PAVEMENT MODEL TESTS TO INVESTIGATE THE EFFECTS OF GEOGRID AS SUBGRADE REINFORCEMENT

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ABSTRACT

The stabilization of weak subgrade is commonly required before placing the pavement structural layers. It is well known that geogrids can be used to reinforce the weak subgrades, however, verification using local conditions is needed to convince road authorities. In this study, two identical model pavements: one without composite geogrid and the other with composite-geogrid reinforcement at the interface of the subgrade-base layer were prepared in a steel box with length, width and height of 1m, 1m and 1.2m, respectively. The 500mm thick subgrade was prepared to achieve a CBR value less than 3% and then a 200mm granular layer was compacted on top of the subgrade to achieve 91% of its maximum dry density. The model pavements were instrumented with Linear Variable Displacement Transducers (LVDTs), soil pressure transducers and moisture sensors. Both pavement models were subjected to repeated loading (more than 110, 000 cycles) at the centre using a 200mm diameter plate to simulate the maximum tyre pressure of 550kPa. The test results showed that the inclusion of composite geogrid at the base-subgrade interface can significantly reduce the rutting depth of granular pavement on weak subgrade (CBR < 3 %). At 50mm rutting, an approximate Traffic Benefit Ratio (TBR) of 5 could be achieved by using composite-geogrid-reinforced subgrade. Furthermore, the pressure transmission to the subgrade was significantly reduced by the composite geogrid at the interface.

1 INTRODUCTION

Weak subgrade materials are commonly found in most areas of Australia. Therefore, thick granular layers are required to be placed as the subbase or base of granular flexible pavements in order to withstand the design number of standard axle repetitions. However, in most countries including Australia, the availability of required quality aggregate materials for road construction is limited. It is even rarer that these materials are available within a short haulage distance (Duncan-Williams and Attoh-Okine 2008). According to Jersey et al. (2012), the abovementioned circumstances have become challenges for transportation professionals, especially when infrastructure systems are built and maintained under shrinking budgets. It therefore demands a solution for significantly reducing the required quantity of aggregate materials for construction and rehabilitation of roadways (Abu-Farsakh et al. 2014).

A number of researches (Ferrotti et al., 2011; Al-Qadi et al., 2011; Jersey et al., 2012; Abu-Farsakh et al., 2014; Kwon and Tutumluer, 2009; Schuettpelz et al., 2009; Tang et al., 2014; Ghafoori and Sharbaf, 2015) agree that the inclusion of geogrid in pavement systems as subgrade reinforcement is a viable option for reducing the granular-base thickness, extending the service life of the pavement and reducing costs. According to (Kwon and Tutumluer, 2009), the required thickness of the aggregate layer depends on the strength of aggregate and subgrade material, and the type and the strength–stiffness characteristics of the geosynthetic reinforcement. The same authors further explained that the required base course thickness can be further reduced when geogrid reinforcement is used instead of geotextiles. This is due to the fact that interlocking of soil and aggregate particles in the apertures of the geogrid creates additional bearing resistance. Conversely, geotextiles placed at the interface of two different material layers avoids intermixing of those materials. Similarly, it maintains the functionality and integrity of pavement materials in different layers (Zornberg, 2017). Therefore, the inclusion of both geotextiles and geogrids in a pavement structure has been identified as the most effective geosynthetic application (Kwon and Tutumluer, 2009). Hence, it is clear that inclusion of composite geogrids, which are geogrids combined with a nonwoven geotextile component, in to the pavement structure assists to maximise the benefits of geosynthetic-reinforcement in granular flexible pavements.

