An Australian approach for designing geogrid reinforced flexible pavements

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ABSTRACT: The use of geosynthetic materials has become an acceptable practice in road construction including flexible pavements as a sustainable environmentally friendly solution. Studying the behavior of geogrid reinforced roads over the last 40 years has led to several empirical and mechanistic-empirical methods being developed for the design of geosynthetic reinforced unpaved and paved roads. There is no single design method for this application in the world as the road conditions vary from one region to another. Adopting an empirical design method from another region or indeed another country requires local verification and calibration. In Australia, the peak organisation of Australasian road transport and traffic agencies (Austroads) offers a design method for unreinforced flexible pavements and gives some recommendations for using geosynthetics but there is no design guideline for geogrid reinforced pavements. Local road authorities such as Queensland Transportation and Main Roads (QTMR) has published a product specification for geogrids in subgrade reinforcement, but again without providing a design method for this application. This paper reviews the available pavement design methods in Australia and provides a design procedure in accordance with Australian design guidelines for geogrid reinforced flexible pavements based on international and local experience and test results.

Keywords: geogrid, subgrade reinforcement, flexible pavement, Austroads

1 INTRODUCTION

Geosynthetic reinforcement provides short-term and long-term benefits and improves the performance of the road over its design life. When used in flexible pavements, geosynthetic reinforcement provides two main benefits: reducing the pavement thickness (Base Course Reduction-BCR), and/or increasing the serviceability and design traffic (Traffic Benefit Ratio-TBR) as well as reducing the maintenance work required and cost (Perkins el. Al 1997, Perkins et al. 2005). In the case of a very weak subgrade, geosynthetics can also provide a thinner and stiffer working platform or semi-infinite subgrade for road construction. This will again lead to a reduction in the pavement thickness or increase in the design traffic indirectly, as the pavement will have a stiffer subgrade. Geosynthetics offer a cost-effective alternative to other expensive stabilisation methods such as dewatering, excavation and replacement with a thick layer of selected granular material, realignments, or chemical methods such as lime or cement stabilisation. A geosynthetic reinforced layer enables contractors to meet the required deflection criteria beneath the subbase layer. Geosynthetics improve the reliability of the pavement and its long term performance, especially for weak subgrade conditions (Perkins et al. 2005, Perkins et al. 2010).

Current Australian guidelines do not consider the benefit of the geogrid reinforcement in designing pavements on soft subgrades. The only geosynthetic application discussed and recommended in pavement design guideline by the peak organisation of Australasian road transport and traffic agencies (Austraods) is the use of geotextile for separation and filtration. According to Section 3.14.1 *Soft Subgrades* of Austroads 2012 Guide to Pavement Technology Part 2: Pavement Structural Design, some form of treatment or, alternatively, a working platform, is required to enable construction over soft subgrades with CBR values less than 3%, to assist in compaction of pavement layers and to provide improved stability over the life of the pavement. Using a geotextile is suggested in this section to provide separation and filtration to the working platform layer (Austroads 2012). Local State road authorities have also published specifications for required properties of a geotextile to be used as a separation and filtration layer (MRTS27 2017, R63 2017).

Some local guidelines such as the QLD Pavement Design Supplement, Supplement to 'Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology suggest a working platform wrapped in a separation/filtration geotextile layer as a treatment for construction on soft subgrades with a design CBR of less than 3%, and provide a design table for the suggested working platform, but no use of geogrids and their confinement benefit is considered in these guidelines (QLD pavement design 2013). Geogrids are not included in the current Austroads empirical pavement design charts nor can be modelled in the current Austroads mechanistic pavement design method and relevant software called CIRCLY. On the other hand, the current geogrid specification available in Australia (MRTS58) published by QTMR is only a product specification for subgrade reinforcement and does not provide any design procedure (MRTS58 2015).

Christopher and Wardle (2013) studied two approaches for considering the benefits of geogrids within current Australian design methods. Results showed that the benefit of geogrid reinforcement in improving the vertical modulus and stiffness of a geogrid reinforced layer and reducing the pavement thickness cannot be completely evaluated and calculated following the current Austroads approach and equations. Their research also demonstrated that the suggested equation in section 8.2.2 of "Part 2: Pavement Structural Design' of the Austroads Guide to Pavement Technology for determining the vertical modulus of the top sublayer of selected subgrade (Austroads 2012) cannot be used for geogrid reinforced layers as it ignores any additional improvement from geogrid reinforcement and confinement effects.

