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Monotonic Loading Test to Investigate the Benefits of Composite Geogrids for Subgrade Improvement

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Abstract. The presence of weak subgrades is one of the greatest challenges in constructing road pavements. Conventionally, techniques such as refiling with suitable material and soil stabilisation are considered to improve subgrade condition, ignoring the additional project cost. However, geogrids have gained popularity as economical, expedite and sustainable subgrade improvement techniques over recent times. Although many studies have been conducted to assess the suitability of biaxial geogrids, limited studies have been performed to check the suitability of composite geogrids for subgrade improvement, despite assuming that composite geogrids extend additional benefits. In this study, two model tests: one unreinforced and one composite geogrid reinforced, were constructed in a steel box with length, width, and height of 1m, 1m and 1.2m, respectively. The subgrade was prepared to a thickness of 500mm, achieving CBR 2.5% bearing capacity. A granular layer of 200mm was constructed on top of the subgrade achieving 100% degree of compaction from maximum dry density. In the reinforced section, composite geogrid was placed at the base subgrade interface. Both model sections were subjected to a monotonic load at a rate of 1mm/min, applied on the top surface of the granular layer through a circular plate of 200mm diameter, until the occurrence of ultimate failure. Results demonstrate that reinforcing the weak subgrade by a composite geogrid has increased the ultimate bearing capacity by 53%. In addition, the overall section modulus of the composite geogrid reinforced section is higher than the modulus of the unreinforced section.

Keywords: Pavement Engineering, Pavement Material, Composite Geogrid, Geogrids, Weak Subgrade, Bearing Capacity.

1 Introduction

Road design engineers have to face numerous challenges to deliver high standard road networks constraining themselves to limited investments. The weak subgrade is one of the key challenges that could substantially increase the construction cost[1, 2]. The issue of the weak subgrade is extremely common in most of the road construction sites in the state of Queensland, Australia, owing to the presence of expansive clay type soil [3-10]. Therefore, soft subgrade treatment methods: such as backfilling with suitable materials, increase the granular cover thickness or soil stabilisation, are required to be considered to improve the subgrade condition[11-16]. In fact, finding suitable subgrade soil for backfilling is extremely difficult in the state of Queensland and therefore, backfilling, if requires, will mostly be done using granular material. Therefore, inevitably, the presence of a weak subgrade will consequentially increase the demand for natural gravel material[17, 18]. Although recycled aggregate has been recommended to fulfil the extensive demand for granular material in road construction[19-21], the ongoing rate of production would not fulfil a significant portion of the demand for granular material. Accordingly, the road construction industry is searching for an effective and sustainable solution for the issue of weak subgrades.

Geosynthetics are used in different geotechnical applications: such as for pavement construction[12, 22, 23], water-related works[24, 25] and in environmental geotechniques[26-28]. Geosynthetics have become popular in pavement engineering applications due to economic and environmental benefits, convenient and expedite construction and durability[29]. The reinforcement function of geosynthetics can effectively be used to improve the condition of weak subgrades[30]. Although geosynthetics are available in different types, such as geogrids and geotextiles, researchers have confirmed that geogrids are the best type to achieve the reinforcement function of a road pavement[31]. Besides, geotextiles are also popular in road construction as they can provide layer separation and act as a filter layer between the subgrade and the granular layer[32]. The migration of soil particles from subgrade to the granular is common in weak subgrades, and therefore, the specifications of the Queensland Department of Transport and Main Roads states that a geotextile should be placed on subgrade before placing the geogrid[33]. As a result, composite geogrids, which has a geotextile layer attached under the geogrid, are popular in the local road construction industry as a hybrid product that extends the functions of reinforcement and separation simultaneously[2].

Geogrids can extend the pavement life, reducing the rutting depth and reducing the required base layer thickness[32, 34]. This performance depends on many factors such as type of geogrid, type of granular and the location of geogrid[35]. In order to assess the impact of different factors, researchers have conducted large scale pavement model testing under monotonic loading and cyclic loading[36, 37]. The cyclic loading tests can assess the long-term performance (rut depth and permanent deformation), while monotonic loading tests will assess the bearing capacity of the surface. Bearing capacity-based design methodologies are used mainly for unbound granular pavements and also to design working platforms[38]. This study focuses on assessing the bearing capacity of weak subgrade reinforced with a composite geogrid and a granular cover. The bearing capacity of the improved subgrade surface will be a direct input for the empirical design method[39] of unbound granular pavement to develop a rational pavement design that accounts the effect of geogrid reinforcement.