Cyclic plate load tests are well known for successfully demonstrating the effect of geotextile or geogrid reinforcement in pavement structures under repeated loading. In general, the cyclic plate load tests on unpaved granular sections have been carried out as large scale laboratory experiments with unreinforced and reinforced pavement sections in box type experimental setups with different dimensions (Subaida et al., 2009; Palmeira, 2009; Mekkawy et al., 2011; Qian et al., 2012; Suku et al., 2016; Elleboudy et al., 2016; Suku et al., 2017). Similarly, various types of subgrade and base materials with different layer thicknesses have been used for these experimental studies. These experimental studies have been conducted with a different number of load cycles under a selected frequency, simulating the standard tyre pressure (Approximately 550kPa in most of the tests). The effect of different geogrid and geotextile types placed at material interfaces or within material layers has also been investigated. However, no significant study has been reported on the use of composite geogrid as subgrade reinforcement in unpaved road sections. Hence, this research study was conducted to investigate the effects of composite geogrid as a subgrade reinforcement on the performance of granular pavements using laboratory pavement model tests.

2 MATERIALS USED FOR THE STUDY

2.1 COMPOSITE GEOGRID

As shown in Figure 1, a composite geogrid made of Polypropylene was used in this research study. The properties for both Machine Direction (MD) and Cross Machine Direction (CMD) of composite geogrid measured in the library complies with technical specifications "Transport and Main Roads Specifications MRTS58-Subgrade Reinforcement using Pavement Geosynthetics", as shown in Table 1.

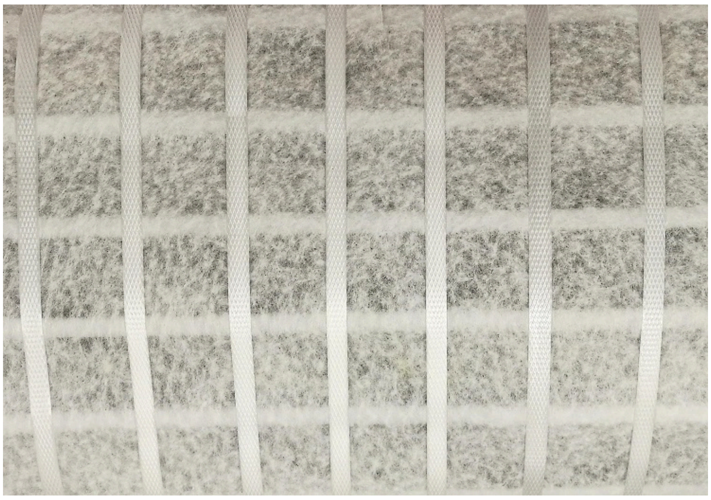


Figure 1: Composite geogrid

Table 1: Properties of composite geogrid

Property	Units	MD/CMD	Pavement geosynthetic property requirement specified in MRTS58	Comply/Non-comply
Nominal Strength	kN/m	30/30	-	-
Maximum Tensile Strength	kN/m	32/39	-	-
Tensile Strength at 2% Elongation	kN/m	16/15	≥ 14	Comply
Tensile Strength at 5% Elongation	kN/m	30/28	-	-
Elongation at Nominal Strength	%	5.0/5.5	-	-
Aperture size	mm	32/32	Min $\geq D_{50} \approx 9.5$ mm Max $\leq 2 \times D_{85} \approx 38$ mm	Comply
Thickness	mm	1.4/1.4	-	-

2.2 BASE MATERIAL

Type 2.3 unbound granular material (UGM) was adopted as the base material in this research study. As shown in Figure 2, the particle size distribution of Type 2.3 UGM measured in the library complies with the technical specifications in "Transport and Main Roads Specifications MRTS05-Unbound Pavements", as illustrated in Figure 2. According to the Standard Proctor compaction test, the maximum dry density and the optimum moisture content of granular material are 2.21 t/m^3 and 7.5% respectively, they are shown in Figure 3 (a).

2.3 SUBGRADE MATERIAL

The subgrade material consisted of Black Soil which is one of the common soil types in Queensland. It is a type of clay soil with shrink-swell properties that exhibits strong cracking when dry. The soil has a liquid limit of 74%, plastic limit of 54% and linear shrinkage limit of 13.5%. According to the Australian Soil Classification, this soil would be classified as Black Vertosols. The specific gravity of this clay soil is 2.62. Based on the Standard Proctor compaction test shown in Figure 3 (b), the maximum dry density and the optimum moisture content of subgrade material are 1.32 t/m^3 and 32% respectively.

