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EFFECT OF GEOGRID REINFORCEMENT IN WEAK SUBGRADES

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ABSTRACT: Geogrids can be identified as comparatively low cost alternative for pavement construction on soft subgrades. However, comprehensive mathematical models are yet to be developed to define the composite behaviour of geogrid pavements. Therefore, it is required to perform pavement model testing to understand the performance of geogrid reinforcements under different pavement and geogrid conditions. Hence, this research study aims to compare the behaviour of composite geogrid in a weaker subgrade (CBR <3%) by performing two pavement model tests under repeated loading conditions. A steel test box with length, width and height of 1m, 1m, 1.2m respectively were used to construct both models with a subgrade having 500mm thickness and 3% CBR. A 200mm thick granular layer was compacted on top of the subgrade by achieving 91% degree of compaction. One model was selected as the control section and a composite geogrid at the base subbase interface was included in the other one. Both pavement models were tested for more than 100,000 repeated load cycles using a 200mm diameter plate on top of the granular base to simulate a tyre pressure of 550kPa. The results demonstrated that the inclusion of a composite geogrid significantly reduced the rutting depth of the granular layer and achieved a Traffic Benefit Ratio (TBR) of 5 at 50mm rutting. Furthermore, a significant reduction of pressure transmission to the subgrade by the composite geogrid was observed.

Keywords: Geogrids, Cyclic Plate Loading, Soft Subgrades, Rutting

1. INTRODUCTION

As most of the Australian soils are expansive in nature [1-4], the weak subgrade is a common issue in road pavement construction across the continent. 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 [5]. However, in most countries including Australia, the availability of required quality aggregate materials for road construction is limited [6]. Although recycled aggregate has been considered as a substitution of natural aggregate [6-9], the yield could not be sufficient to meet the massive aggregate requirement in infrastructure development. It is even rarer that these materials are available within a short haulage distance [12]. According to Jersey [13], 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 aggregate materials for construction and rehabilitation of roadways [14], and introducing geosynthetic reinforcement into the pavement system is one of the best solutions to reduce the material requirement.

Geotextiles have wider geotechnical applications, such as being used in pavement construction [5,15,16], water engineering works [17,18] and environmental applications [19]. Moreover, geogrids are the widely accepted type of geotextiles for soft subgrade treatment. Despite ground improvement techniques such as lime stabilization, geogrids have become popular in subgrade reinforcement [20] owing to its cost effectiveness and convenience in terms of construction. A number of researches [13,14,21-26] 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 [23], 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 avoid intermixing of those materials. Similarly, it maintains the functionality and integrity of pavement materials in different layers [27]. Therefore, the inclusion of both geotextiles and geogrids in a pavement structure has been identified as the most effective geosynthetic application [23]. Hence, it is clear that the inclusion of composite geogrids, which are geogrids combined with a nonwoven geotextile component, into the pavement structure assists to maximise the benefits of geosynthetic-reinforcement in granular flexible pavements[28].

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 [29-33]. 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 Base Material

Type 2.3 unbound granular material (UGM) was adopted as the base material in this research study. The particle size distribution of Type 2.3 granular material is shown in Fig.1.

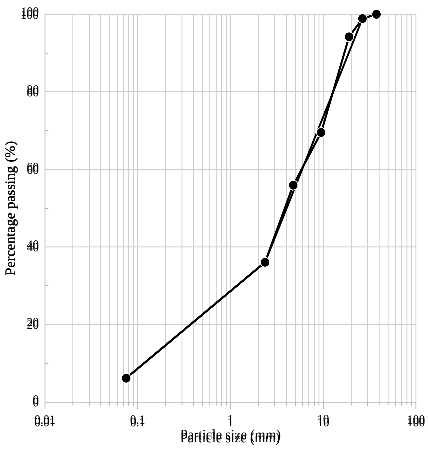

Fig.1 Particle size distribution of the base material

According to the Standard Proctor compaction test, the maximum dry density and the optimum moisture content of granular material are 2.21g/cm^3 and 7.5% respectively, as indicated in Fig.2(a).