This paper suggests a useful method to combine the current Australian pavement design method including Austroads design charts and CIRCLY software with geogrid reinforcement benefit, which enables designers to consider the real benefit of geogrid reinforcement.

2 CURRENT AUSTRALIAN PAVEMENT DESIGN APPROACH

Austroads provides both empirical and mechanistic pavement design approaches. Pavement types addressed in the empirical section are those which are comprised of unbound layers of granular material and which are surfaced with either a bituminous seal or thin asphalt (less than 40 mm thick). The design procedure is based on an empirical design chart which provides the allowable design traffic in terms of rutting and shape loss of these pavements. This design chart does not make any provision for a limitation on the allowable design traffic caused by the fatigue cracking of an asphalt surfacing. Two separate design charts are provided by Austroads for moderate-to-heavily trafficked pavements and lightly-trafficked flexible pavements (Austroads 2012). To assess the fatigue life of such surfacing, the use of mechanistic procedures is suggested. The thickness of an unbound granular pavement required over the subgrade is determined using these empirical design charts, the subgrade design CBR and the design traffic in Equivalent Standard Axle (ESA). Figure 1 shows the empirical design chart for moderate-to-heavily trafficked pavements without any geogrid reinforcement.

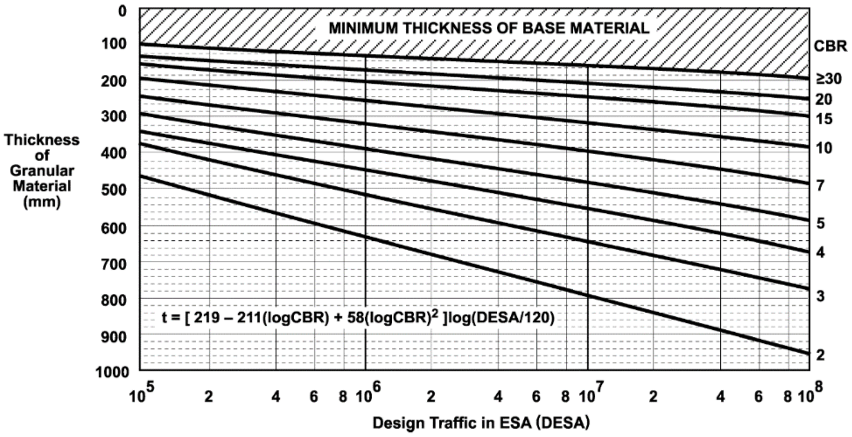


Figure 1. Empirical Austroads design charts for moderate-to-heavily trafficked pavements (Austroads 2012).

The Austroads mechanistic design procedure is based on the structural analysis of a multi-layered pavement subject to normal road traffic loading. In the mechanistic design of flexible pavements, the pavement is designed to limit the vertical compressive strain at the top of the subgrade to a tolerable level throughout the life of the pavement.

Response to load is calculated using a linear elastic model, such as the computer program CIRCLY (Mincad Systems 2004). The critical responses assessed for pavement and subgrade materials are horizontal tensile strain at bottom of asphalt layer, horizontal tensile strain at the bottom of the cemented layer, and vertical compressive strain at the top of the subgrade and the selected subgrade material. The vertical compressive strain at the top of the subgrade is actually taken as a determinant for surface rutting in the unbound portions of the pavement structure. The critical locations of the strains within a pavement model with an idealised loading situation are shown in Figure 2.

