ANNUAL SUMMARY REPORT

Project Title: P49: Quantifying the Benefits of Geosynthetics for the Mechanical Stabilisation of Subgrade Soils. (Year 1 – 2015/16): An interim design approach

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Authors: Dr Erik Denneman

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AN INITIATIVE BY:

P49: QUANTIFYING THE BENEFITS OF GEOSYNTHETICS FOR THE MECHANICAL STABILISATION OF SUBGRADE SOILS. (YEAR 1 – 2015/16): AN INTERIM DESIGN APPROACH

SUMMARY

Geosynthetics have been used in pavement design for over three decades. Geosynthetics offer the potential to reduce granular pavement thicknesses, which can lead to cost reduction and sustainability benefits. It is envisaged that in the near future TMR may conduct a full scale pavement trial with a range of geosynthetic products. This trial is expected to inform the development of a state-of-the-art design method for pavements containing geosynthetics. In the interim, there is a need to implement a practical approach to allow the design of pavements containing geosynthetics in Queensland.

The object of this explorative study was to perform a review of international trials and based on this to quantify the benefits that may be expected in terms of thickness reduction of granular layers due to the use of geosynthetics, and to recommend possible interim design approaches that can be introduced to the TMR pavement design supplement.

The literature review showed that subgrade stabilisation using geosynthetics may lead to increased performance of pavements. The action of geosynthetics is more effective where large deformations activate more of the stabilisation potential of geosynthetics.

As an interim measure it is proposed that mechanical stabilisation of soft subgrades with geosynthetics could be allowed. A requirement could be that the effectiveness of the geosynthetics option is verified in situ.

Recommendations are made with respect to the organisation of the proposed field trials and verifying test methods for the assessment of geosynthetics in situ.

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1 INTRODUCTION

Geosynthetics have been used in pavement design for over three decades. Pavement geosynthetics offer the potential to reduce granular layer thicknesses, which can lead to cost reduction and sustainability benefits. The Queensland Department of Transport and Main Roads (TMR) has recently released a material specification for pavement geosynthetics used in subgrade reinforcement (MRTS58-2015). There is however still some uncertainty around the characterisation of geosynthetic materials for use in pavement design.

1.1 Problem Statement

It is envisaged that in the near future TMR may conduct a full scale pavement trial with a range of geosynthetic products. This trial is expected to inform the development of a state-of-the-art design method for pavements containing geosynthetics. In the interim, there is a need to implement a practical approach to allow the design of pavements containing geosynthetics in Queensland.

1.2 Objectives

The objectives of this explorative study are to:

1. Based on a review of international trials, quantify the benefits that may be expected in terms of thickness reduction of granular layers due to the use of geosynthetics.
2. Recommend possible interim design approaches that can be introduced to the TMR pavement design methodology.

1.3 Scope

The scope of the study is the use of pavement geosynthetics for subgrade reinforcement.

1.4 Structure of the Report

The review of international data on the performance of geosynthetics in pavements is presented in Section 2 . An overview of approaches to pavement design using geosynthetics is also provided in Section 2. Section 3 presents a possible interim design methodology for consideration by TMR. Conclusions are provided in Section 4.

2 LITERATURE REVIEW

The term geosynthetics covers a range of planar products made up of polymeric materials used in a variety of engineering applications. Products typically used in pavement subgrade reinforcement can be further classified into geotextiles, geogrids and geocomposites. Geotextiles are permeable fabrics that can provide a separation between different granular materials in the pavement structure, in addition to reinforcement and are available in both woven and nonwoven types. Geocomposites are manufactured with at least one geosynthetic component and are typically composed of a geogrid bonded to a geotextile. The main purpose of geogrids is to provide reinforcement in uniaxial, biaxial, or triaxial directions, depending on the product. This literature review seeks to address two questions:

1. Is there evidence that the use of geosynthetics for subgrade reinforcement can lead to reduced granular pavement thickness?
2. Are there design methods available that can be implemented in Queensland to design granular pavements including geosynthetic subgrade reinforcement?

