Experimental Investigation of Geogrid Reinforced Unpaved Sections Under Repeated Loads

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Abstract Rutting has been one of the major pavement distresses that affect the performance and longevity of pavements constructed on weak or soft subgrades. Rutting is often associated with excessive deformation of the pavement layers under wheel loads, caused by layer densification and excessive vertical stress on the subgrade exceeding subgrade strength. Over the past two decades, geosynthetics have been used to reduce this excessive deformation by decreasing the vertical stresses on the subgrade. The primary objective of this study was to determine the effect of high-moduli geogrid-reinforced layers in reducing the vertical stresses on the subgrade. The current study addresses the objective by experimental investigation on reinforced pavement layers subjected to repeated loads. The experimental investigation involves conducting laboratory-based large-scale repeated load tests on geogrid-reinforced pavement sections constructed over weak subgrades. Based on the large-scale repeated load test results, it was observed that the geogrid-reinforced pavement sections reduced the vertical stress on the subgrade by 35–75% as compared to the unreinforced sections.

Keywords Geogrid · Vertical stresses · Repeated loads · Pavement

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1 Introduction

The pavement performance and service life mainly depend on the thickness and stiffness of pavement layers. Pavement that is constructed on weak or soft soils often experiences distress and failure due to repetitive traffic loading, causing distress like rutting and fatigue cracking. To prevent these structural and functional failures, pavement thickness and material combinations are designed based on phenomena like rutting, fatigue cracking, and accumulative damage. The design life of pavements is determined by connecting the number of load repetitions to the compressive strains developed on the subgrade, considering permanent deformations. Unpaved pavements constructed on weak or soft subgrade often require good quality aggregate and thicker base layers for better, longer service life. However, due to material availability constraints and increased focus on sustainable materials, there is a need to reduce pavement thickness without compromising its design life.

Over the last two decades, geosynthetics have been gaining popularity for reinforcing pavements, which helps reduce pavement layer thickness compared to unreinforced layers for given traffic loading and improves the performance of unbound pavement layers. Research focused on geogrid reinforcement showed significant improvements in pavement performance, including resistance to rutting, reflective cracking, and fatigue cracking [1]. Various studies indicated that geogrids' interlocking effect with aggregates was the main mechanism behind their performance enhancement, rather than their membrane tension effect. The inclusion of geogrids led to reduced deformation and, consequently, decreased base material thickness, resulting in cost savings. Field monitoring studies confirmed the effectiveness of geosynthetics in improving pavement performance and increasing service life by reducing rutting and enhancing tensile strength [2, 3]. Large-scale laboratory tests were conducted to replicate field conditions and evaluate permanent and resilient deformations, emphasizing the rut depth reduction ratio (RDR) and traffic benefit ratio (TBR) as performance indicators [4–6]. Studies also explored the stress distribution within the base and subgrade layers and the pressure exerted on the subgrade. Placing strain gauges and pressure cells on the subgrade helped understand load transfer and establish a relationship between base layer thickness and pressure transferred to the subgrade [7]. These findings contribute to a better understanding of the reinforcement effect and stress distribution in reinforced and unreinforced pavement sections.

In summary, geogrid reinforcement has proven effective in reducing permanent deformation, vertical stress on subgrade, enhancing pavement performance, and extending its service life. However, most previous studies focused on geogrids with a lower aperture stability modulus, and even the widely used geogrid design methodology for unpaved roads is not valid for geogrids with an aperture stability modulus greater than 0.65 m N/° [8, 9]. With advancements in polymer technologies, stiffer geogrids with an aperture stability modulus ranging from 0.8 to 1.5 m N/° are now being manufactured. Unfortunately, transportation practitioners are not fully utilizing these stiffer geogrids' potential due to design limitations. There is a need to conduct a comprehensive study to quantify the performance improvements offered by these stiffer geogrids. In the current research, large-scale repeated plate load tests were employed to assess the performance of geogrid-reinforced pavement sections, focusing on pavement vertical stresses on the top subgrade layer, utilizing these stiffer geogrids.

2 Objective and Scope of the Work

The current study aims to measure the vertical stresses at the interface between the base and subgrade layers of geogrid-reinforced pavement sections using large-scale repeated plate load tests. Three pavement test sections were constructed within a large-scale box, each employing different geogrid reinforcements, along with one unreinforced section as a control section. The performance improvement of the geogrid-reinforced sections was evaluated by comparing the results with the unreinforced section using two metrics: vertical stress reduction factor and stress distribution angle. The scope of the study was limited to measuring vertical stresses at the base and subgrade layer interface in pavements constructed using stiffer geogrids, with an aperture stability modulus (j) of 0.98 and 1.5 m N/°.