The main objective of this study is to examine the possibility of using composite geogrids for weak subgrade improvement under local conditions. Accordingly, two laboratory scale model tests were conducted using locally available materials. This study compares the stress vs deformation results of the two model tests to verify that composite geogrids are beneficial in reinforcing weak subgrades. Moreover, vertical stress distribution on weak subgrade surface was analysed.

2 Material properties

2.1 Subgrade soil

This project used a clay type black soil, collected from a road construction site in Toowoomba, Australia (ref. Figure 4.a). The collected subgrade soil was subjected to a series of standard geotechnical tests aiming to estimate the basic soil properties. These classification tests were conducted based on the standard procedures stipulated in the Material Testing Manual (MTM) of Queensland Department of Transportation and Main Roads[40]. Figure 1 illustrates the particle size distribution of the subgrade soil and the estimated subgrade soil properties are listed in Table 1. This soil was classified as high plastic silt based on the standard classification guidelines given in Unified Soil Classification System (USCS). Besides, the same soil stands in par with the category A-7-6 of AASHTO soil classification method.

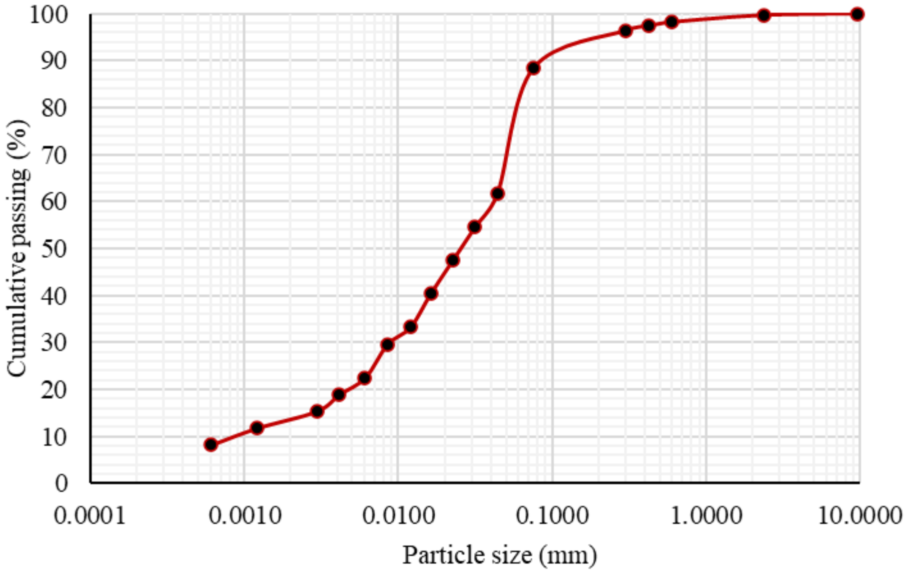

Figure 1. Particle size distribution of subgrade soil

Table 1. Properties of subgrade soil

Soil Property	Value
Soil Particle Density	2.62
Maximum Dry Density (g/cm^3)	1.316
Optimum Moisture Content (%)	32
Liquid Limit (%)	73
Plastic Limit (%)	53
Shrinkage Limit (%)	20
USCS Classification	MH

2.2 Granular material

A bulk of granular material, classified as type 2.1 based on MTRS05 specification of the Queensland Department of Transport and Main Roads[40] was received from the Logan City Council material storage for road construction (ref. Figure 4.b). The laboratory gradation test was performed, following the TMR specification, and verified that the selected granular material complies with the requirements for "Grading C' under granular material type 2 in MTRS05 specification (ref. Figure 2). In addition, fine ratio, the ratio between the percentage of passing of 0.075mm sieve to the 0.425mm, was estimated at 0.51 and hence, it was confirmed that this granular material complies with TMR specification type 2.1. The standard proctor compaction test for this material confirmed that Maximum Dry Density and Optimum Moisture Content of the granular material as 2.3 g/cm^3 and 7% respectively.