2.1 Mechanisms of Geosynthetic Reinforcement

The inclusion of geosynthetics in flexible pavement design can lead to three main benefits (Zornberg & Gupta 2010):

1. Lateral restraint; at the interface of the geosynthetic and the granular material, a shear resisting interface is formed. The shear load in the granular material is transferred into a tensile load in the geosynthetic. Lateral restraint is a characteristic typically associated with geogrid type products. The geosynthetic also confines the base aggregate, thereby increasing the shear capacity of the material. For the interlock between geosynthetic and aggregate to develop properly, the size of the aperture of the geosynthetic needs to be selected with care. The lateral restraint effect can be considered the most relevant to sealed pavements, as it is activated at relatively small displacements.
2. Increased bearing capacity; the geosynthetic changes the failure surface of the granular material. The shear forces are distributed over a wider area, thereby reducing the stresses on the subgrade. This effect is considered more relevant to unsealed roads where large displacements occur.
3. Tension membrane effect; where large vertical forces occur, the geosynthetic can function as a tension membrane, providing an opposite vertical reaction. This final benefit is considered less relevant to the design of sealed roads, as large displacements are required to activate the effect. This effect is considered more relevant to unsealed roads where large displacements occur.

2.2 Outcomes of Full Scale Field Trials with Geosynthetics

This section presents a review of selected studies where the performance of different geosynthetics was investigated using purpose built trial sites.

2.2.1 Montana Trial

The State of Montana Department of Transportation performed an extensive trial with the use of different geosynthetics in unsealed roads (Cuelho and Perkins 2009). Ten sections were constructed with different types of geosynthetics, two control sections without geosynthetic reinforcement were constructed as well.

The geogrids were placed on top of an artificial subgrade, which consisted of a material described as weak and wet with a plasticity index of 15. A 200 mm granular base was constructed on the geogrid. A loaded three axle dump truck was driven over the trial sections to traffic the pavement.

The results showed that the sections reinforced with geosynthetics had a much improved resistance to rutting. However, the stresses in the pavement were very high and ruts of 100 mm were achieved for all sections in less than 100 passes of the dump truck.

The outcomes indicated that the FHWA (1995) and Giroud and Han (2004) design models underestimate the base thickness required to carry this (small) number of load repetitions.

It would appear that the outcomes of the Montana trials hold relevance mainly for the design of low volume, unsealed roads in high stress situations. Since the function of geosynthetics is stress dependent, the outcomes of these trials would seem to be less relevant to the performance of sealed granular pavements designed to carry thousands of heavy vehicles at lower working stresses.

2.2.2 Minnesota 10 Year Performance Survey

Geosynthetics are widely used in road construction in Minnesota for both sealed and unsealed pavements. Geotextiles are used as a separation layer. Geogrids have been used because they were expected to improve strength of granular materials and reduce maintenance costs. Geogrids are applied without reducing granular layer thickness. The Minnesota Department of Transportation monitored the performance of paved highways with geotextiles over a 10 year period (Clyne 2011). Ride quality, rutting and cracking were measured annually during this period.

The performance of sections containing geotextile separation layers and geogrid stabilisation was compared to control sections without geosynthetics. The results indicate that the use of geotextiles did not lead to increased pavement performance. The use of geogrids however did result in slightly improved rut resistance recorded over the 10 year period. The sections with geogrid did maintain ride quality better and less cracking was observed compared to the control sections.

2.2.3 Texas Trials

Gupta (2009) and Zornberg and Gupta (2010) describe a series of case studies and trials with geosynthetics over active clay subgrade in Texas. The pavement configurations included:

- a granular base on top of a lime stabilised subbase
- a granular base reinforced with geosynthetics over a lime stabilised subbase
- a granular base on top of granular subbase
- a granular base reinforced with geosynthetics on top of granular subbase.