3 Materials and Testing Methods

3.1 Materials

The base aggregates and subgrade soil used in this study were obtained from a local supplier. To characterize these materials, several standard tests were conducted in accordance with ASTM standards, including particle size analysis, Atterberg limits, and Proctor compaction tests (Table 1). The grain size distribution of the subgrade and base material is illustrated in Fig. 1a.

Table. 1 Properties of subgrade soil and base aggregate materials

Parameters	Standard	Values	
		Subgrade	Base
Liquid limit (%)	ASTM D4318	20	–
Plastic limit (%)	ASTM D4318	14	–
Plastic Index (%)	ASTM D4318	6	–
Maximum dry unit weight (kN/m^3)	ASTM D698	19.6	19.0
Optimum moisture content (%)	ASTM D698	10.5	7.5
USCS classification	ASTM D2487	SM-SC	GW

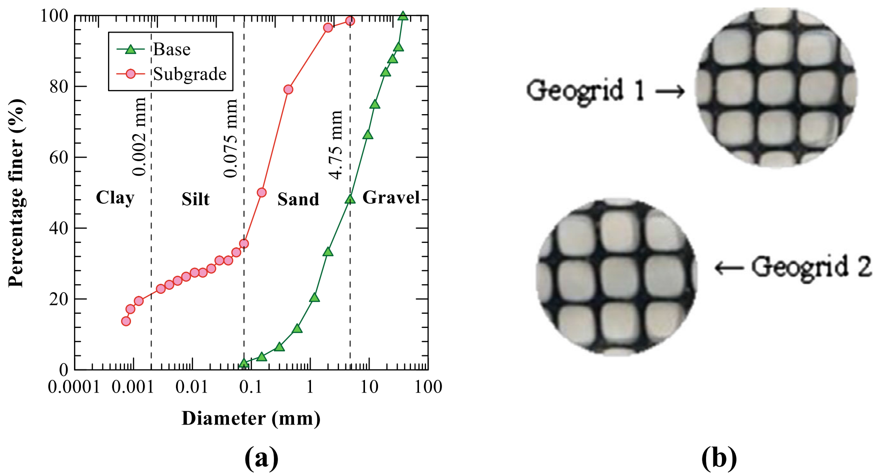


Fig. 1 **a** Grain size distribution of subgrade soil and base aggregate material. **b** Biaxial geogrids

Table. 2 Properties of geogrids

Parameters*	Geogrid 1	Geogrid 2
Aperture dimensions, mm	33 × 33	33 × 33
Minimum rib thickness in MD, mm	2.5	3
Minimum rib thickness in XMD, mm	2.1	2.1
Aperture stability, m N/°	0.98	1.5
Ultimate Tensile Strength, kN/m	31	38

* *Note* Values were obtained from the manufacturer's website

3.2 Materials

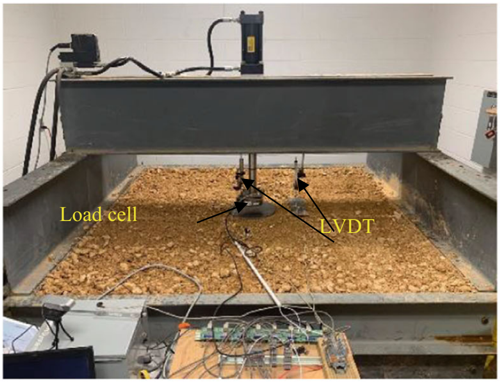
Two commercially available punched and drawn biaxial geogrids with different polypropylene stiffness were used for this study. These biaxial geogrids have an aperture opening size of 33 × 33 mm (1.3 × 1.3 in.) with different aperture stability modulus values. Additional specifications of the geosynthetic products used in this study are provided in Table 2. Figure 1b shows the two biaxial geogrids used in the study. For ease of reference, the biaxial geogrids are named as geogrid 1 (GG1) and geogrid 2 (GG2).

3.3 Experimental Setup of the Large-Box Test Section

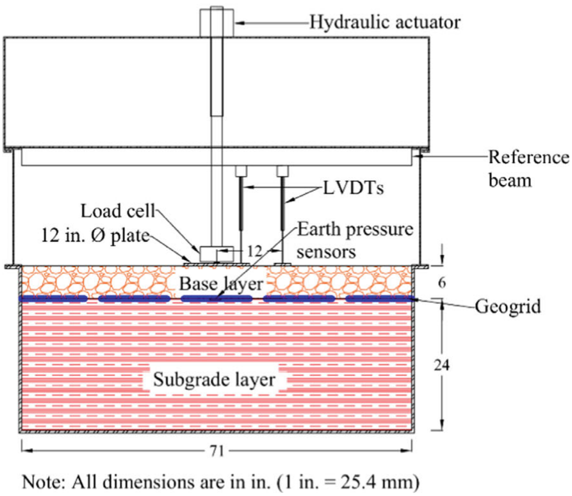
To evaluate the performance of the pavement section, a large-scale laboratory test setup was designed and constructed specifically for conducting repeated load tests.