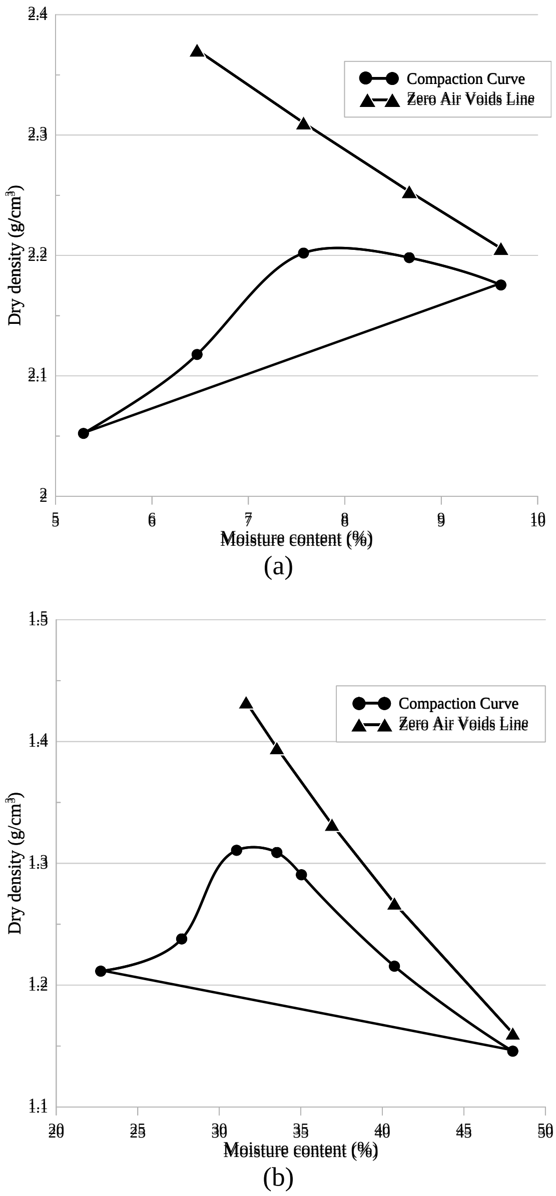

Fig.2 Compaction curves of (a) base material; (b) subgrade material, obtained from Standard Proctor compaction test.

2.2 Subgrade Material

The subgrade material consisted of Black Soil which is one of the common soil types in Queensland. It is a soil with shrink-swell properties that exhibits strong cracking when dry. The soil has a liquid limit of 74%, plastic limit of 54% and a linear shrinkage limit of 13.5%. According to the AASHTO, this soil would be classified as A-7-5, and according to the Unified Classification System (UCS), it would be classified as MH. The specific gravity of this soil is 2.62. Based on the Standard Proctor compaction test shown in Fig.2(b), the maximum dry density and the optimum moisture content of subgrade material are 1.316g/cm^3 and 32% respectively.

2.3 Composite Geogrid

As shown in Fig.3, a composite geogrid made of Polypropylene was used in this research study. The manufacturer-specified properties of both Machine Direction (MD) and Cross Machine Direction (CMD) of composite geogrid have been shown in Table 1. The nominal strength of the composite geogrid is 40kN/m in both directions.

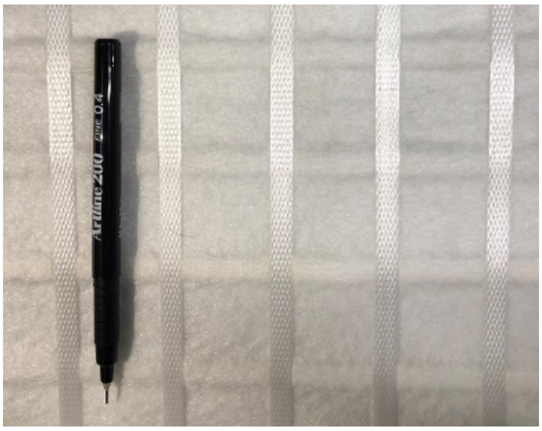

Fig.3 Composite geogrid

Table 1 Properties of composite geogrid

Property	Units	MD/CMD
Geogrid		
Maximum Tensile Strength	kN/m	≥ 40/ ≥ 40
Elongation at Nominal Strength	%	≤ 8/ ≤ 8
Tensile Strength at 2% Elongation	kN/m	16/16
Tensile Strength at 5% Elongation	kN/m	32/32
Aperture Size	mm	31/31
Geotextile		
Maximum Tensile Strength	kN/m	7.5/11
Elongation at Maximum Tensile Strength	%	40/30

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 Fig.4.