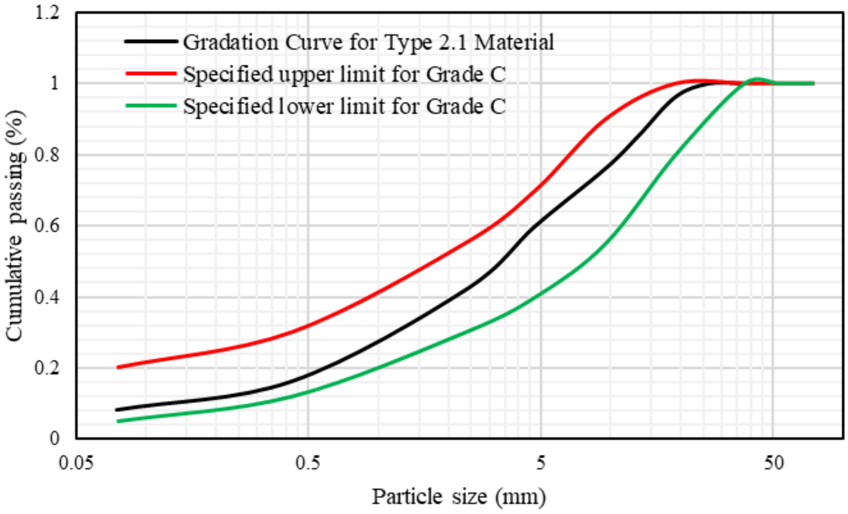

Figure 2. Particle size distribution of type 2.1 material

2.3 Reinforced material

The reinforced material selected for this pavement model testing was a welded type composite geogrid made of a polypropylene with a non-woven geotextile as the bottom layer (ref. Figure 3). The aperture size of the geogrid was measured as 31mm x 31mm and the tensile strength in both machine direction and cross machine direction was specified as 40kN/m. Table 2 lists the manufacturer specifications of the selected type of composite geogrid.

Figure 3. Composite geogrid

Table 2. Technical specifications of composite geogrid

Property	Value	Unit
Geogrid		
Ultimate tensile strength (MD/CMD)	≥ 40/40	kN/m
Elongation at nominal strength	800%	%
Tensile strength at 2% elongation	≥ 16/16	kN/m
Tensile strength at 5% elongation	≥ 32/32	kN/m
Aperture size	31 x 31	mm
Geotextile		
Maximum tensile strength (MD/CMD)	7.5/11	kN/m
Elongation at maximum tensile strength (MD/CMD)	40/30	%

MD-Machine direction, CMD - Cross machine direction

3 Large scale model test

The pavement models were constructed in a steel test box with length width and height of 1.0m, 1.0m and 1.2m, respectively. In this study, two test models: i.e. one unreinforced and one reinforced with composite geogrid, were prepared and subjected to monotonic loading. In each pavement model, a weaker subgrade of CBR 2.5% was constructed at the bottom of the model box to a thickness of 500mm. The granular layer was constructed on top of the subgrade layer to a height of 200mm for both reinforced and unreinforced tests. In some countries, unbound granular is mainly used to construct the granular base layer of pavement, while subbase is usually constructed by suitable soil. However, it is common to use granular material to construct a subbase layer in Queensland, Australia, as finding suitable soil is challenging in the vicinity. Therefore, this study used unbound granular material to construct a cover layer on the subgrade. In the reinforced test section, the composite geogrid was placed between subgrade and granular cover and hereafter will be referred as “interface”.

3.1 Material preparation

The black soil was air dried aiming to remove moisture to a possible extent. This has left larger lumps of clay that are rock hard and difficult to break for remixing with water to achieve the desired moisture content. Therefore, a mechanical crusher was used for crushing the clay lumps into small sizes (ref Figure 4.c). Afterwards, the subgrade soil was oven-dried at 60 degrees of Celsius for further removing of moisture. A series of trial CBR tests were conducted to establish the relationship between the unsoaked CBR of subgrade soil with moisture content and the degree of compaction. Accordingly, it was decided to mix dried subgrade soil with water to achieve 46.5% moisture content, which can be used to create a weaker subgrade of 2.5%. Further details of estimating CBR relationship with soil properties could be found in [41]. The prepared subgrade soil was stored in airtight containers and completely sealed and cured for minimum of 7 days to sequalise moisture throughout the soil.