The findings indicate that the geogrid reinforcement was effective in reducing the occurrence of longitudinal cracking induced by expansive subgrades. The cracks instead relocated to the shoulders, outside the area reinforced with geosynthetics (Zornberg & Gupta 2009).

The effect of the inclusion of geosynthetic reinforcement on the deflection of the pavements under FWD was less well pronounced. The deflections of the pavements with geosynthetics and lime stabilisation was lower than for the pavements with only lime stabilisation. For the trials and the case study comparing granular pavements over granular subbase to that of granular pavements reinforced with geogrid over granular subbase, the effect on deflection was inconclusive.

2.3 Repeated Loading Testing of Geosynthetics

The effectiveness of geosynthetic reinforcement of granular materials under repeated loading has been studied by a large number of researchers. Berg et al. (2000) provide an overview of literature on the topic, including accelerated pavement testing (APT) studies, as well as stationary cyclic plate load testing. Perkins (2016) provides an overview of additional research published after the paper by Berg et al. (2000). In the overviews presented by Berg et al. (2000) and Perkins (2016), the benefit of the use of geosynthetics compared to the unreinforced control experiments is expressed as the traffic benefit ratio (TBR). TBR is the ratio of the number of loading cycles to achieve a critical rut depth in the reinforced and unreinforced test sections. TBRs ranging from smaller than 1 (negative effect) to 220 are reported in the published results. Berg et al. (2000) found that for geogrids the TBR typically ranged from 1.5 to 70 for the published studies.

A precursory review of a selection of the original publications that informed the reports by Berg et al. (2000) and Perkins (2016) appears to indicate that high TBR values were typically reported for experiments with high stress conditions and a low number (less than 10 000) of load cycles to failure. Lower TBR values were reported for experiments that were run at lower stress conditions. For instance, a study using the US Army Corps of Engineers heavy vehicle simulator reported TBRs of 0.87, 1.33 and 1.47, for three experiments where geosynthetics were applied under the granular subbase of an asphalt pavement. The equivalent standard 80 kN axle load repetitions imparted on the trial pavement were in a range from $1x10^6$ to $6.5x10^6$. This review of repeated load test results, combined with the results for field trials discussed in the previous section, suggest that the benefits of geosynthetics are more easily demonstrated for high stress situations, which are not necessarily representative of sealed main roads.

2.4 Geosynthetics in Pavement Design

There are several guidelines and methods available for the design of pavements incorporating geosynthetics. Some of the better known methods are primarily intended for unsealed roads, these include the method developed by the US Forestry Service (Christopher 2010). This method is intended for pavements carrying less than 10 000 vehicle passes. The Federal Highway Administration (FHWA 1995) released design and construction guidelines for pavements with geosynthetics. This method, as well as the method by Giroud and Han (2004), which was later included in the FHWA design guidelines, are also intended for the design of unsealed roads. European texts on use of geotextiles in low volume roads and temporary road pavements are presented in CUR (1995) and DGGT (2010). All of these methods have limited relevance for the current study, because they are primarily intended for the design of unsealed or temporary roads. This section describes geosynthetic design approaches intended for sealed pavements.

2.4.1 Perkins Model

The most advanced mechanistic-empirical design model for pavement design incorporating geosynthetics identified by this review is the method proposed by Perkins et al. (2009). The method is intended for both sealed and unsealed pavements. The method makes use of a 2D finite element model in which the interaction between geosynthetics and the aggregate base is simulated. The model was calibrated based on the results for APT and repeated loading experiments. The method can be used in combination with the models for permanent deformation of granular materials in the National Cooperative Highway Research Program (NCHRP) Mechanistic Empirical Pavement Design Guide (MEPDG), to compare the difference in performance between reinforced and unreinforced sections. The method can also be used to calculate the difference in vertical strain at the top of the subgrade for reinforced and unreinforced sections. The subgrade strain criterion is used as the predictor for permanent deformation in the pavement structure in the current Austroads Guide to Pavement Technology Part 2: Structural Pavement Design (AGPT) (Austroads 2012). Use of the Perkins model for design of pavements in Queensland may be investigated as part of a medium to long term research effort into the use of geosynthetics in the state. It is not considered a viable option for an interim solution that will allow

