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A large California Bearing Ratio (CBR) mould to quantify the effectiveness of geogrid-reinforced subgrades

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ABSTRACT: Geogrids have successfully been used to reinforce granular pavement layers to reduce rutting and increase the resilient modulus. Past studies have shown that the geogrids can stabilise weak subgrades (CBR < 3 %) to build the platform for the pavement layers. However, all the past research studies have emphasised the importance of investigating the effectiveness of geogrid-reinforcement with local materials. Therefore, this study attempts to investigate how geogrid can be used to stabilise weak expansive soil (Black soil) subgrade in Queensland, Australia or elsewhere and how to estimate the improved CBR valve /vertical elastic modulus (E_v) (E_v = 10 x CBR) of geogrid-reinforced subgrade to be used with the existing granular pavement design charts. To achieve the objectives of this study, a large CBR mould (diameter of 305 mm and the height of 520 mm) was designed and built to minimise the boundary effects when testing geogrid-reinforced subgrades. A subgrade with CBR < 3 % was compacted into the mould up to the height of 240 mm. Then a granular layer with different thicknesses (e.g 50 mm, 100 mm, and 150 mm) was placed on the top of the subgrade with and without geogrid at the interface (subgrade - granular). Each sample was subjected to monotonic loading at the centre using a 61 mm diameter plunger and the obtained load penetration curves were used to determine the CBR values following the standard procedure. The CBR value of the geogrid-reinforced sample was greater than that of unreinforced sample. However, the percentage increase of CBR value due to geogrid-reinforcement decreased with the increase in the granular layer thickness above the geogrid.

1 INTRODUCTION

Currently, geogrid is extensively used throughout Europe and the United States of America as a subgrade reinforcement. However, extensive design guidelines do not yet exist in Australia. This is primarily due to the abundance of locally available subbase material for the pavement construction in the past. However, nowadays, there is an increased demand for methods that reduce the required granular base thickness in a pavement structure due to the fact that the performance maximization and competing demands of cost minimization are main concerns for pavement designers and maintainers at the state and local levels.

Geogrids can be used to stabilise weak subgrade, especially when the subgrade CBR is less than 3 % (Demir et al. 2013). This subgrade stabilisation involves placing geogrid between the subbase and subgrade layers to increase stiffness and to reduce the permanent deformation (rutting) of the pavement structure. These enhanced performances are caused by particle interlocking and membrane effects of geogrids (Bergado et al. 1993). Therefore, it is important to consider geogrid-enhanced properties in the pavement design to build long lasting, low cost, and climate resilient pavements on weak subgrades.

In Austroads pavement design guidelines (Austroads 2012), granular pavements with thin bitumen surfacing are designed using empirical design charts. These charts need the design traffic in ESAs (Equivalent Standard Axels) and subgrade CBR value to determine the minimum cover thickness of the pavement. Therefore, to use these charts to design granular pavements with subgrades stabilised with geogrids, the CBR value of the stabilised subgrade should be known. The standard CBR mould can't be used to determine CBR value of the subgrade stabilised with geogrid as a multi-layer specimen with a geogrid has to be moulded and boundary effects need to be minimised (Nair & Latha 2010).

Therefore, in this study, a large CBR mould with a 305 mm diameter and a 500 mm height was designed and built. Then it was used to determine the CBR value of the subgrade stabilised with a geogrid and layer of gravel on top of the geogrid. A series of CBR tests using this large CBR moulds were conducted and the benefits of having a geogrid at the interface in subgrade stabilisation were assessed.

2 MATERIALS USED FOR THIS STUDY

2.1 *Geogrid*

The biaxial geogrid (Fig. 1) used for this research study is made of Polypropylene and is commercially available. Due to its physical properties for both Machine Direction (MD) and Cross Machine Direction (CMD) mentioned in Table 1, it has a wide range of potential uses including the subgrade stabilisation. The geogrid product selected for this research study meets the current technical specifications outlined in “Transport and Main Roads Specifications MRTS58-Subgrade Reinforcement using Pavement Geosynthetics” (DTMR, 2017a).