(a) (b) (c)

Figure 4. a). Clay type black soil; b). Type 2.1 granular; c). Mechanical soil crusher

As same as subgrade soil, type 2.1 gravel were oven-dried at 60 degrees of Celsius for at least 2 days to remove moisture. Thereafter, the gravel was mixed with water to achieve a gravimetric moisture content of 5.5%. In real road construction, water is added into granular to increase moisture content closer or above optimum moisture content, which demands less effort to achieve the desired level of compaction. Subsequently, the compacted granular layer is left to be dried for a certain time to reduce the moisture content. In this way, the premature shear failure of gravel layer can be eliminated. However, as it is practically difficult to follow the same method in model box testing, it was decided to maintain the moisture content of the granular layer 1.5% below the optimum moisture content to avoid premature shear failure.

3.2 Preparation of model sections

The schematic arrangement of a model section is illustrated in Figure 5. At first, a 500mm thick subgrade layer of CBR 2.5% was compacted at the bottom of the model box. This subgrade was compacted as 10 equivalent layers of 50mm each to maintain uniformity across the subgrade layer. From the standard CBR trials, it was confirmed that a subgrade of CBR 2.5% could be created by compacting subgrade soil of 46.5% moisture to a density of 1.118 g/cm^3. Accordingly, the required amount of soil for a 50mm layer was calculated and dumped into the model box. Thereafter, the soil was carefully levelled and manually compacted using a hand tamper that is 20kg in weight and has a square shape bottom of 200mm length of each side. The tamping hammer was dropped from a height of 150mm approximately throughout the compaction process to ensure applying of equal compaction energy. After compacting the layer to 50mm height, the top surface of the layer was scratched prior to compacting the next layer to ensure bonding between adjacent layers. The granular cover was constructed on the completed subgrade by following the same procedure as the subgrade layer. However, a mechanical compactor (see. Figure 6.c) was used to compact granular layer instead of hand tamper owing to the fact that the achievement of the desired compaction of 100% (from MDD) in the unbound granular layer is difficult with a hand tamper. In addition, all efforts were taken to maintain equal duration to prepare each layer.

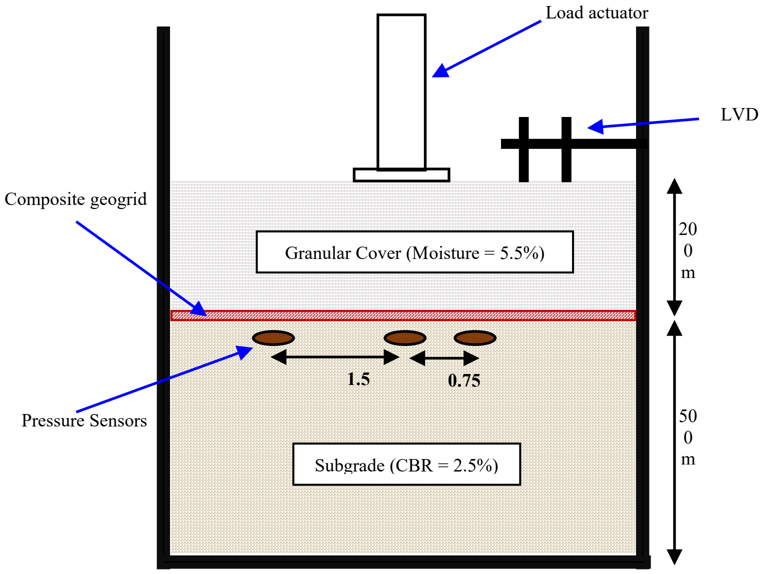

Figure 5. Schematic arrangement of a test section

The composite geogrid was placed at the interface in the reinforced test section. The geogrid was trimmed to fit the internal dimensions of the steel test box and thereafter, was placed on the subgrade. The four corners were anchored with u shaped pins of 5cm to ensure that the geogrid stays flat until the first 50mm granular layer was constructed. Placing the geogrid flat is important, owing to the reason that an initial deformation can have a significant impact on the performance of geogrid. Both reinforced and unreinforced test pavement models were instrumented with pressure plates, moisture sensors and Linear Variable Differential Transducers (LVDTs) to obtain the necessary data to analyse the behaviour of two pavements under monotonic loading. Finally, a monotonic loading at a rate of 1mm/min deformation was applied on the granular surface through a circular loading plate of 200mm diameter until to the ultimate failure state (see Figure 6.a.).