The reinforced large-scale laboratory test setup schematic is illustrated in Fig. 2b. In contrast, Fig. 2a displays the completed test section with the placement of LVDTs (linear variable displacement transducers) and a load cell. Additionally, pressure sensors were used to measure the load at the top subgrade under the load center and 305 mm away from it. The data acquisition system recorded data from the LVDTs, load cell, and pressure sensors at a frequency of 0.1 s. During the tests, a maximum load of 40 kN was applied on the 305 mm diameter plate, resulting in a loading pressure of 550 kPa which simulates traffic conditions of a single axle load. The loading cycle had a duration of 1.3 s, resulting in a load pulse frequency of 0.77 Hz as shown in Fig. 3.

The control section was prepared by thoroughly mixing the oven-dried soil with a target water content of 10.1% corresponding to CBR 3. The wet soil mixture was



(a)



(b)

Fig. 2 Large-scale test box **b** Completed test section with 610 mm (24 in.) subgrade and 152 mm (6 in.) base layers **a** Schematic of the reinforced test box with geogrid. *Note* All dimensions are in in. (1 in. = 25.4 mm).

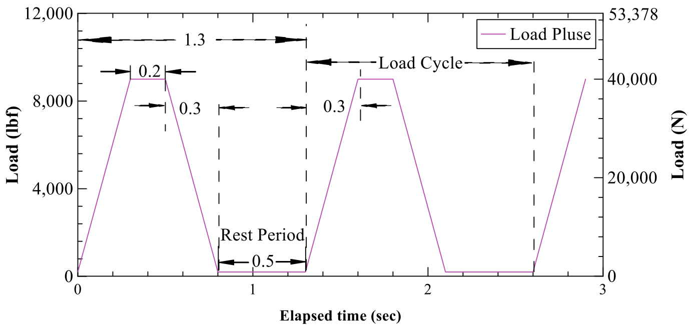


Fig. 3 Repeated load pulse to simulate the single axle load

homogeneously placed in four layers at the bottom of the test box. Each layer was raked, leveled, and compacted to achieve a desired height of 152 mm using a 4.5 kg compaction hammer with a drop height of 610 mm. The base course layer was then prepared in one lift by placing the gravel over the subgrade layer. Similar to the subgrade layer, the base layer was compacted manually using a hammer to the desired height. In the case of reinforced sections, the geogrids are placed at the interface between the base and subgrade materials. The quality control and quality assurance of the constructed test section were evaluated by measuring in-situ test properties, including moisture content, and Variable Energy Dynamic Cone Penetration test (VE-DCP). These in-situ tests were performed at four different locations to assess the quality of the constructed section.

4 Results and Discussions

4.1 Vertical Stress at the Interface

Vertical stress acting on top of the subgrade layer plays an important role in the overall performance of the pavement foundation system. In this study, vertical compressive stress under the loading center was determined from the average load computed from the pressure cells placed at the top of the subgrade layer. Figure 4a illustrates the vertical stress on the top of the subgrade at the load center of different test sections. The vertical stresses were compared for an increasing number of loading cycles. It was observed that the vertical stresses increased immediately during the first few cycles and reached a plateau after 500 cycles for all the test sections (Fig. 4a). Compared to the unreinforced section, the reinforced sections demonstrated a significant reduction in vertical stress due to geogrids. Including geogrids led to a 35–75% decrease in vertical stress as compared to the unreinforced sections. Irrespective of the reinforcement strength, a reduction in vertical stress at the interface was observed starting from the first cycle.

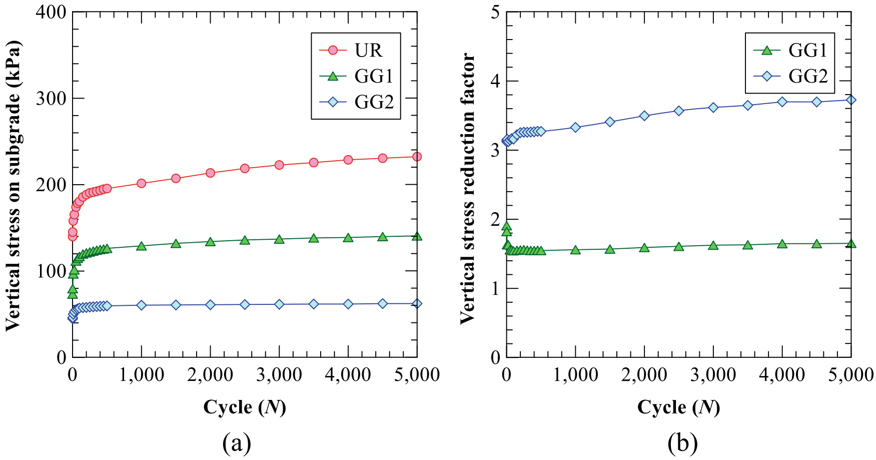


Fig. 4 **a** Variation of vertical stress on subgrade under load center with the number of loading cycles. **b** Vertical stress reduction factor