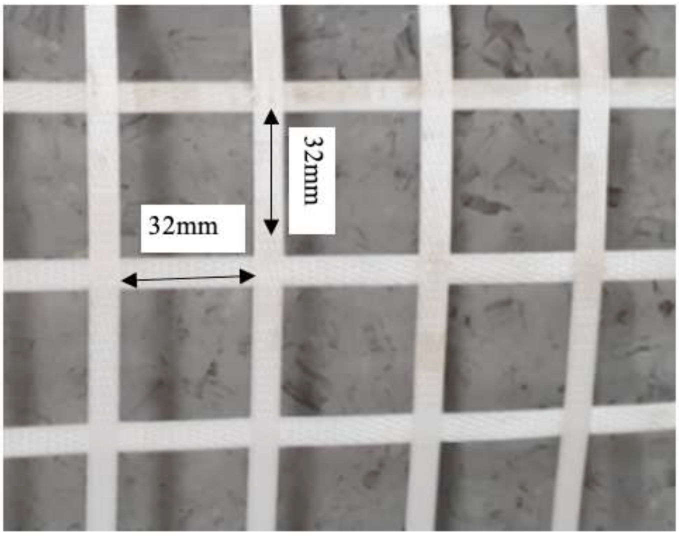

Figure 1. Biaxial polypropylene geogrid (Aperture 32mm x 32mm)

Table 1. Physical properties of geogrid

Property	Units	MD/ CMD	MRTS58 Specification	Compliant/ Non-compliant
Nominal Strength	kN/m	30/30	-	-
Maximum Tensile Strength	kN/m	32/32	-	-
Tensile Strength at 2% Elongation	kN/m	11/12	≥ 10.5	Compliant
Aperture Size	mm	32/32	Min ≥ D ≈ 9.5 mm Max ≤ 2 x D ≈ 38 mm	Compliant
Thickness	mm	1.4/.4	-	-

2.2 *Subbase Material*

Unbound granular material (UGM) classified as Type 2.3 according to DRMT (2017b) was selected as the subbase material for this experimental study. The particle size distribution for this material is shown in Figure 2, and it complies with “Transport and Main Roads Specifications MRTS05-Unbound Pavements” as the gradation curve is within the specified upper and lower limits (DTMR, 2017b). According to the Standard Proctor compaction test results shown in Figure 3, the maximum dry density and the optimum moisture content are 2.08 t/m³ and 8.5% respectively.