As 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.

As shown in Fig.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 1.12g/cm^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 1.12g/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 20kg. 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 2.01g/cm^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 Fig.4. All sensors were calibrated with the data logging system that was used for these experiments. Soil-specific calibration 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

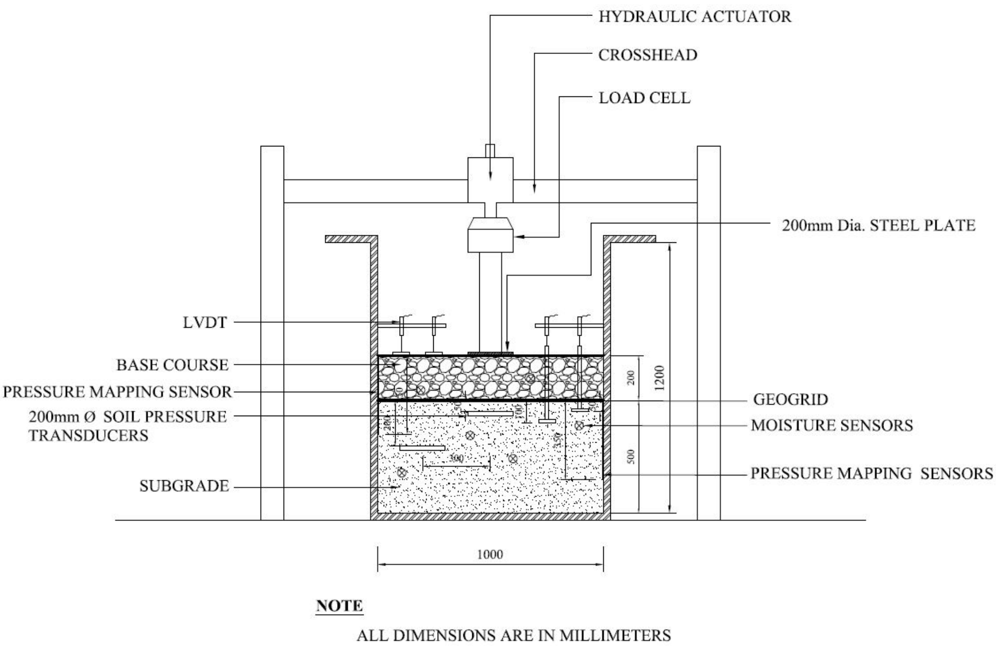

Fig.4 The schematic diagram of the experimental setup

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 25mm from the surface and 200mm and 350mm from the centre of the loading area. Two more LVDTs were set to measure deformations at a depth of 300mm from the surface and 200mm and 350mm 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 Fig. 5 was repeatedly applied to simulate the wheel

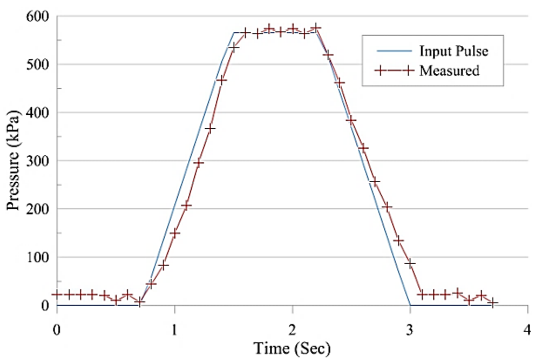

Fig.5 The load pulse applied in the test series

loading on the 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.