Figure 4b illustrates the reduction in vertical stress at the interface at the load center relative to the unreinforced section for the GG1 and GG2 sections. After 5000 cycles, the reduction in vertical stress at the interface for GG1 and GG2 sections was 1.65 and 3.72 times, respectively. The aperture modulus of the geogrids played an important role in transferring the load on top of the subgrade layer. Geogrids were interlocked with the aggregate base material and resisted the vertical deformation by providing lateral restrain. GG2 geogrid had the highest aperture stability modulus (j) of 1.5, and hence maximum reduction of vertical stress was observed for this geogrid. This reduction in vertical stress helps reduce the surface deformation of the pavement sections. The surface deformation after 5000 cycles was 24.7 mm and 18.6 mm for GG1 and GG2 geogrid-reinforced sections, respectively, compared to 37 mm in unreinforced sections.

4.2 Vertical Stress Distribution

Previous section showed that the inclusion of geogrids at the interface of the base and subgrade layer helped to reduce the stresses acting on top of the subgrade layer, and hence there will be an enhancement of pavement section capacity. The pavements base thickness is designed assuming the zone of influence for an applied traffic load has a slope pattern spreading the load over a wider area, reducing the stresses as the depth increases. This zone of influence can be called as a vertical stress distribution pattern in pavement layers, and it depends on the stiffness of the pavement layers and the height of the layers. A typical stress distribution pattern is shown in Fig. 5. The vertical stress distribution pattern can be interpreted by back-calculating the stress

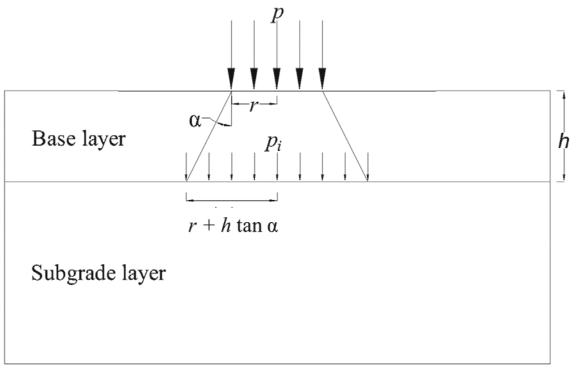


Fig. 5 Schematic of stress distribution in two-layered pavement system

distribution angle (α) using Eq. (1).

$$\tan\alpha = \frac{r}{h} \times \left(\sqrt{\frac{P}{\pi r^2 p_i}} - 1\right) \quad (1)$$

where P is the vehicular load applied through the loading plate of radius r; h is the thickness of the base layer, α is the stress distribution angle. p_i is the vertical stress at the interface of the subgrade and base layer.

In the current study, the stress distribution angle for the unreinforced section was 28°, whereas the stress distribution angle increased to 44° for the GG1 reinforced section and 62° for GG2 reinforced section after 5000 cycles. The stress distribution angle tends to increase with the application of geogrid products indicating the efficacy of the application of such products in improving the long-term pavement serviceability.

5 Summary

This study summarizes the findings from the large-scale laboratory repeated plate load tests conducted on different pavement sections with geogrid reinforcement. This study measured the vertical stress at the interface of the base and subgrade of geogrid reinforcement sections; the significant findings are summarized below.

- In all three tests, the increase in the rate of vertical stress at the interface was higher during the early loading cycles. However, with the number of loading cycles, the vertical stress rate decreased.
- The reduction in vertical stress at the interface after 5000 cycles for GG1 and GG2 sections was 1.65 and 3.72 times, respectively.

- The stress distribution angles (α) after 5000 cycles for GG1 and GG2 sections were 44° and 62°, respectively compared to 28° in the case of the unreinforced section.
- The inclusion of geogrid reinforcement in an unpaved road section over a weak subgrade can help to spread the load over a large area decreasing the vertical stress at the interface. This shows that stiffer geogrids can improve the unbound pavement layer performance more effectively.

It is to be noted that the current study only considers biaxial grids with two aperture stability moduli and a single aperture size. Further studies with different geogrids, geo material and testing conditions are needed to develop a comprehensive design recommendation.

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