(a) (b) (c)

Figure 6. a). Loading with 200mm plate; b). Model test box; c). Mechanical compactor

4 Results and discussion

4.1 Effect of composite geogrid layer

The surface stress vs deformation graphs for unreinforced and geogrid reinforced model subgrade sections are illustrated in Figure 7. It was observed that the stress required for a certain deflection in reinforced section is significantly higher than that of the unreinforced section. However, the stress to make a deflection up to 2mm was found almost equal for both reinforced and unreinforced sections. Moreover, the ultimate stress of the reinforced section was observed as 1975 kPa while the unreinforced section has recorded ultimate stress of 1290kPa. Hence, it can be seen that the composite geogrid has increased the ultimate stress of the improved subgrade by 1.53 times. Hence, it is evident that composite geogrids can contribute to a significant improvement of the bearing capacity of a weak subgrade. In fact, Abu-Farsak et al. [38] has also observed similar behaviour for biaxial and triaxial geogrids covered by a 305mm thick granular layer.

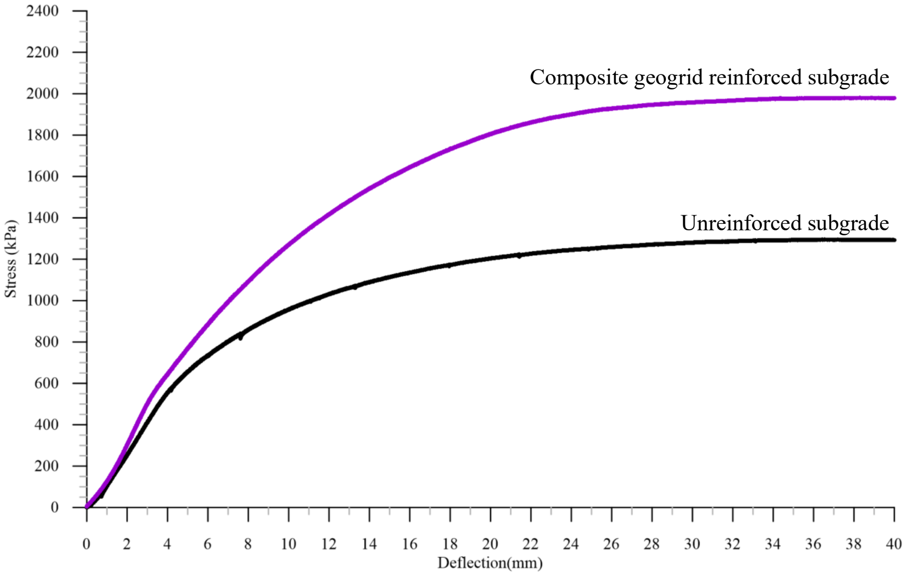

Figure 7. Stress vs deformation of unbound granular test pavements under monotonic loading

The Plate Load Test results can be used to derive different types of elastic modulus such as initial tangent modulus, tangent modulus at given stress level, reloading modulus and secant modulus [38]. The elastic modulus from the plate load test could also be calculated at given stress by the following equation:

$$E_{PLT} = \frac{2P(1-\upsilon^2)}{\pi R\delta} \qquad \text{Equation 1}$$

Where P is the applied load; R is the radius of the loading plate, δ is the deflection of plate at load P, and υ is the Poisson ratio. Using equation 1, elastic modulus for both reinforced and unreinforced sections were calculated at 17.27 kN vertical load which is equal to 550kPa stress on top of the granular surface, equal to the standard tyre load. The Poisson ratio was assumed as 0.5 and the elastic modulus of the unreinforced section was estimated as 10.31MPa, while the elastic modulus of the reinforced section was estimated as 13.3 MPa. This provides clear evidence that composite geogrid reinforcement can contribute to the improvement of pavement modulus.