TMR to rapidly implement a robust design method. Challenges that would need to be overcome before the Perkins model can be used for pavement design in Queensland include:

- calibration of the model for local materials
- validation of the model against the performance of typical Queensland pavements with a granular base and subbase and sprayed seal surfacing
- comparison of the modelled behaviour of granular materials in the Perkins model to the response of granular materials modelled using the anisotropic approach with different sublayer moduli applied in the AGPT.

2.4.2 Caltrans Guidelines

The California Department of Transportation (Caltrans) developed guidelines for the design of granular bases incorporating biaxial geogrids specifically (California Department of Transportation 2012). The guideline is intended for asphalt pavements over a granular base, where the geogrid is placed either on top of the subgrade, or within the granular base. In the guideline, the subgrade conditions are expressed in terms of resistance “R” value. The R value is determined in accordance with California Test 301. The proposed maximum reductions in granular base thickness provided in the guideline are shown in Table 2.1.

Table 2.1: Maximum granular base thickness reduction factors

Subgrade effective R-value	Maximum % reduction in granular base thickness
R-value ≤ 20	25
20 < R-value ≤ 40	20

Source: California Department of Transportation (2012).

An R-value of 20 is considered approximately equivalent to a subgrade CBR of 3, an R-value of 40 is equivalent to a CBR of 6.5 (California Department of Transportation 2013). For the reduction to apply, the minimum thickness of the granular base layer has to be greater or equal to 110 mm. If the thickness of the granular layer exceeds 460 mm, a second layer of biaxial geogrid is to be placed. Other requirements include that the plasticity index (PI) of the granular base material does not exceed 12 and that the particle grading of the base materials fall within a specified envelope.

Caltrans has also produced a guide for subgrade enhancement using geosynthetics (California Department of Transportation 2013). The difference with the guideline described above is that this document provides guidance on the improvement of subgrade bearing capacity. The guidelines allow an enhancement of the R-value used in the design, if a geosynthetic is placed directly on the cleared subgrade, between the subgrade and the granular base.

Where a geotextile is incorporated, a design R-value of 20 (CBR of 3) may be assumed for a subgrade which without geotextile had an R-value below 20.

Where a geogrid is incorporated, a design R-value of 25 (CBR of 3.5) may be assumed for a subgrade which without geogrid had an R-value below 25.

The Caltrans subgrade enhancement guide further provides direction for the selection and specification of geosynthetic products.

