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# INVESTIGATION OF GEOSYNTHETIC-SOIL INTERFACE SHEAR CHARACTERISTICS USING A LARGE DIRECT SHEAR APPARATUS

*Ravindu Ranasinghe, Glen Barnes, and Jay Rajapakse

School of Civil & Environmental Engineering, Queensland University of Technology (QUT), Australia

*Corresponding Author, Received: 14 Feb. 2025, Revised: 24 April 2025, Accepted: 15 May 2025

**ABSTRACT:** Geosynthetics, including geogrids, geotextiles, and geocomposites, have become increasingly popular as a more sustainable and cost-effective alternative to traditional chemical and mechanical treatments. Geosynthetics could improve pavement performance by providing separation, filtration, and tensile reinforcement, by effectively distributing loads across the pavement structure. This study examines the interface properties of geocomposites used with subgrade and subbase materials. Pullout tests were conducted to assess the interlocking and frictional resistance between the geosynthetics and soils, considering both sides of the geosynthetic in contact with different soil materials. The results indicated that geosynthetic performance varied with soil type, with the weakest interaction occurring in the subgrade-subgrade condition and the strongest in the subbase-subbase condition. The study further quantified the shear stress and friction angle for various soil-geosynthetic combinations, finding that the simulated field conditions fell between the extremes of subbase-subbase and subgrade-subgrade interactions. The measured peak shear stresses exceeded the calculated values by 15% for geocomposites. This discrepancy suggests the need for a correction factor to enhance the accuracy of design predictions, thereby ensuring safer and more reliable geosynthetic applications in pavement construction. The obtained interface shear properties can be applied to develop reliable finite element models. Moreover, the testing methodology can be used to establish reliable numerical models for evaluating the shear behaviour of various geosynthetic materials.

*Keywords: Geocomposite, Interface Properties, Shear Strength, Pullout Test*

## 1. INTRODUCTION

Australia has the fifth-largest road network globally, spanning approximately 800,000 km [1]. Over 90% of this network comprises granular roads, critical in connecting remote and regional areas [2]. However, the construction and maintenance of these roads face significant challenges due to the limited availability of high-quality materials [3-8]. Consequently, marginal materials have been increasingly employed, necessitating innovative approaches to enhance performance. Optimising layer thickness, integrating waste materials for sustainability, and adopting advanced road design methodologies are used to minimise resource usage and improve efficiency [9-17].

Expansive soil presents an additional challenge in Australia, with approximately 20% of the country's soils and up to 50% of soils in Queensland exhibiting expansive properties. These subgrade soils require stabilisation to improve strength and durability [18-25]. Conventional techniques such as lime stabilisation [26-28], novel sustainable binders, and gravel replacement often raise environmental concerns [29-31]. This has driven the need for sustainable materials and advanced pavement design methods to enhance performance while reducing reliance on finite resources [32-36].

Geosynthetics have gained significant traction in the industry as a solution for reducing material usage, improving efficiency, and stabilising subgrades. In pavement engineering, geosynthetics play a critical role in separation, filtration, and reinforcement [37-43]. Among these, geogrids and geocomposites are particularly effective in stabilising weak subgrades [44-50]. Their utilisation increases stiffness, minimises deformation, and enhances the resilience of pavements constructed on soft subgrades [51-53]. Despite their widespread use, there is a notable research gap in comparative studies evaluating the performance of geogrids and geocomposites, necessitating further investigation.

Early research investigated the interactions between cohesive-frictional soils and geogrid reinforcements, making substantial contributions to our understanding of pullout resistance processes. Notably, the adoption of specialist pullout test equipment aims to standardise experimental methodologies and provide a foundation for future study. Geogrid or geomembrane pullout performance was found to be influenced by confining pressure, soil density, boundary conditions, and geotextile properties. Understanding these factors is still crucial for appropriately understanding interface behaviour during pullout testing and assuring the reliability and repeatability of test results.

This study investigates the interface friction characteristics of geosynthetics, which are critical for assessing their performance in subgrade stabilisation. Controlled pullout tests were conducted with geocomposite samples positioned at the subgrade-subbase interface, interacting with fine-grained subgrade and granular subbase soils. The analysis focused on determining frictional interface properties between geosynthetics and subbase material, followed by evaluations with subgrade soil. These properties were used to calculate pullout resistance, and the results were validated against experimental observations.