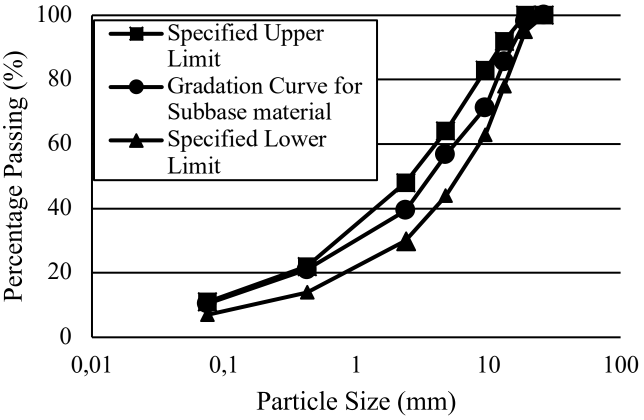

Figure 2. Grain size distribution of subbase material

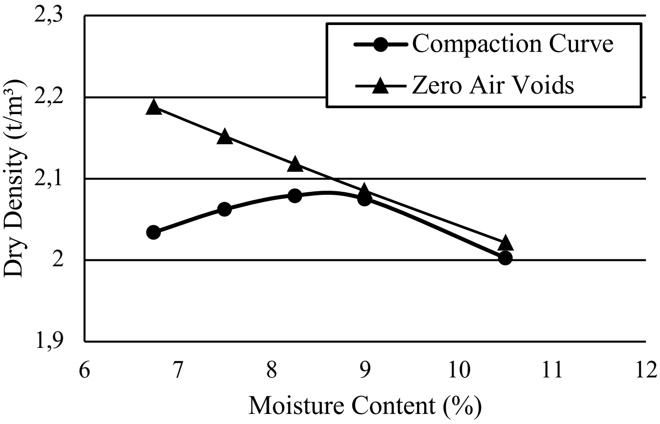

Figure 3. Compaction curve of subbase material

2.3 *Subgrade Material*

The subgrade material used for this research study is typically known as black clay, and it is commonly found in most of the regions in Queensland, Australia. This soil was selected due to its poor strength and wide availability. According to the Australian Soil Classification, this soil is classified as Black Vertisol. Based on the results of the Standard Proctor compaction test shown in Figure 4, the maximum dry density and the optimum moisture content of this soil are 1.48 t/m³ and 27.65 % respectively.

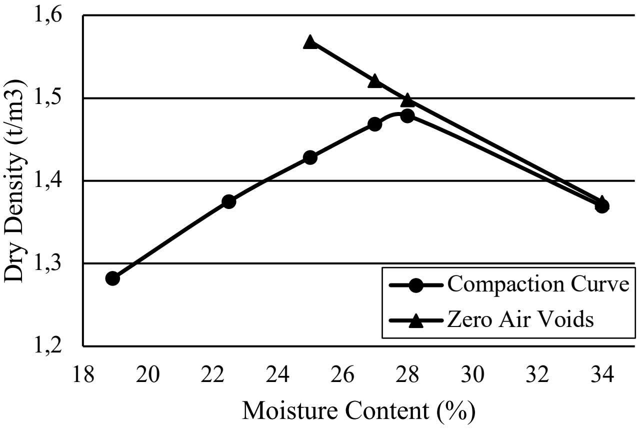

Figure 4. Compaction curve of subgrade material

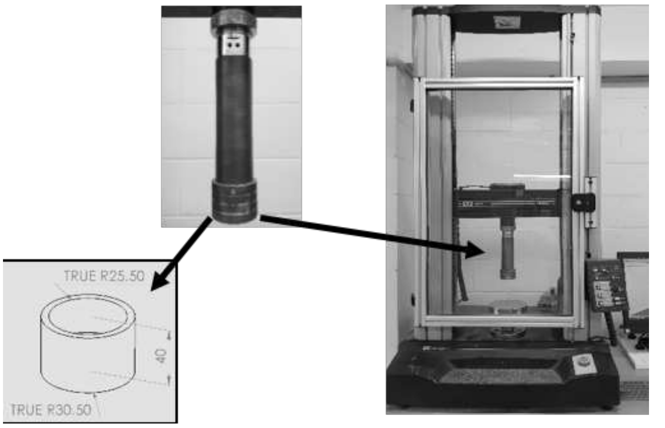

Figure 6. Universal testing machine with modified plunger attachment used for testing

3 TESTING APPARATUS

In order to assess the stiffness (CBR value) of geogrid-reinforced subgrade, a large cylindrical mould with the internal diameter of 305 mm and the height of 520 mm was designed and built at QUT and it is shown in Figure 5. The cylindrical mould was made of 5 mm thick galvanised mild steel, whereas the base is made of 20 mm thick anodised mild steel. In addition, it has a 2 mm thick cylindrical aluminium internal sleeve which facilitates the easy removal of the compacted sample. The loading plunger was designed having an external diameter of 61 mm which maintains the same plunger-to-mould diameter ratio (1:5) as in the standard CBR test. All the tests were performed using an Instron Universal Testing Machine (Figure 6) which has the capacity of 50kN.