4. RESULTS AND DISCUSSIONS

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 Fig. 6. The plastic deformation was found to be reduced due to the inclusion of composite-geogrid reinforcement. In fact, similar behaviour was observed by [34] and [35] with respect to permanent deformation of reinforced and unreinforced sections subjected to cyclic loading. 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 5can be achieved by using composite-geogrid-reinforced subgrade. Moreover, TBR is increased

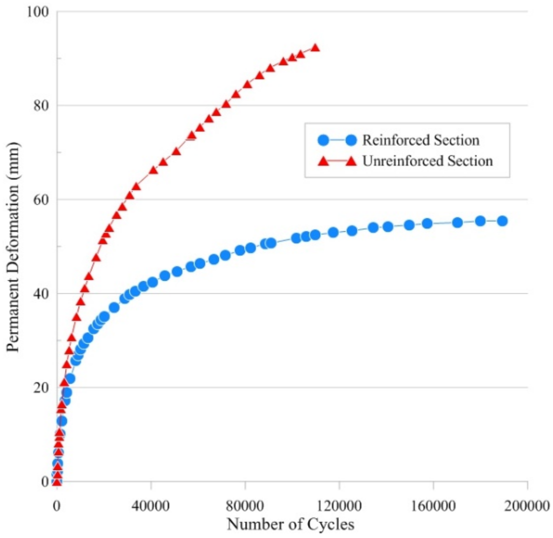

Fig.6 Variation of permanent deformation with a number of cycles.

when the rutting depth is increased indicating that better performance can be expected when a geogrid-reinforced subgrade is used in a granular pavement.

$$TBR=\frac{N_U}{N_R} \quad (1)$$

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 d
epth.

4.2 Vertical Stresses on the Subgrade

Fig. 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. Similarly, [35] and [36] performed the model test for geogrids and geotextiles respectively and reported that the vertical stress at the base subgrade interface is comparatively lower for reinforced section. Also, the geogrid effect is prominent in weak subgrades as geogrid tensile stresses contribute to bear a significant portion of the applied vertical stresses[37].

Table 2 Traffic benefit ratio

Rutting depth (mm)	Unreinforced section (Cycle count)	Geogrid reinforced section (Cycle count)	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

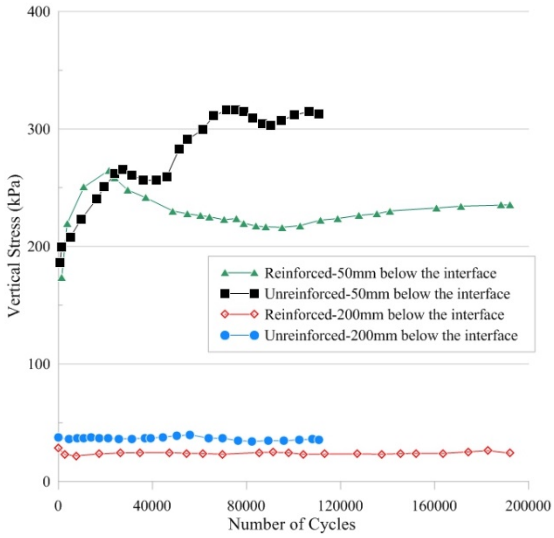

Fig.7 Variation of vertical stresses in subgrade with a number of cycles.

The vertical stress measurements obtained from the soil pressure transducer placed 200mm below the interface at 300mm away the centre were constant throughout the test. The approximate vertical stresses applied to 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 approximately36% when the composite-geogrid is used as the subgrade reinforcement in the granular pavements.

5. CONCLUSIONS

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 50mm 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. ACKNOWLEDGEMENTS

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7. REFERENCES

[1].Kodikara J., Rajeev P., Chan D. and Gallage C., Soil moisture monitoring at the field scale using neutron probe. Canadian Geotechnical Journal, 2013, 51(3):332-45.