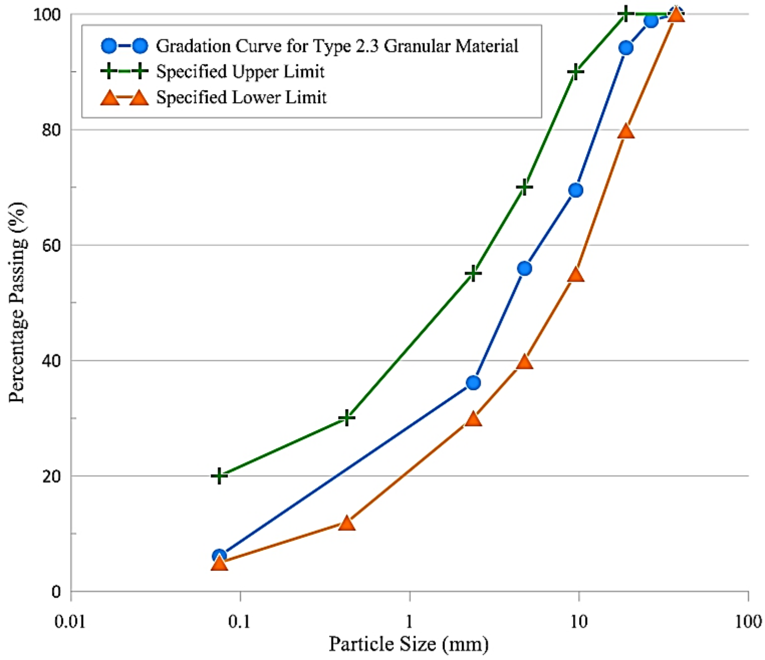
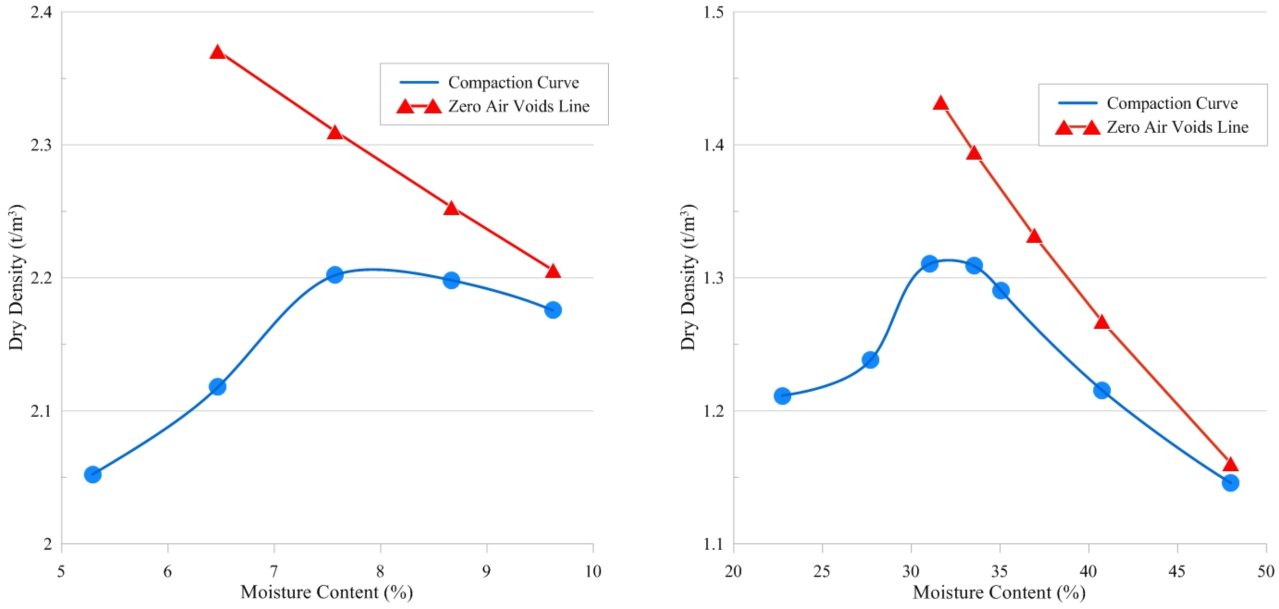