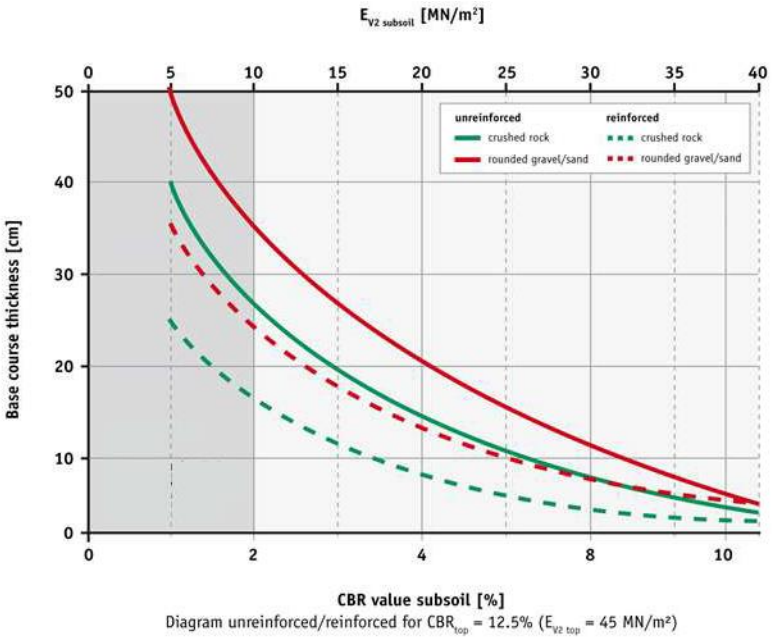
2.5 German Design Guidelines

The use of geosynthetics in Germany is limited to improvement of the foundation of the pavement. The Richtlinien für die Standardisierung des Oberbaus von Verkehrsflächen (Guidelines for the Standardisation of the Superstructure for Roads) (FGSV, 2011), requires a minimum support for the superstructure of 45 MN/m^2 (modulus of subgrade reaction). Interconversion of plate load tests and in situ CBR results have to be done with caution, but 45 MN/m^2 is roughly equivalent to a CBR of 12%.

Geosynthetics may be applied to improve the bearing capacity of the foundation in order to meet the modulus of subgrade reaction requirement. Guidelines for the application are provided in Merkblatt über die Anwendung von Geokunstoffen im Erdbau des Straβenbaues (Code of Practice for the use of Geosynthetics in Earthworks for Road Construction) (FGSV 2005). The code of practice includes information on application and the specification of suitable geosynthetic products. It does not provide a methodology for the design of foundations to meet the 45 MN/m^2 requirement. Compliance with this bearing capacity requirement is verified by means of plate load tests in the field.

Practitioners can make use of empirical design charts to assess the improvement in bearing capacity offered by different types of geosynthetics. Figure 2.1 shows an example of a design chart developed for a NAUE product. The chart shows the granular base course thickness required to achieve a modulus of subgrade reaction of 45 MN/m^2. Design charts are developed based on empirical field results.

Figure 2.1: Example of a design chart



Source: Shahkolahi (2015).

2.6 French Design Guidelines

The French pavement design catalogue (LCPC 2010) allows a 100 mm to 150 mm reduction of the capping layer thickness if a suitable geotextile has been laid between the capping layer and the surface of the earthworks. This however appears to be related to the reduction of contamination of the granular material by subgrade particles. Geosynthetics are not applied to improve bearing capacity.

3 OPPORTUNITIES FOR INTERIM IMPLEMENTATION

TMR is considering full-scale field trials with a range of geosynthetic products to validate the benefits of these materials for road construction in the state. This section explores whether there are opportunities to implement an interim approach based on international practice discussed in the previous section. Such an interim approach would have to be compatible with the AGPT (Austroads 2012) and the TMR Pavement Design Supplement (TMR 2013).

3.1 Geosynthetics within the Austroads Pavement Design Framework

The intended use of geosynthetics by TMR is for mechanical subgrade stabilisation underneath granular pavement layers. The benefits of the use of geosynthetics in this application would have to be expressed in terms of reduction of permanent deformation. Permanent deformation is the assumed failure mechanism for unbound pavement layers and subgrade within the AGPT. The vertical compressive strain at the top of the subgrade is taken as a determinant for surface rutting in the combined unbound portions of the pavement structure. The allowable number of repetitions of a standard axle (*N*) before an unacceptable level of pavement surface deformation develops is calculated using Equation 1.

$$N = \left(\frac{9300}{\varepsilon_v}\right)^7 \qquad (1)$$

where

ε_v = Elastic vertical compressive strain on top of subgrade

The limiting subgrade strain criterion is therefore the most suitable indicator for possible benefits of geosynthetic subgrade reinforcement within the AGPT design framework. It may be possible to show that thinner pavement structures including geosynthetics have the same vertical strain at the top of the subgrade as thicker structures without geosynthetic reinforcement. Alternatively, the traffic benefit ratio (TBR) from the inclusion of geosynthetics could be calculated. The TBR from the use of geotextiles within the AGPT design framework could be expressed using Equation 2.