[2].Udukumburage R., Gallage C.P. and Dawes L.A., Investigation of the effect of initial water content and surcharge on volume change behaviour of compacted grey vertosol, Proceedings of the 13th Australia New Zealand Conference on Geomechanics, 2019, p1029-1033

[3].Udukumburage R., Gallage C.P. and Dawes L.A., Loaded swell tests to estimate the heave of the expansive soil in instrumented soil column, Proceedings of the 8th International Conference on Geotechnique, Construction Materials and Environment, GEOMATE 2018, p390-395

[4].Gallage C.P., Tehrani N. and Williams D., Instrumented large soil-column to investigate climate-induced ground deformation in expansive soil, Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, 2017, p1147-1150

[5].Gallage C., Eom T., Barker D. and Ramanujam J., Falling Weight Deflectometer (FWD) tests on granular pavement reinforced with geogrids–Case study. Proceedings of the International Conference on Geotechnical Engineering "Geotechnics for Sustainable Development", 2015, Vol. 1, No. 1, pp. 597-600.

[6].Jayakody S., Gallage C. and Kumar A., Assessment of recycled concrete aggregate for road base and sub-base, Proceedings of the Second International Conference on Geotechnique, Construction Materials and Environment, 2012, pp.575-579

[7].Jayakody S., Gallage C. and Ramanujam J., Effects of reclaimed asphalt materials on geotechnical characteristics of recycled concrete aggregates as a pavement material, Road Materials and Pavement Design, 2019, 19;20(4):754-72.

[8].Jayakody S., Gallage C. and Kumar A., Assessment of recycled concrete aggregates as a pavement material, Geomechanics and Engineering, 2014, 6(3):235-48.

[9].Gallage C., Jayakody S. and Ramanujam J., Effects of moisture content on resilient properties of recycled concrete aggregates, Proceedings of Fourth International Conference on GEOMATE, 2014, pp. 394-399.

[10].Clark B.R., Piacere L. and Gallage C.P., Effects of recycled asphalt pavement on the stiffness and fatigue performance of multigrade bitumen asphalt, Journal of Materials in Civil Engineering, 2017, pg.1-8

[11].Zhu C., Chavez-Garcia F.J, Thambiratnam D.P. and Gallage CP, Quantifying the edge-induced seismic aggravation in shallow basins relative to the 1D SH modelling, Soil Dynamics and Earthquake Engineering, 2018, p402-412

[12].Duncan-Williams E. and Attoh-Okine N.O., Effect of geogrid in granular base strength–An experimental investigation. Construction and building materials, 2008, 22(11):2180-4.

[13].Jersey S.R., Tingle J.S., Norwood G.J., Kwon J. and Wayne M., Full-scale evaluation of geogrid-reinforced thin flexible pavements, Transportation Research Record, 2012, 2310(1):61-71.

[14].Abu-Farsakh M.Y., Gu J., Voyiadjis G.Z. and Chen Q., Mechanistic–empirical analysis of the results of finite element analysis on flexible pavement with geogrid base reinforcement, International Journal of Pavement Engineering, 2014, 15(9):786-98.

[15].Gallage C. and Jayalath C., Use of Particle Image Velocimetry (PIV) technique to measure strains in geogrids, E3S Web of Conferences 2019, p. 12007.

[16].Zornberg J.G. and Gupta R., Geosynthetics in pavements: North American contributions, Theme Speaker Lecture, Proceedings of the 9th

International Conference on Geosynthetics, Guarujá, Brazil, Vol. 1, 2010, pp. 379-400.

[17].Cheah C., Gallage C., Dawes L. and Kendall P., Impact resistance and evaluation of retained strength on geotextiles., Geotextiles and Geomembranes, 2016, 1;44(4):549-56.

[18].Cheah C., Gallage C., Dawes L. and Kendall P., Measuring hydraulic properties of geotextiles after installation damage., Geotextiles and Geomembranes, 2017, 1;45(5):462-70.

[19].Weerasinghe I.A., Gallage C. and Dawes L., Optimizing geosynthetic clay liner overlaps: Implications on hydraulic performance, Environmental Geotechnics, 2019.

[20].Gallage C., Cochrane M. and Ramanujam J., Effects of lime content and amelioration period in double lime application on the strength of lime treated expansive sub-grade soils., Proceedings of the 2nd International Conference on Transportation Geotechniques 2012, pp. 99-104.