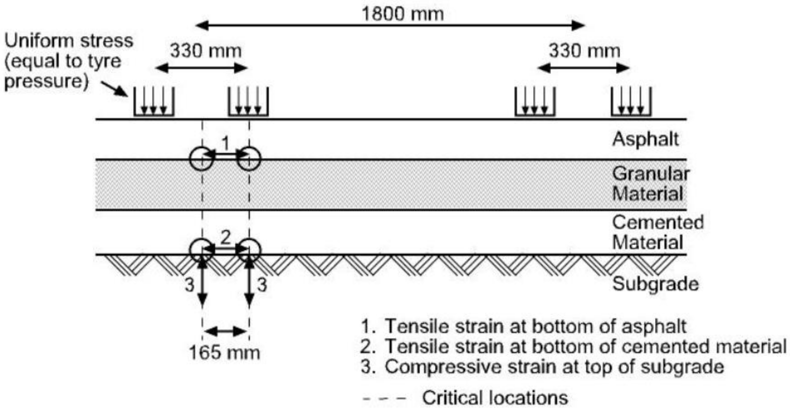
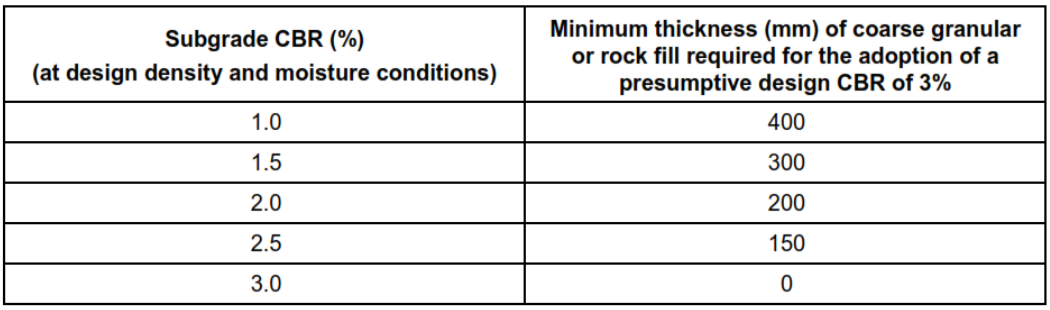


Figure 2. Pavement model for mechanistic design procedure (Austroads 2012).

In summary, the procedure consists of evaluating the input parameters (subgrade CBR, pavement material properties, traffic, environment etc.), selecting a trial pavement section, analysing the trial pavement to determine the allowable traffic, comparing this with the design traffic, and finally accepting or rejecting the trial pavement. The selection of a trial pavement involves determining the pavement materials to be used, the thicknesses and modulus of each material and the relative positions of these materials in the pavement. As a result, geogrid reinforcement cannot be modelled directly as a separate layer in the currenty available linear elastic models such as CIRCLY. At this time neither the specific inputs for geogrid reinforcement nor the method for evaluating the benefits of using geosynthetics are included in the current version of CIRCLY.

If a subgrade design CBR value is less than 3%, then some treatment is suggested prior to the pavement construction (Austroads 2012). For example, according to QLD Pavement Design (2013), “for flexible pavements that are designed mechanistically, and where the pavement design subgrade strength is less than 3%, a rockfill working platform or semi-infinite subgrade wrapped in the separation geotextile is suggested. A presumptive design CBR is typically adopted for the semi-infinite/working platform layer which accounts for the combined strength of the soft subgrade and the treatment”. The suggested presumptive CBR in the supplement is minimum 3%. The supplement provides a table for the required thickness for the semi-infinite subgrade for the adoption of a presumptive CBR of 3% on top (Figure 3). The use of additional geogrid reinforcement and the benefits are not considered and addressed in this supplement/design table, or other similar national or local guidelines.



Subgrade CBR (%) (at design density and moisture conditions)	**Minimum thickness (mm) of coarse granular or rock fill required for the adoption of a presumptive design CBR of 3%**
1.0	400
1.5	300
2.0	200
2.5	150
3.0	0

Figure 3. Minimum thickness of (unreinforced) coarse granular or rock fill required for the adoption of a presumptive design CBR of 3% (QLD Pavement Design 2013)

3 DESIGNING GEOGRID REINFORCED FLEXIBLE PAVEMENTS IN ACCORDANCE TO AUSTRALIAN GUIDELINES

3.1 *Background*

As mentioned, the Australian design approach of flexible pavements is to limit the vertical compressive strain at the top of the subgrade. Geogrid reinforcement can be used in the subgrade treatment to limit the subgrade strain and provide a stiffer semi-infinite subgrade/working platform. To be able to consider the effect of geogrid reinforcement in reducing the deformation or improving the stiffness of a granular layer, the deformation modulus (Ev) is used. The deformation modulus Ev can be obtained using the expressions from DIN 18134 Plat Load Test. Plate Load Test is a test in which a load is repeatedly applied and released in increments using a circular loading plate aided by a loading device, with the settlement of the loading plate being measured. According to DIN 18134, Ev expresses the deformation characteristics of a soil, calculated from the secants of the load settlement curves obtained from the first or repeat loading cycle between points $0.3\sigma_{0max}$, and $0.7\sigma_{0max}$, where σ_{0max} is the maximum average normal stress below the loading plate in the first loading cycle (DIN 18134). The strain modulus Ev1 can also be calculated from the curve of the first loading cycle and the strain modulus Ev2 can be calculated from the curve of the second loading cycle.