Figure 2: Particle size distribution of base material



(a) **(b)**

Figure 3: Compaction curves of (a) base material; (b) subgrade material, obtained from Standard Proctor Compaction Test

3 THE EXPERIMENTAL SETUP

The unpaved granular pavement section was constructed in a steel test box with internal dimensions of 1.0m (length), 1.0m (width) and 1.2m (height). A hydraulic actuator having the capacity of 500kN was used to load test specimens. The tests were conducted on both unreinforced and reinforced unpaved granular base. The schematic diagram of the experimental setup is shown in Figure 4.

Due to the fact that the cyclic loading applied onto a model pavement structure prepared in a steel box, bubble wrap was installed as a wave absorbing material on the inside walls of the steel box to minimize measurement errors in the data collected from the sensors due to the reflection of the waves at the boundary. Similarly, the diameter of the steel loading plate was limited to 200mm to help to eliminate the boundary effect. Two Tekscan's pressure mapping sensors were used to capture and graphically observe the pressure applied to opposite-inside wall surfaces of the test box.

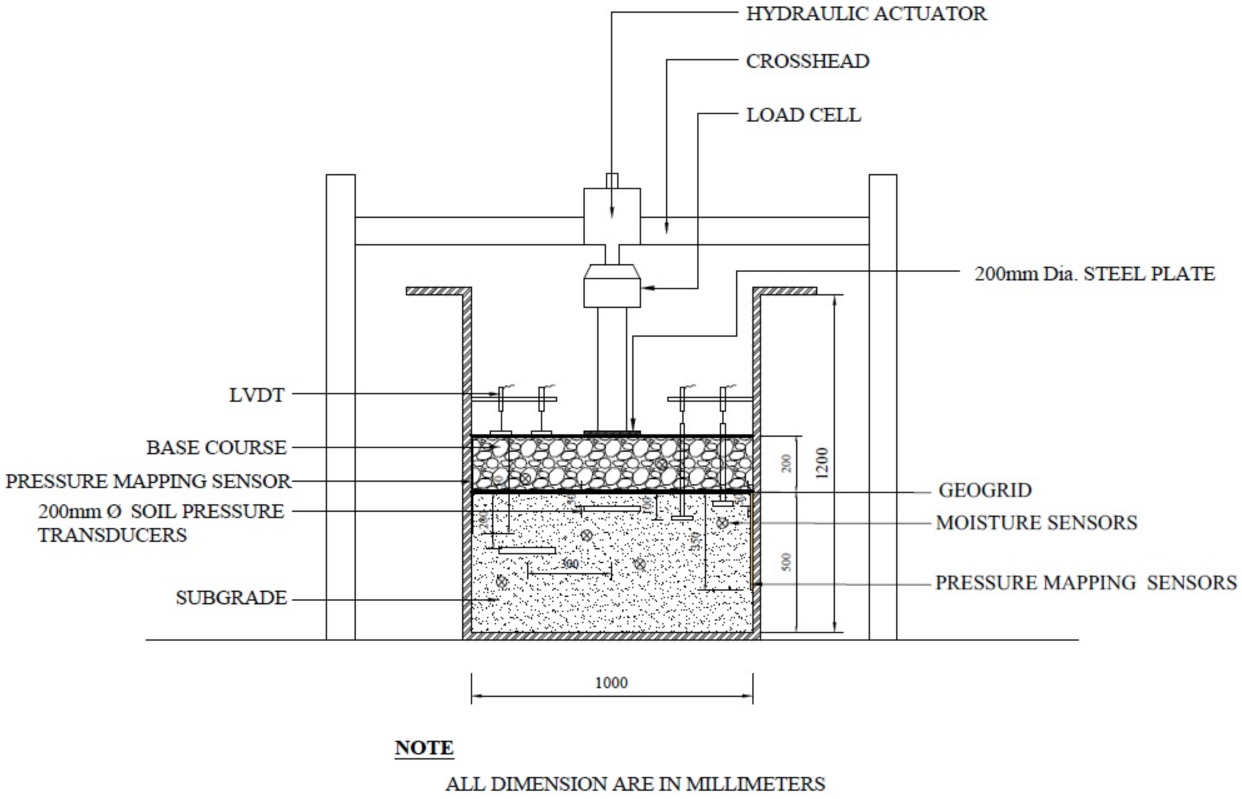


Figure 4: The schematic diagram of the experimental setup

As shown in Figure 4, subgrade soil was compacted into the box up to the height of 500mm from the bottom of the box. The water content and density of the subgrade were maintained at 46±1% and 1.12 t/m^3 (85% of Maximum Dry Density under standard compaction of subgrade material) in both tests in order to achieve the unsoaked CBR value of 2.5%, which was pre-determined through a series of unsoaked CBR tests. Firstly, the required amount of wet soil (approximately 90% degree of saturation) to achieve the dry density of 1.12 g/cm^3 when compacted to the target thickness of 50mm in each lift was measured and placed. After that, the soil was rake levelled and manually compacted to the target thickness of 50mm using a 200mm (length) and 200mm (width) steel plate compactor which has a total mass of 20 kg. The drop height of the compactor was maintained at 150mm while compacting each layer. A 200mm thick granular layer (Type 2.3 UGM) was compacted on the top of subgrade and the thickness of each lift was limited to 50mm. The UGM layer was compacted to achieve a dry density of 2.01 t/m^3 (i.e. 91% of Maximum Dry Density under standard compaction of the granular material), with a moisture content of 5.5±0.5%. In the reinforced pavement section, the composite geogrid was placed at the interface of subgrade and the granular base layer.