[21].Ferrotti G., Canestrari F., Virgili A. and Grilli A., A strategic laboratory approach for the performance investigation of geogrids in flexible pavements, Construction and Building Materials, 2011, 25(5):2343-8.

[22].Al-Qadi I.L., Dessouky S., Tutumluer E. and Kwon J., Geogrid mechanism in low-volume flexible pavements: accelerated testing of full-scale heavily instrumented pavement sections, International Journal of Pavement Engineering, 2011, 12(02):121-35.

[23].Kwon J. and Tutumluer E., Geogrid base reinforcement with aggregate interlock and modeling of associated stiffness enhancement in mechanistic pavement analysis, Transportation Research Record, 2009, 2116(1):85-95.

[24].Schuettpelz C., Fratta D. and Edil T.B., Evaluation of the zone of influence and stiffness improvement from geogrid reinforcement in granular materials, Transportation Research Record, 2009, 2116(1):76-84.

[25].Tang X., Stoffels S. and Palomino A.M., Mechanistic-empirical performance prediction of geogrid-modified soft soil subgrade, Geo-Congress 2014: Geo-characterization and Modeling for Sustainability, 2014, pp. 3054-3061.

[26].Ghafoori N. and Sharbaf M., Evaluation of triaxial geogrids for reduction of base thickness in flexible pavements, Bituminous Mixtures and Pavements VI, 2015, pp. 141.

[27].Zornberg J.G., Functions and applications of geosynthetics in roadways, Procedia engineering, 2017, 189:298-306.

[28].Shahkolahi, A., & Crase, J.,Application of geogrids and geocomposites in designing working platforms on cohesive subgrades; Case study: Harvey norman bulky goods development, Australia, Proceedings of the 5th Asian Regional Conference on Geosynthetics,2012.

[28].Subaida E.A., Chandrakaran S. and Sankar N., Laboratory performance of unpaved roads reinforced with woven coir geotextiles, Geotextiles and Geomembranes, 2009, 27(3):204-10.

[29].Palmeira E.M., Soil–geosynthetic interaction: modelling and analysis, Geotextiles and Geomembranes, 2009, 27(5):368-90.

[30].Mekkawy M.M., White D.J., Suleiman M.T. and Jahren C.T., Mechanically reinforced granular shoulders on soft subgrade: Laboratory and full-scale studies, Geotextiles and Geomembranes, 2011, 29(2):149-60.

[31].Qian Y., Han J., Pokharel S.K. and Parsons R.L., Performance of triangular aperture geogrid-reinforced base courses over weak subgrade under cyclic loading, Journal of Materials in Civil Engineering, 2012, 25(8):1013-21.

[32].Elleboudy A.M., Saleh N.M. and Salama A.G., Assessment of geogrids in gravel roads under cyclic loading, Alexandria engineering journal, 2017, 56(3):319-26.

[33].Suku, L., Prabhu, S. S., & Babu, G. S., Effect of geogrid-reinforcement in granular bases under repeated loading, Geotextiles Geomembranes, 45(4),2019, pg. 377-389

[34].Byun, Y. H., & Tutumluer, E., Local stiffness characteristic of geogrid-stabilized aggregate in relation to accumulated permanent deformation behaviour, Geotextiles and Geomembranes, 47(3), 2019, pg. 402-407.

[35].Palmeira, E. M., & Antunes, L. G., Large scale tests on geosynthetic reinforced unpaved roads subjected to surface maintenance, Geotextiles and Geomembranes, 2010, pg. 547-558.

[36].Subaida, E., Chandrakaran, S., & Sankar, N., Laboratory performance of unpaved roads reinforced with woven coir geotextiles, Geotextiles and Geomembranes, 2009, pg. 204-210.

[37].Mekkawy, M. M., White, D. J., Suleiman, M. T., & Jahren, C. T., Mechanically reinforced granular shoulders on soft subgrade: Laboratory and full scale studies, Geotextiles and Geomembranes, 2011, pg. 149-160.