Various laboratory and field studies show the effect of geogrid reinforcement in improving the strain modulus of a granular layer. For example, Minazek and Mulabdic (2014) used a large box with dimensions of 1900x900x1200 mm to facilitate the plate load test. The standard plate load test in accordance to DIN 18134 was used to determine the reinforced soil modulus. Test results showed up to a 39% increase in the deformation modulus Ev1 and up to a 12% increase in the deformation modulus Ev2 of the soil layer reinforced with a biaxial laid and welded geogrid, compared to an unreinforced section with the same thickness and properties (Figure 4). This verifies the reduction in the layer deformation and improvement in the layer stiffness due to the geogrid reinforcement. As a result, a geogrid reinforced layer can be used as a semi-infinite subgrade with reduced deformation and higher modulus underneath the pavement.

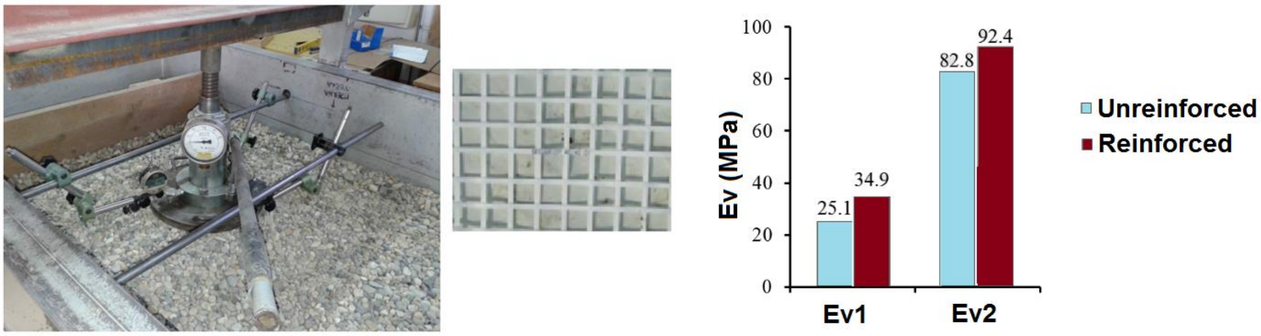


Figure 4. Deformation modulus Ev1 and Ev2 in tests on unreinforced and geogrid reinforced soil of the same thickness with the biaxial laid and welded geogrid (Minazek and Mulabdic, 2014)

By measuring the improved Ev2 value on top of the geogrid reinforced layer, the equivalent CBR value on top of the reinforced layer can be calculated using experimental equations. This equivalent CBR value can then be used as a new presumptive CBR on top of the geogrid reinforced layer (geogrid reinforced semi-infinite subgrade) in the Austroads mechanistic design method (CIRCLY) or within Ausroads empirical design charts. As the measured Ev2 is based on field Plate Load Tests from insitu granular layer and existing subgrade, it reflects the real behavior and performance of the geogrid and geogrid reinforced layer in field conditions.

3.2 *Design procedure*

As this procedure is used for soft subgrades, reinforcement and separation are both required. A geocomposite including a geogrid (for reinforcement) and a nonwoven geotextile (for separation/filtration) is suggested to be used instead of a nonwoven geotextile alone in the Austroads design procedures (e.g. suggested procedure and table by QLD Pavement Design (2013) for the required thickness of a semi-infinite subgrade. As a result, a geocomposite reinforced semi-infinite subgrade/working platform can be built instead of a traditionally working platform with a separation geotextile. This can be applied by excavating the soft subgrade and replacing it with a geocomposite reinforced granular material, or by placing a geocomposite reinforced granular material directly on top of the existing subgrade. Through using a geocomposite instead of a separation geotextile, reinforcement and separation can be achieved at the same time. In conclusion, a thinner semi-infinite subgrade can be built and a higher presumptive CBR value can be achieved on top of that geocomposite reinforced semi-infinite subgrade compared to the traditionally presumptive CBR value of 3% for an unreinforced section. The higher modulus and correlated CBR due to the geocomposite reinforcement can be used instead of traditionally suggested presumptive design CBR of 3% in the empirical or mechanistic pavement design procedures using Austraods design charts or CIRCLY.