Each model pavement section was instrumented with different types and numbers of sensors to measure surface and sub-surface soil deformation, soil moisture content and sub-surface soil pressure, as shown in Figure 4. All sensors were calibrated with the data logging system that was used for these experiments. Soil-specific calibration was conducted for soil moisture sensors in order to accurately measure the water content of pavement materials throughout the experiments. Two Linear Variable Displacement Transducers (LVDTs) were set to measure the vertical surface deformation on the surface of the compacted granular base at 200mm and 350mm distance from the centre of the loading location. The vertical deformation at the centre of the top of the granular layer (loading point) was measured by the loading machine itself. Another two LVDTs were set to measure the subsoil deformation at a depth of 250 mm from the surface and 200 mm and 350 mm from the centre of the loading area. Two more LVDTs were set to measure deformations at a depth of

300 mm from the surface and 200 mm and 350 mm from the centre of the loading area. Two soil pressure transducers, each with 200mm diameter and 25mm thickness, were used to measure the vertical stress applied on the subgrade. One soil pressure transducer was placed 50mm below the interface directly at the centre of the loading area. The other soil pressure transducer was placed 200mm below the interface, 300mm away from the centre.

Once the preparation of the instrumented model box was completed, the pavement section was subjected to cyclic plate loading at the centre of the surface. The loading waveform shown in Figure 5 was repeatedly applied to simulate the wheel loading on pavement. In these experiments, the maximum load of 17.31kN was applied through a 25mm thick and 200mm diameter steel plate to create a tyre contact pressure of 550kPa with a frequency of 0.33Hz. The loading was continued until 90mm permanent deformation was accumulated at the centre or 190,000 loading cycles were reached.