$$TBR = \left(\frac{\varepsilon_{vu}}{\varepsilon_{vr}}\right)^7 \qquad (2)$$

where

TBR = Traffic benefit ratio

ε_{vu} = Elastic vertical compressive strain at the top of subgrade in the unreinforced pavement section

ε_{vr} = Elastic vertical compressive strain at the top of subgrade in the reinforced pavement section

The challenge is to reliably characterise the influence of geosynthetics on the vertical strain at the top of the subgrade.

3.2 Determining ε_{vr}

The effect of the geosynthetics on the vertical strain at the top of the subgrade parameter will depend on the interaction between the geosynthetics and the granular layer directly above it. The effectiveness of the mechanical subgrade stabilisation would have to be measured in the field, which may prove challenging.

3.2.1 Conventional Determination of Subgrade Modulus

Subgrades show stress dependent behaviour. The Shell (1978) pavement design manual states that the material may be modelled as linear elastic, provided that the moduli are determined under appropriate loading conditions. According to the manual, the subgrade modulus should preferably be determined using dynamic deflection measurements (e.g. FWD). Alternatively, CBR may be used as a convenient approximation. The AGPT recommends the use of design CBR values determined at a representative moisture content. These CBR values are then converted to a design modulus using an empirical relationship. The use of FWD is not recommended in the AGPT due to inherent variability in back calculated results.

3.2.2 Deflectometer Testing on Geosynthetics

The most convenient method of determining the effectiveness of geosynthetics in reducing the vertical strain at the top of the subgrade would be through FWD testing. However, from published results it does not appear that the use of geosynthetics necessarily leads to increases in moduli values as back calculated from FWD. Tingle and Jersey (2009) found that the initial stiffness of the reinforced test items was not a good indicator of performance. The effect of the geosynthetics on modulus only became apparent after initial consolidation under traffic and mobilisation of the reinforcement.

3.2.3 In situ CBR Test

Although no examples of this were found in literature, the effectiveness of subgrade stabilisation using geosynthetics could possibly be verified by means of in situ CBR testing in accordance with method 6.1.3 of AS1289-1998 (R2013). Although, due to the limited diameter of the plunger, performing repeatable in situ CBR tests on a constructed crushed rock layer may be a challenge. Also, due to the difference in confinement, the results of in situ CBR tests will differ from those of laboratory CBR tests. This difference is reported to be small for heavy clay and cohesive soils with high air void contents. The difference is large for most other granular materials and cohesive soils (Croney & Croney 1997). Nevertheless in situ CBR testing may be suitable to compare the bearing capacity of a conventional granular capping layer over unreinforced subgrade to that of a thinner capping layer over subgrade stabilised with geosynthetics.

3.2.4 Plate Load Test

Section 2.5 described the German practice of using the plate load test to evaluate the effectiveness of stabilisation using geosynthetics. In Australia, the plate load test is generally not used to characterise the bearing capacity of pavement structures. The Northern Territory Department of Infrastructure does have a test method for it (NTTM 211.1). Plate load test results are of limited use in determining elastic properties of pavement materials, as most of the deformation in the test is unrecoverable (Croney & Croney 1997). The equipment is available locally, as it is regularly used in other fields of civil engineering. The results of plate load testing could possibly be used to get an indication of the improvement in CBR of the subgrade, as there are some empirical relationships between plate load test results and CBR available (Croney & Croney 1997). The industry chart for the effectiveness of geosynthetics in Figure 2.1 shows both modulus of subgrade reaction and CBR. The in situ CBR values in the Figure are estimated from an empirical correlation with plate load test results (Klompmaker 2015).