A minimum improved presumptive CBR of 12.5%, equivalent to Ev2 of 45 MPa (Schwabbaur et al. 2002), is suggested to be achieved on top of the geocomposite reinforced semi-infinite subgrade according to international guideliness and best practice (RStO12 2015). The required thickness of the geocomposite reinforced semi-infinite subgrade to achieve the presumptive CBR of 12.5% (Ev2 of 45 MPa) or higher depends on the subgrade condition, type of granular material, and the type of geogrid, and can be determined using onsite testing or relevant design charts for each geogrid. By using these design charts, the required thickness for a geocomposite reinforced layer to achieve an improved presumptive CBR (e.g. 12.5% or 15%) can be determined. This layer acts as the semi-infinite subgrade. The improved presumptive CBR will then be considered as the new subgrade design CBR value to be used in CIRCLY or within Austroads empirical design charts to design the pavement layers including subbase and base layer.

This approach is practical as it is based on field tests and measurements and can be applied for different geogrids. It can provide up to a 50% saving in the pavement thickness depending on the subgrade conditions, the granular material used and the design traffic. This procedure has been used in various projects in Australia and the performance of the pavement has been verified through field measurements and monitoring. Figure 5 briefly shows the design procedure.

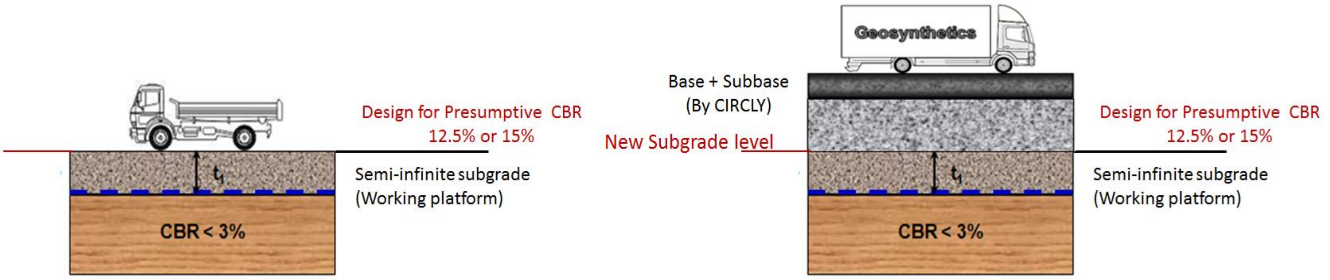


Figure 5. Design procedure for geogrid reinforced pavement in accordance to Australian design methods.

3.3 *Design charts for geogrid reinforced semi-infinite subgrade*

Some design charts were presented in the report by Saathoff et al. (1999) for Ev2 modulus for unreinforced unbound granular layers and geogrid reinforced layers using a biaxial punched & drawn (extruded) geogrid. These charts provided the required thickness with and without geogrid reinforcement for the formation layer to achieve a specific Ev2 modulus (45 Mpa, 80 Mpa, or 150 MPa) for different subgrade conditions and granular materials using the specific biaxial punched & drawn (extruded) geogrid. In 2000, Reuter et al. (2000), developed similar design charts for a laid and welded geogrid on the basis of multiple verification field trials using plate loading tests following the methodology of DIN 18134. In 2003, a design manual for the laid and welded geogrid was published which included different design charts for different granular materials (Geogrid Design Manual 2003). A design software was also developed to determine the required semi-infinite subgrade thickness with and without the laid and welded geogrid based on the above design manual and design charts. These design charts or design software can be used to design the required thickness of the geogrid/geocomposite reinforced semi-infinite subgrade to achieve the target presumptive CBR value of 12.5% or 15%, as described in the design procedure in section 3.2.

4 DESIGN EXAMPLE

The above procedure is adopted for a flexible pavement with a 40mm sealing layer, subgrade design CBR of 2% and design traffic of 2,000,000 ESA. The results are then compared to the unreinforced pavement with and without the treatment layer as suggested by the QLD Pavement Design (2013).