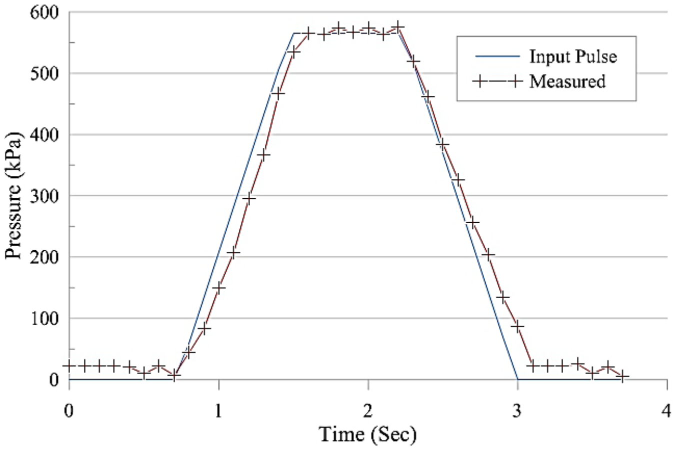


Figure 5: The load pulse applied in the test series

4 RESULTS AND DISCUSSION

4.1 PERMANENT DEFORMATION

Two tests were conducted, one was on the unreinforced section and the other one was on the reinforced section with a geogrid layer placed at the interface of the subgrade and granular layers. The relationship between the number of load cycles and the permanent deformation for both unreinforced and reinforced sections are shown in Figure 6. The plastic deformation was found to be reduced due to the inclusion of composite-geogrid reinforcement.

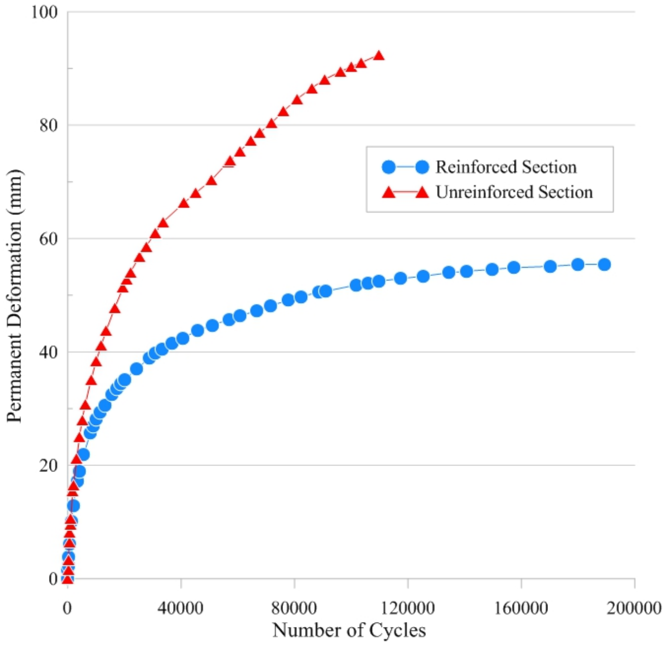


Figure 6: Variation of permanent deformation with a number of cycles

Based on the results from these two tests, a Traffic Benefit Ratio (TBR) was calculated using Eq. (1), in order to determine the benefit of the composite-geogrid reinforcement in granular pavements. The calculated TBR for different rutting depths are shown in Table 2. According to the test results, at 50mm rutting, an approximate TBR of 5 can be achieved by using composite-geogrid-reinforced subgrade. Moreover, TBR is increased when the rutting depth is increased indicating that better performance can be expected when a geogrid-reinforced subgrade is used in a granular pavement.

$$\text{TBR}=\frac{N_U}{N_R} \tag{1}$$

where, N_U is the number of load repetitions on an unreinforced pavement section with same material constitute and geometry to reach the same rutting depth,

N_R is the number of load repetitions on a reinforced pavement section to reach a given rutting depth.