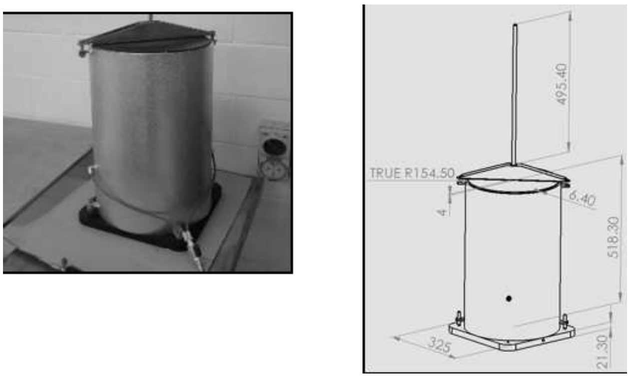

Figure 5. The newly designed CBR mould

4 METHODOLOGY AND TEST PROGRAM

First, a series of standard CBR tests were conducted on subgrade material at different moisture contents and dry densities to find out the moisture content and the dry density to achieve the CBR value of 3 or less. The moisture content of 31 % and the dry density of 1.40 g/cm^3 were found to achieve the CBR value of 3.

When preparing test samples in the large CBR mould, the soil mixed with 31% of moisture content (after allowing 7 days for moisture equalisation) was manually compacted into the CBR mould in six equal layers having a layer thickness of 40mm to reach the total subgrade thickness of 240mm. The amount of wet soil required to achieve the dry density of 1.4 g/cm^3 in a 40 mm thick layer was calculated and that amount poured into the mould and compacted to achieve the pre-determined height.

Once the subgrade is fully compacted, the geogrid was placed on top of the subgrade (some test samples were prepared without a geogrid layer on top of the subgrade. Then, similar to subgrade preparation, the subbase material (Type 2.3 gravel) mixed with 8.5 % was poured into the mould and manually compacted into 50 mm thick layers to achieve the dry density which is 95 % of the maximum dry density under standard compaction.

Once the sample was prepared, the loading was applied through a 61 mm diameter plunger. During the load application, the applied load and the corresponding displacement were recorded and the load-deformation curves were produced. These load-deformation curves were used to estimate the CBR values following the standard CBR test procedure (AS 1289.6.1.1:2014)

5 RESULTS AND DISCUSSION

Figure 7 shows the load versus deformation curves obtained for the unreinforced test samples. Four curves were produced by loading samples with 0 (subgrade only), 50 mm, 100 mm, and 150 mm granular base layer thickness on top of the subgrade. Test results show that the stiffness and the load bearing capacity of the subgrade increase with the increase in the granular layer (cover) thickness. It is well understood that the increase in cover thickness reduces the stress applied on the weak subgrade. Therefore, the overall deformation of the layered pavement structure decreases with the increase in the cover thickness above the subgrade resulting higher overall stiffness and the bearing capacity of the pavement structure.

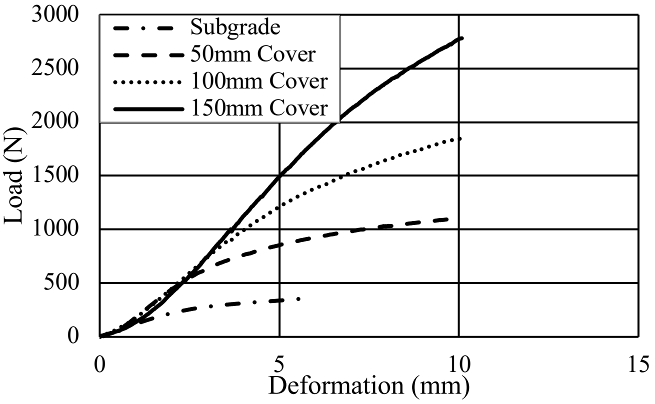

Figure 7. Load versus deformation curves for the unreinforced condition

To investigate the effects of geogrid at the base-subgrade interface on the overall stiffness and bearing capacity the stabilised subgrade, three tests were conducted: zero cover layer (subgrade only), 100 mm thick cover layer, 100 mm thick cover layer with a geogrid at the interface. The load-deformation curves of these three tests are depicted in Figure 8. It can be seen that the weak subgrade can be enhanced/improved significantly by placing a granular layer on the top. When a geogrid is introduced at the base-subgrade interface, the better performance than the structure without geogrid can be achieved. So, it is evidenced that geogrid can enhance the performance and stiffness of subgrade stabilised with geogrid.