4.1 *Geogrid reinforced design*

As the design subgrade CBR is less than 3%, the geosynthetic material to be used is a geocomposite. A laid and welded geocomposite combined of a laid and welded biaxial geogrid for reinforcement and an integral nonwoven geotextile integrated between geogrid bars for separation and filtration has been used. A geocomposite reinforced semi-infinite subgrade is used to achieve a target Ev2 and equivalent CBR value. The target Ev2 on top of the semi-infinite subgrade is selected to be 45 MPa, which is equivalent to a CBR value of about 12.5%. The design software discussed in section 3.3 was used to determine the required thickness for the semi-infinite subgrade layer to achieve the target CBR value of 12.5% on top of the reinforced layer, which resulted in a 200mm well graded crushed gravel. This means 200mm excavation of the existing subgrade and replacing with a laid and welded biaxial geocomposite plus a 200mm well graded compacted crushed gravel layer on top. This layer is considered as the foundation layer or semi-infinite subgrade with the presumptive CBR value of 12.5% on top (figure 6).

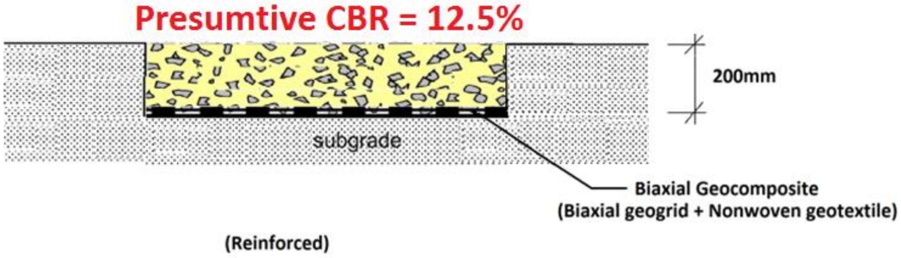


Figure 6. Geocomposite reinforced semi-infinite subgrade to achieve target presumptive CBR value of 12.5%

The presumptive CBR value of 12.5% is then used as the new design CBR within Austroads charts or CIRCLY to design the pavement structure, which leads to a 100mm of subbase material and 140mm of base course material being required (figure 7).

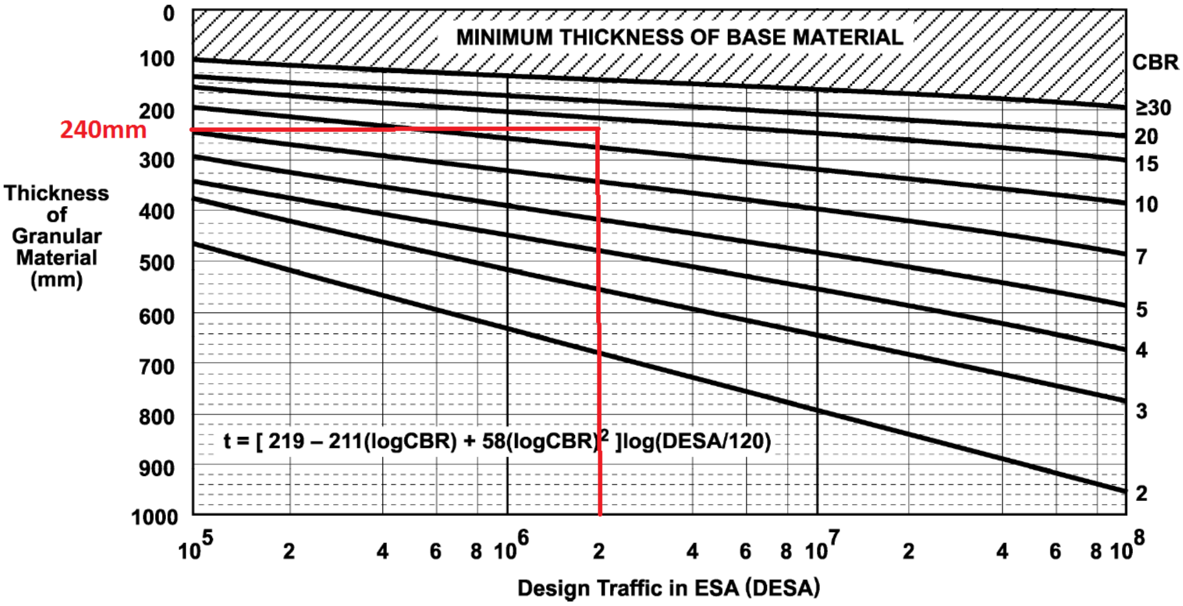


Figure 7. Using Austraods design chart to design the pavement on top of the geocomposite reinforced semi-infinite subgrade

The total required thickness of the granular layer to be used in the project will then be 200mm of semi-infinite subgrade plus 100mm of subbase plus 140mm of base or 440mm in total using a laid and welded biaxial geocomposite underneath the semi-infinite subgrade.