Table 2: Traffic benefit ratio

Rutting depth (mm)	Unreinforced section (number of cycles)	Composite-geogrid reinforced section (number of cycles)	TBR
25	4200	7900	1.9
30	6000	13000	2.2
40	11000	33200	3.0
50	19000	88000	4.6
55	24000	170000	7.1

4.2 VERTICAL STRESSES ON THE SUBGRADE

Figure 7 shows the vertical stress variation with a number of cycles for both unreinforced and reinforced sections at depths of 50mm (at the centre of loading) and 200mm (300mm away from the centre of loading) below the subgrade-granular interface respectively. According to the vertical stress measurements obtained from the soil pressure transducer placed 50mm below the interface at the centre, the vertical stresses kept increasing until approximately 80,000 cycles and then stabilized to a constant value (around 315kPa) for the unreinforced case. For the geogrid-reinforced case, the vertical stresses rapidly increased during the initial cycles, later they slowly decreased by a small magnitude and, then became constant at approximately 230kPa. The maximum vertical stresses measured directly at the centre, 50mm below the interface are 316kPa and 261kPa for unreinforced and geogrid reinforced section, respectively. It is shown that approximately a 25% vertical stress reduction can be achieved at the centre, 50mm below the interface, using the composite-geogrid reinforced subgrade in the granular pavements.

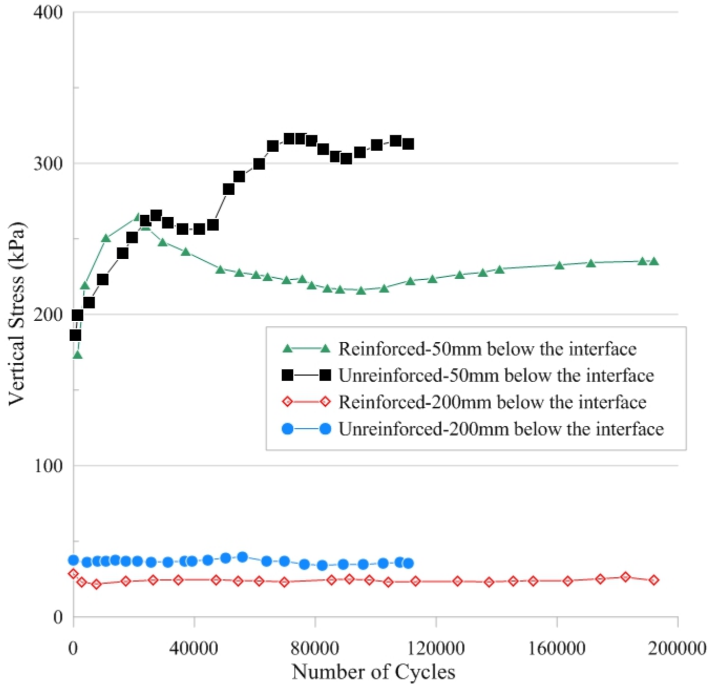


Figure 7: Variation of vertical stresses in subgrade with a number of cycles

The vertical stress measurements obtained from the soil pressure transducer placed 200mm below the interface at 300mm away the centre were moreover constant throughout the test. The approximate vertical stresses applied on this location were around 36kPa and 23kPa for unreinforced and geogrid reinforced cases, respectively. Therefore, it is clear that the vertical stress on this point can be reduced by approximately 36% when the composite-geogrid is used as the subgrade reinforcement in the granular pavements.

5 CONCLUSION

Based on the test results from the experimental study described above, it can be concluded that;

- The inclusion of composite geogrid as subgrade reinforcement can significantly reduce the rutting depth.
- At 50 mm rutting, an approximate TBR of 5 can be achieved by using composite-geogrid-reinforced subgrade.
- The vertical stress applied on the subgrade can be reduced by about 25% - 35% when using a composite geogrid at the interface of the base-subgrade.

6 ACKNOWLEDGEMENT

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