series of large-scale repeated loading tests were performed on high-density polyethylene (HDPE) geocell-reinforced RAP base layer to quantify the structural support provided by geocell foundations. M_r of unreinforced and geocell-reinforced RAP base layers with respect to the number of load cycles was computed analytically and compared. Parametric studies were also performed to evaluate the effect of height, the location of loading and the gradation of RAP in the resilient behavior of geocell-reinforced RAP base.

FIGURE 1 4-inch (10-cm) HDPE geocell layer used for testing

Test Materials

Geocell and Geosynthetic Membrane

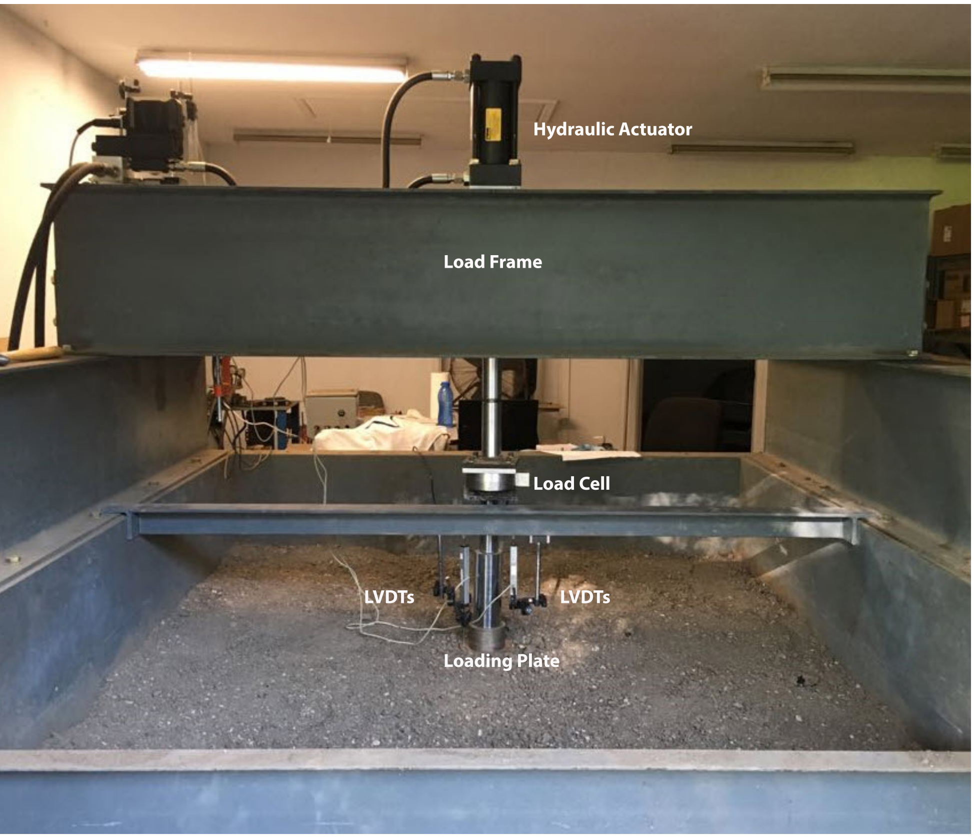
HDPE geocell was used as the reinforcement to impart confinement to the RAP material. The 4-inch (10-cm) Envirogrid geocell mattress manufactured by Geo Products LLC used in this study is shown in **Figure 1**. The properties of HDPE geocell, including cell size, cell depth, polymer density and seam 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 (RAP) 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 was performed to characterize both the RAP materials, including sieve analysis

(ASTM D1241), compaction (Tex-113 E), specific gravity (ASTM D854), unconfined compression strength test (ASTM D2166) and resilient modulus test (NCHRP 01-28A). From the test results, it was observed that R2 contained finer particles than R1.

FIGURE 2 Large-scale repeated load testing facility



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) of the clay subgrade was determined to be 42.1% and 17.1%, respectively. The maximum dry density of subgrade was 123 pounds/cubic foot (1,963 kg/m^3) corresponding to an optimum moisture content (OMC) of 11.5% from a modified Proctor test (ASTM D1557).