The geogrid can confine the granular material adjacent to it through particle interlocking and this can lead to the greater overall stiffness and higher bearing capacity. Further, when the geogrid is loaded, it is subjected to tension. This tension-membrane effect will increase the overall bearing capacity of the layered structure.

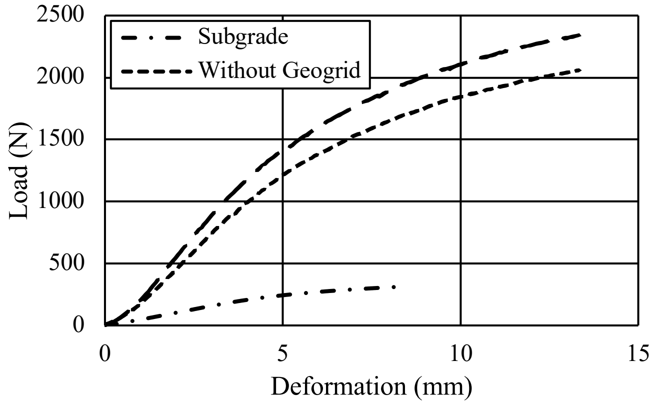

Figure 8. Load versus deformation curves for test specimens with 100mm granular layer

To assess the benefit of geogrid in subgrade stabilisation and the effects of the thickness of granular cover layer, a series of tests were conducted with and without geogrid at the interface and with different cover layer thicknesses (e.g 50 mm, 100 mm, and 150 mm). The load-deformation curve of each test was used to calculate the CBR value following the stan-dard CBR procedure given in AS 1289.6.1.1. Figure 9 depicts the CBR values obtained from the unreinforced and geogrid-reinforced test samples with different cover layer thicknesses. Irrespective of the thickness of granular cover layer, test results clearly demonstrate that irrespective of the thickness of gra-nular cover layer, the higher CBR values are achieved for the geogrid-reinforced subgrades compared to that of unreinforced test specimen when the granular thickness is higher.

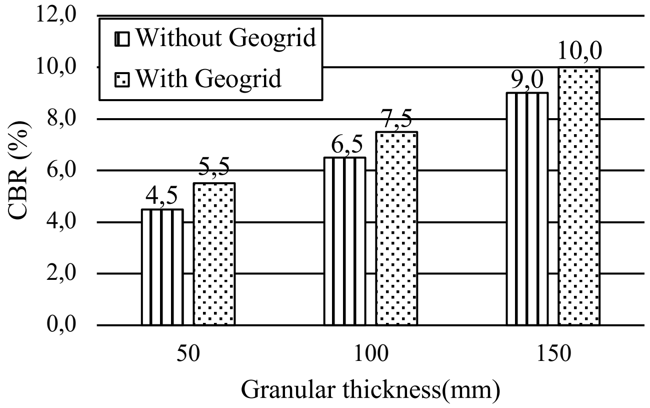

Figure 9. The effect of geogrid and cover thickness on CBR

To investigate the effects of the cover thickness on the improvement in CBR due to geogrid, the percentage increase in CBR of reinforced subgrade over the unreinforced subgrade was calculated for each granular layer thickness. The variation of the percentage increase in CBR was plotted with the granular layer thickness as shown in Figure 10.

It is also evident from Figure 10 that the effectiveness of geogrid reinforcement (the percentage of increase in CBR) decreases when the granular thickness is increased. For example, the percentage increment in CBR is approximately 22 % for 50 mm granular thickness, and it is reduced to 11 % when a 150 mm granular thickness is used. It is evidenced that the benefit of geogrid decreases with the increase in the cover thickness. Thus, it is important to determine the optimum cover thickness to be used with the geogrid-reinforced subgrade. As the cover thickness increases, the induced stress at the depth of geogrid decreases. The geogrid will not be tensioned to induce tension-membrane effects as well as the confinement to gravel particles by the interlocking mechanism.