4.2 Vertical stress at base-subgrade interface

The vertical stress distributions at interface level for reinforced and unreinforced sections were measured by three pressure transducers placed 50mm below the base subgrade interface. These pressure transducers were arranged as one at the centre of the loading plate and other two are 1.0D and 1.5D away from the center of the loading plate in the same line, where D is the diameter of loading plate. Figure 8 shows the vertical stress distribution measured along the centerline of the plates when the vertical stress applied on the granular surface is 1290kPa. The geogrid reinforced section shows a clear reduction of transferred vertical stress at the centre compared to the unreinforced subgrade section. This is due to the increased vertical stress distribution angel and tension membrane effect of geogrid. Moreover, it is also evident that vertical stress is distributed at a maximum circular area of 1.5D radius at the interface level. In addition, vertical stress at the interface is negligible beyond 1.5D away from the centre of the interface along the centerline of pressure plates.

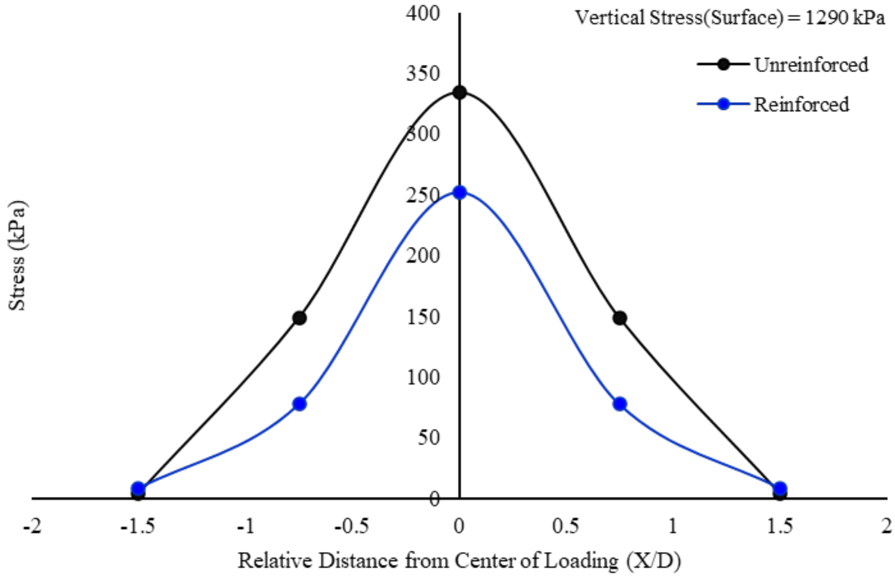

Figure 8. Vertical stress distribution at interface level

In past studies, researchers have reported a reduction of vertical stress at the centre of base subgrade interface in the reinforced section compared to the unreinforced model[36]. Furthermore, Abu-Farsakh et al. [38]has observed an increase of vertical stress at 1.0D and 2.0D away from the centre at the interface in the reinforced section compared the unreinforced section. Moreover, they have observed a vertical distribution of stress around an area of 2.0D radius. Hence, that study has concluded that geogrid reinforcement redistributes the applied load to a wider area. In contrast, this study has recorded a lower vertical stress at 0.75D away from the center of interface. A slight increase of vertical stress was observed at 1.5D away from the center of interface in the reinforced section than the unreinforced section.

5 Conclusion

This study has tested two instrumented laboratory scale model sections under a monotonic load. One of the subgrades was reinforced with a composite geogrid, placed at granular subgrade interface, while the other model was considered as the control test. Based on the observed test results, the study has drawn the following conclusions:

- A composite geogrid on the subgrade with a 200mm granular cover improves the ultimate bearing capacity of a weak subgrade with the same granular cover by approximately 1.5 times.
- The composite geogrid at interface contributes to the improvement of overall pavement modulus.
- Composite geogrid reinforcement demonstrates a 25% reduction of vertical stress at the centre of the granular-subgrade interface.
- The vertical stress distribution spans across a circular area of 1.5D radius on the interface. Moreover, the measured vertical stress at a point beyond 1.5D away from the center is negligible compared to the applied vertical stress inside the circular area of 1.5D radius.
- Although a slight increase of the measured vertical stress at 1.5D away from the center of the granular-subgrade interface was measured in the reinforced section, further investigations are needed to conclude the capacity of composite geogrids to redistribute the stress bulb.

In general, the presented results in this study clearly emphasis that composite geogrids can be used effectively to improve the condition of weak subgrades. However, future studies are needed to investigate the suitability under different conditions such as: increased granular covers and type of gravel. Moreover, it is also recommended to conduct full scale field studies to link laboratory-scale monotonic results with the long-term performance of a geogrid reinforced pavement.

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