Large-Scale Laboratory Test

Large-scale repeated load tests were conducted on a steel tank of dimensions 6 × 6 × 2.5 feet (1.83 × 1.83 × 0.76 m), as shown in **Figure 2**. The clay subgrade was compacted at 95% maximum dry density (MDD) maintaining the water content at OMC. The subgrade was placed in three equal lifts by compacting each lift using a vibratory compactor. A geotextile was

TABLE 1 Properties of the geocell reinforcement. *Table courtesy of Geo Products LLC*

Material Properties	Values	Standards
Nominal Expanded cell size (cm)	32 × 29	-
Nominal Expanded cell area (cm2)	460	-
Cell depth (cm)	10.16	-
Seam Peel strength (N)	1423.43	-
Polymer Density (kg/m3)	935.5– 964.3	ASTM D1505
Carbon black content (% minimum by weight)	1.5	ASTM D1603
Nominal sheet thickness after texturing (mil)	60 -5%, +10%	ASTM D5199

used as a separator between the geocell-reinforced RAP layer and the 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 6-inches (15.2-cm) diameter and 0.5-inch (1.3-cm) thickness was used to simulate a 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 8 psi (55 kPa) was applied initially and then the load was increased to a maximum of 80 psi (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 1,000 load cycles. Repeatability of tests was ensured by performing two trials for each parametric study. Two vertical linear variable differential transformers (LVDT) 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** on page 34. The details of the experimental setup used are provided by Saladhi (2017).

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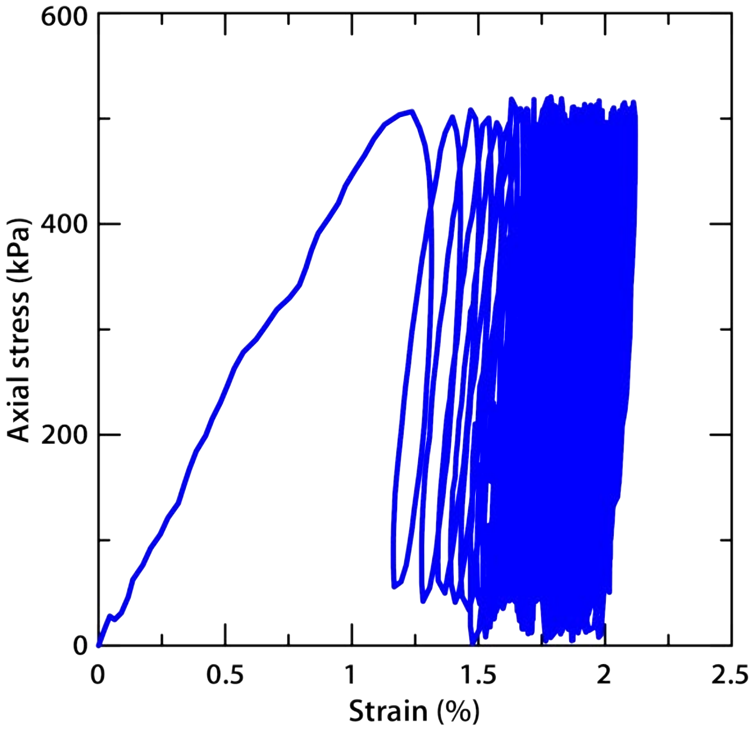

FIGURE 3 Typical stress-strain plot from the repeated load test

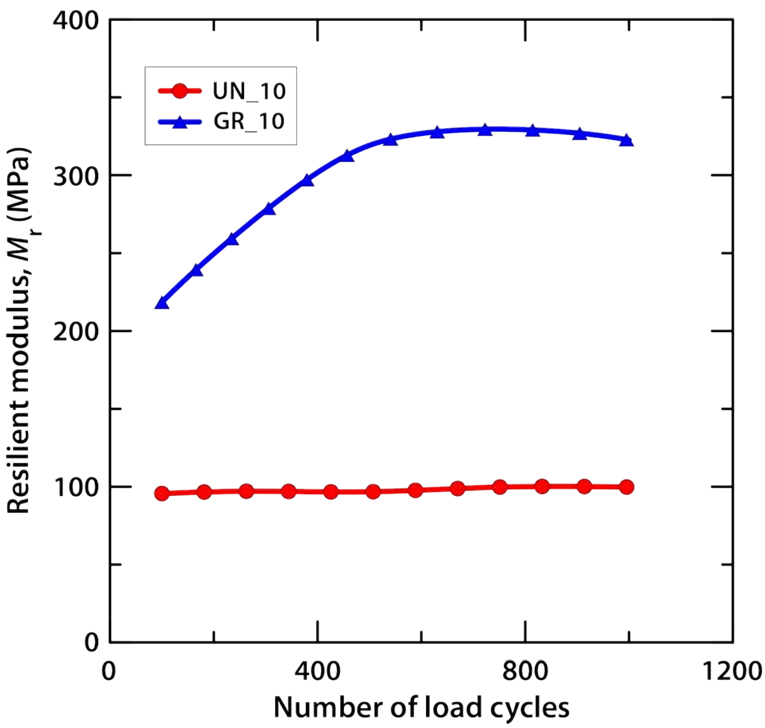

FIGURE 4 Variation of resilient modulus with number of load cycles

Resilient Modulus (M_r)