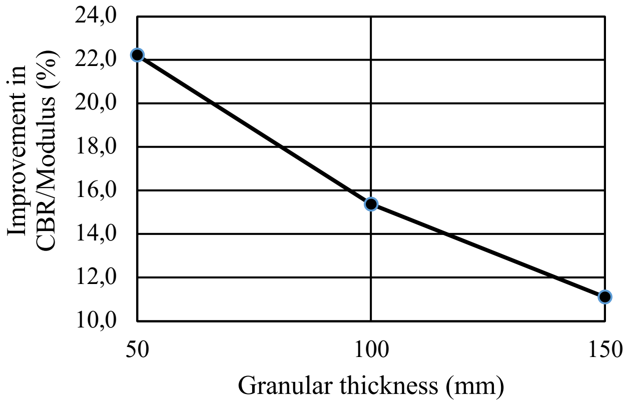

Figure 10. The variation of the percentage increase in CBR value due to geogrid reinforcement with cover thickness

There is a significant improvement in the CBR value in the geogrid-reinforced subgrade (subgrade + geogrid + granular layer) compared to the subgrade without any stabilisation (CBR = 1 %). This shows that the subgrade stabilisation using geogrid reinforcement can be effectively used to minimise the required quantity of granular materials as well as the associated construction and maintenance costs of pavement structures. Similarly, the CBR values obtained from the large CBR mould on unreinforced and reinforced subgrades can be used with granular design charts to determine the cover thicknesses and then assess the possible cost benefits due to geogrid-reinforcement of the subgrade.

In this study CBR value was calculated using a non-standard mould, loading plunger, and without standard surcharged load. It is thus required that the CBR values obtained from this mould are to be correlated with the values obtained from the standard CBR tests. Then the correlations can be used to obtain standard CBR values from this large CBR mould test to be used in the pavement design. Further, the performance of geogrid-reinforced need to be studied through model tests and pavement trial tests to validate the results of this large CBR tests so that the proposed large CBR mould test could be standardised to specify a geogrid product for the stabilisation of a weak subgrade.

6 CONCLUSIONS

This study attempted to assess the benefit of geogrid in subgrade stabilisation. The proposed laboratory testing method would be enhanced and validated to estimate the overall CBR value of geogrid-reinforced subgrade. The following conclusions can be drawn from this study:

- The higher granular cover thickness over a weak subgrade is the stiffer the pavement structure.
- Geogrid at the subgrade-subbase interface will increase the overall stiffness and the bearing capacity of the pavement structure.
- The percentage increase in the CBR due to geogrid will decrease with the increase in the thickness of granular cover over the geogrid.

7 ACKNOWLEDGMENTS

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8 REFERENCES

AS 1289.6.1.1-2014, Methods of testing soils for engineering purposes - Soil strength and consolidation tests - Determination of the California Bearing Ratio of a soil - Standard laboratory method for a remoulded specimen. 2014, Standards Australia.

Austroads. 2009. Guide to Pavement Technology Part 6: Unsealed Pavements. Austroads Inc. Sydney: Australia.

Austroads. 2012. Austroads Guide to Pavement Technology Part 2: Pavement Structural Design. Austroads Inc.: Sydney, Australia.

Bergado, D.T. Chai, J.C. Abiera, H.O. Alfaro, M.C. & Balasubramaniam, A.S. 1993. Interaction between cohesive-frictional soil and various grid reinforcements. *Geotextiles and Geomembranes.* 12(4): 327-349.

Demir, A. Laman, M. Yildiz, A. & Ornek, M. 2013. Large scale field tests on geogrid-reinforced granular fill underlain by clay soil. *Geotextiles and Geomembranes*. 38: 1-15. doi:10.1016/j.geotexmem.2012.05.007

DTMR, Transport and Main Roads Specifications MRTS58 Subgrade Reinforcement using Pavement Geosynthetics. 2017a. Department of Transport and Main Roads.

DTMR, Transport and Main Roads Specifications MRTS05 Unbound Pavements. 2017b. Department of Transport and Main Roads.

Nair, A.M. & Latha, G.M. 2010. Modified CBR Tests on Geosynthetic Reinforced Soil-aggregate Systems. *Indian Geotechnical Conference – 2010*, GEOtrendz.