4.2 *Unreinforced design*

As the subgrade CBR is less than 3%, the QLD Pavement Design (2012) was followed for subgrade treatment and construction of a semi-infinite subgrade. As a result, a 200mm geotextile wrapped granular layer is required as the semi-infinite subgrade. The presumptive design CBR will then be 3% on top of the semi-infinite subgrade as suggested by the supplement. By using Austroads design charts or CIRCLY and a design CBR of 3% for the subgrade, the required pavement thickness will be 550mm of base and subbase layer. The total thickness of the granular layer to be used in this project will be 750mm without using any geogrid reinforcement.

Figure 8 compares an unreinforced layer with a geogrid reinforced layer for this example.

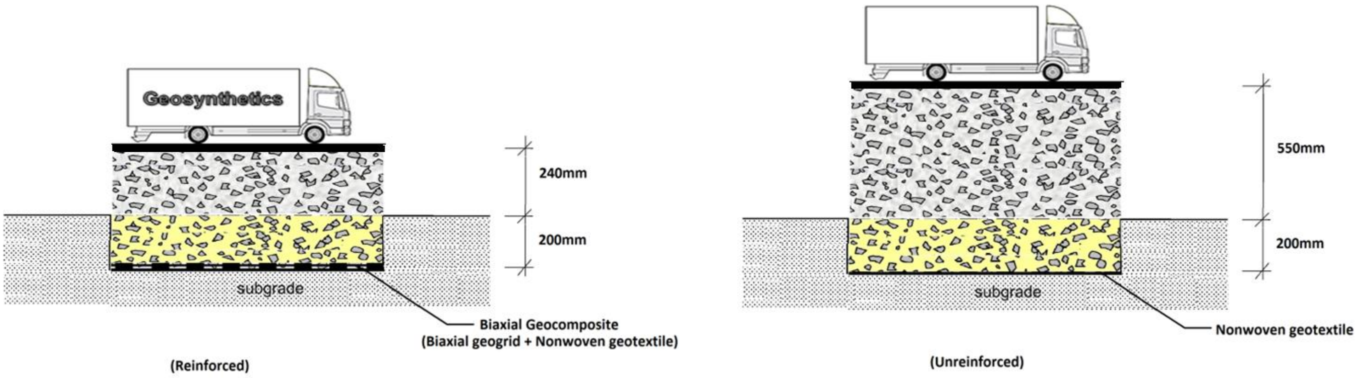


Figure 8. Design example: (a) 440mm thick geocomposite reinforced pavement (left) and (b) 750mm thick equivalent unreinforced pavement in accordance to QLD Pavement Design Supplement (right).

The results show that using a laid and welded biaxial geocomposite with an integral nonwoven geotextile could provide more than 40% savings in the total required thickness of the granular layer. The use of this geocomposite can also provide a stable working platform for construction and control the differential settlements compared to using a geotextile alone, as the geocomposite provide both reinforcement (interlocking and lateral confinement) and separation/filtration, while the nonwoven geotextile provides separation/filtration.

5 CONCLUSION

The benefits and advantages of using geogrids as the reinforcing geosynthetic in flexible pavements have been proven through various laboratory and field tests over the past 40 years. Some of these benefits include reducing the pavement thickness, increasing the serviceability and design life/design traffic of the pavement, providing a thin working platform to start the construction, providing a suitable subgrade with acceptable deflection, controlling possible differential settlements, and reducing the depth of the excavation required for replacing the soft subgrade with good quality crushed stone.

A geogrid/geocomposite reinforced layer can be used as a formation layer or semi-infinite subgrade for construction on soft soils. The improved deformation modulus Ev2 on top of the reinforced semi-infinite subgrade measured with the DIN 18134 test method and correlated to CBR can successfully be used as the presumptive CBR in the structural design of the pavement using Austroads empirical design charts or mechanistic approach (e.g. CIRCLY). This method enables geogrids/geocomposites to be considered in the Australian design procedure for flexible pavements and provide significant saving in the pavement thickness.

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