M_r is the fundamental material property to characterize pavement base materials. It is the key design parameter in AASHTO 1993 and the Federal Highway Administration's Mechanistic Empirical Pavement Design Guide (MEPDG). M_r 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 M_r, stresses developed at the midheight of each layer was calculated. For the 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 M_r 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 M_r of the entire testbed is given by **Equation 1**,

$$M_r = \frac{\sigma_a}{\varepsilon_{axial}} \tag{1}$$

where σ_a is the deviatoric stress applied to the sample and ε_{axial} is the axial elastic strain developed due to the applied σ_a. Total elastic strain (ε_t) developed in the testbed will be equal to the sum of elastic strains developed in the individual layers (**Equation 2**).

$$\varepsilon_t = \varepsilon_{GR} + \varepsilon_s$$
$$\varepsilon_t = \left(\frac{\sigma_1}{M_r}\right)_{GR} + \left(\frac{\sigma_1}{M_r}\right)_s \tag{2}$$

where ε_{GR} and ε_S are the elastic strains developed on the 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 M_r of the geocell-reinforced RAP layer is given by **Equation 3**,

$$M_{rGR} = \frac{\sigma_1 GR}{\varepsilon_t - \left(\frac{\sigma_1}{M_{rS}}\right)} \qquad (3)$$

The variation of M_r with number of load cycles for the unreinforced and geocell-reinforced RAP layer is shown in **Figure 4**. M_r of the geocell-reinforced RAP base is approximately three times that of the unreinforced RAP base after 1,000 load cycles. The M_r of the geocell-reinforced RAP base showed a significant increase until 600 cycles and finally reached almost a constant value of 325 MPa. The exponential increase in the M_r of reinforced RAP material during the 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 interlocking and stiffness of the material. The initial increase in stiffness is equivalent to the preconditioning cycles applied to a traditional repeated-load triaxial test, where 500 to 1,000 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.

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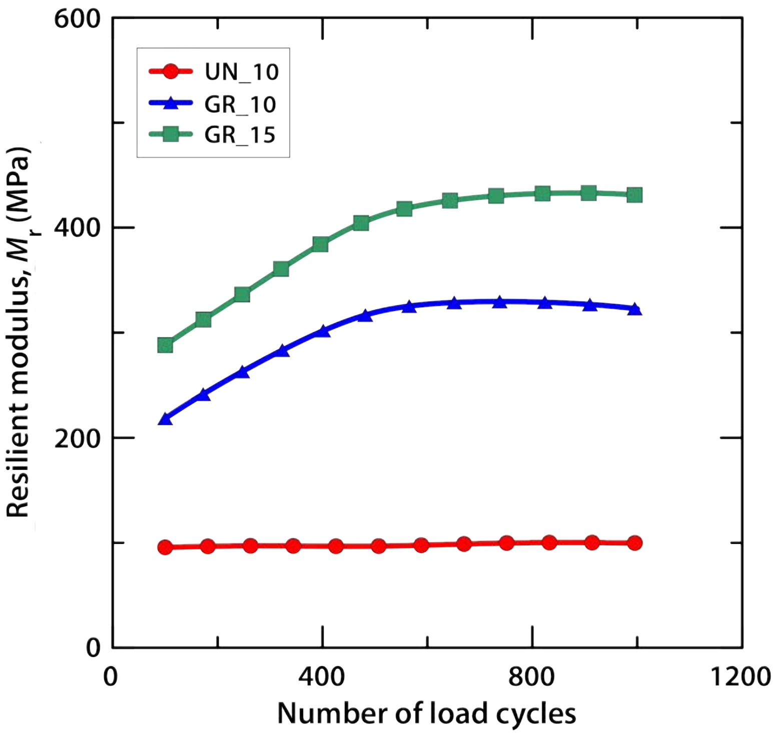