3.3 Interim Implementation within the TMR Supplement

Mechanical stabilisation using geosynthetics is typically only recommended for weak subgrades (CBR < 3%). As an interim measure, TMR could consider including mechanical stabilisation with geosynthetics as part of Section 3.14 *Improved subgrades* of the TMR Pavement Design Supplement (TMR 2013). This section includes a number of subgrade treatments to achieve a presumptive design CBR of 3% for the subgrade. It is proposed that the following subgrade treatment is added to this section as an option:

- Mechanical subgrade stabilisation by means of a geosynthetic and a layer of coarse granular or rock fill, designed by the contractor to provide a bearing capacity equivalent to the improved subgrade measures in Table Q 3.2. Equivalency of these solutions is to be verified on trial pavement structures in situ (using a test method to be confirmed). Geosynthetic material shall comply with MRTS57. Application of the product shall comply with MRTS58.

3.4 Other Applications of Possible Interest to TMR

The comparative field trials in Texas discussed in Section 2.2.3 showed the effectiveness of geosynthetic stabilisation in reducing longitudinal shrinkage cracking induced by expansive subgrades. This is possibly of benefit to TMR for pavements over expansive clays.

4 CONCLUSIONS AND RECOMMENDATIONS

The object of this explorative study was to perform a review of international trials and based on the findings to quantify the benefits that may be expected in terms of thickness reduction of granular layers due to the use of geosynthetics, and to recommend possible interim design approaches that can be introduced to the TMR Pavement Design Supplement (2013).

4.1 Conclusions

The literature review revealed that subgrade stabilisation using geosynthetics may lead to increased performance of pavements. The published data is particularly convincing for unsealed roads carrying relatively low numbers of high loads, which cause high stresses and deformation in the pavement structure. For sealed pavements carrying larger volumes of traffic loads under lower stress conditions, the benefits are of a lower order. This is consistent with the understanding of the reinforcement mechanism of geosynthetics. The action of geosynthetics is more effective where large deformations activate more of the stabilisation potential of geosynthetics.

The literature review also found that if separation between pavement layers is not considered critical there is limited evidence that geotextiles are of benefit. Therefore, for the purpose of subgrade stabilisation, which is the primary focus of TMR, geogrid type products appear the most suitable.

The review of international experience with geosynthetics showed that the proposed trial of subgrade reinforcement for granular pavements in Queensland would not be a duplication of international work. The granular pavement with a sprayed seal surfacing is significantly different from pavement configurations trialled in international experiments.

As an interim measure it is proposed that mechanical stabilisation of soft subgrades with geosynthetics could be allowed. A requirement could be that the effectiveness of the geosynthetic stabilisation is verified in situ by direct comparison to a conventional subgrade improvement allowed under the TMR supplement (TMR 2013). Before this measure is implemented however, a suitable test method to assess the effectiveness of stabilisation using geosynthetics has to be identified through experimental work. Candidate tests are in situ CBR, plate load test and FWD.

4.2 Recommendations

The following recommendations are made based on the outcomes of this study:

- That the trial with mechanical stabilisation of subgrades using geosynthetics in Queensland proceeds as planned. The ideal trial site would combine a granular pavement structure over soft subgrade with relatively high volumes of heavy traffic. Objectives of the trial would include: determining which types of geosynthetic (e.g. triaxial, biaxial) provides the best performance, quantifying the reduction in pavement thickness, quantifying the longevity of the geosynthetic stabilisation under traffic and developing a design method to be used in designing geosynthetic reinforced granular pavements.
- Field experiments of limited scope should be undertaken to compare the effectiveness of in situ CBR, plate load test and FWD for the assessment of mechanical stabilisation of subgrade using geosynthetics.
- It is proposed that TMR considers implementation of the interim design measure described in this report. If the measure is considered too high risk for higher order pavements, the application could be limited to unbound granular pavements with a sprayed seal surfacing.

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