FIGURE 5 Variation of resilient modulus with the height of geocell

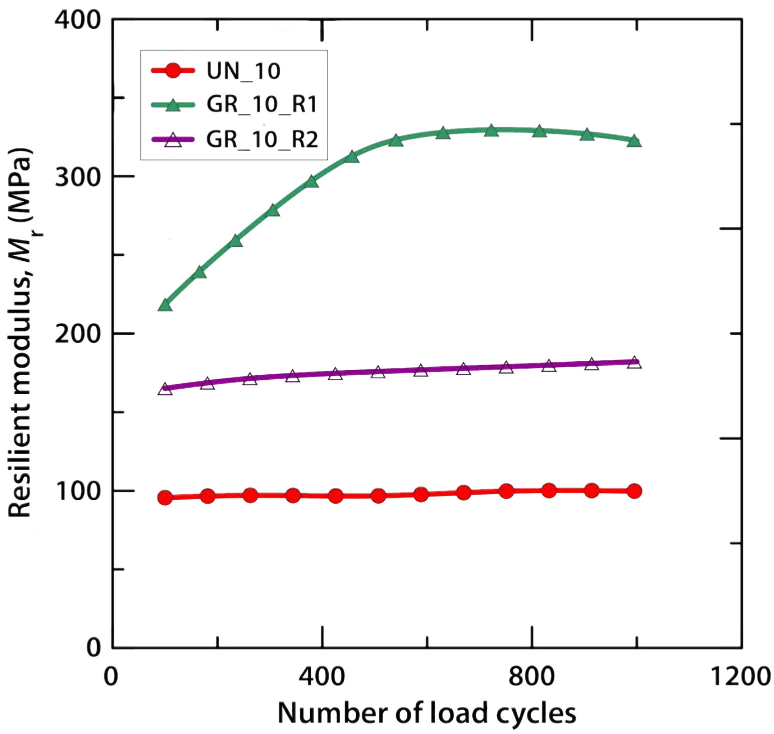

FIGURE 6 Variation of resilient modulus with the gradation of RAP

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 M_r of the geocell-reinforced RAP layer.

Geocell height

Geocell reinforcement with two different heights, 4 inch (10 cm) and 6 inch (15 cm), were used for the study. The M_r variation with number of load cycles for the unreinforced and geocell-reinforced case is shown in **Figure 5**. It can be observed that the M_r 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 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 reinforcement) from different locations in Texas. GR2 contained higher amounts of finer particles than the GR1. The results obtained were plotted and are shown in **Figure 6**. It can be observed that the gradation of the RAP layer has a significant effect on the M_r 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.

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 the loading plate either on the center of the geocell ("a" in **Figure 7**) or on the joint of the geocell ("b" in **Figure 7**). Laboratory testing was performed on both cases and the results were plotted, as shown in **Figure 7**. It can be observed that the testbed with loading on the joint performed better than the loading on the center case. The slight improvement of about 7% in M_r was due to the presence of weld on the joint, which enabled the reinforced testbed to sustain the higher load.

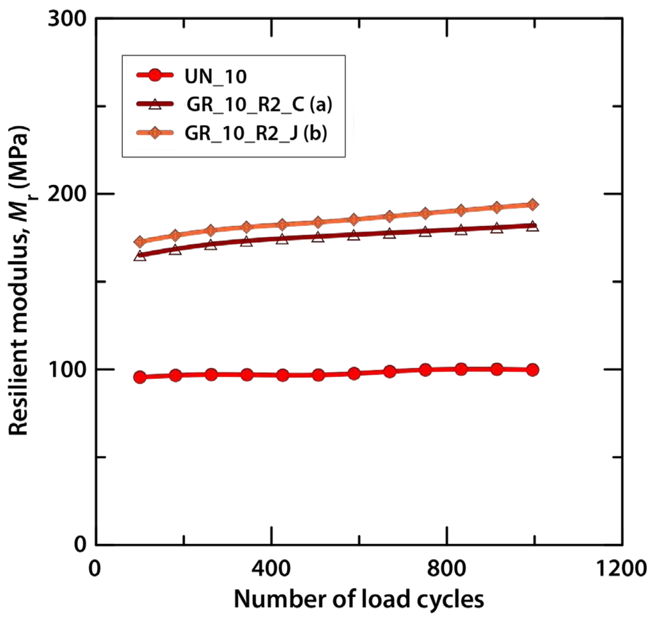

FIGURE 7 Variation of resilient modulus with the location of loading

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 M_r. It was observed that the 4-inch (10-cm) HDPE geocell increased the M_r of the RAP base to approximately three times 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 M_r. Parametric studies were performed to study the effect of height, the gradation of RAP and the 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 M_r of the 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.

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 M_r.

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