The findings provide a foundation for incorporating these characteristics into constitutive models used in numerical analysis software. The findings provide a foundation for incorporating these characteristics into constitutive models used in numerical analysis software. These experimentally determined properties can substantially improve the accuracy of finite element models used for pavement design, thereby enhancing the predictability and reliability of pavement performance analyses. Thus, the present research provides critical data to facilitate more accurate modelling of geosynthetic-reinforced pavement systems, contributing significantly to the field of sustainable pavement engineering.

## 2. RESEARCH SIGNIFICANCE

This study aims to assess the performance of biaxial polypropylene geocomposite within the context of low-strength Queensland expansive clay soils. Given the proven efficacy of geocomposite in enhancing the stability of soft soils, it is crucial to generate quantitative evidence that validates their performance under such conditions. Key properties under examination include the geocomposite's interlocking capabilities and the frictional interaction between the geosynthetic material and the surrounding soil, which are critical determinants of overall system strength. By focusing on these vital factors, this study establishes the foundation for future, more comprehensive laboratory and field studies. The significance of this small-scale model lies in its capacity to illustrate the interaction dynamics between various geocomposite types and different soil materials, which is vital for optimising pavement design strategies.

## 3. TEST MATERIALS

### 3.1 Geocomposites

The biaxial geocomposite employed in this study is fabricated from commercially available polypropylene to make it accessible for widespread use. The design comprises a grid pattern of flat bars intersecting securely at welded points. These bars are designed with a width of 12 mm and a depth of 1.4 mm. The square grid has an aperture size of approximately 32 mm. A local supplier provided geocomposite samples, which are manufactured in Germany. The physical properties of geocomposites in the Machine Direction (MD) and Cross Machine Direction (CMD) are detailed in Table 1. The selected geocomposites comply with the current technical standards outlined in the " Queensland Department of Transport and Main Roads (QDTMR) Specifications MRTS58 - Subgrade Reinforcement using Pavement Geosynthetics"[54].

Table 1. Physical properties of geocomposites

| Property | MD/ CMD | MTRS58 Specification | Complain/ Non-compliant |
|---|---|---|---|
| Nominal Strength (kN/m) | 30/30 | - | - |
| Maximum Tensile Strength (kN/m) | 32/32 | - | - |
| Tensile Strength at 2% Elongation (kN/m) | 11/12 | $\geq 10.5$ | Compliant |
| Aperture Size (mm) | 32/32 | Min $\geq D_{50} \approx 9.5$mm Max $\geq 2 \times D_{85} \approx$ 38mm | Compliant |
| Thickness (mm) | 1.4/1.4 | - | - |

### 3.2 Subbase and Subgrade Materials

The unbound granular material (UGM) used for this study was obtained from a local quarry. The materials are classified as Type 2.3 UGM according to the current specification of the QDTMR for pavement designs in Southeast Queensland. Fig**.** 1 illustrates the particle shapes and textures of the materials used in this study.

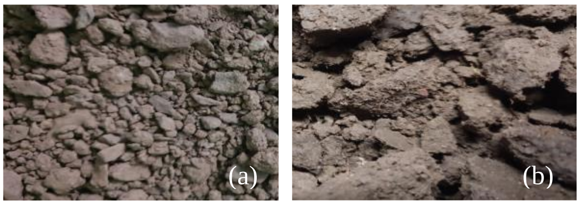


Fig.1 Granular material samples (a) Subbase materials; (b) Subgrade materials

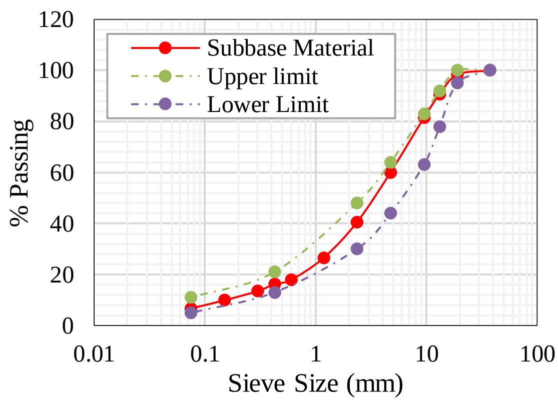


Fig.2 Grain size distribution of subbase material

Figure 2 illustrates the particle size distribution, adhering to the QDTMR MRTS05 Unbound

Pavements. The gradation curve falls within the designated upper and lower thresholds of QDTMR MRTS05.

A comprehensive series of compaction tests were performed on subgrade and subbase materials at moisture content ranges of 19% to 34% and 6% to 8%, respectively, by using the standard compaction method according to the AS 1289.5.1.1 - 2017.

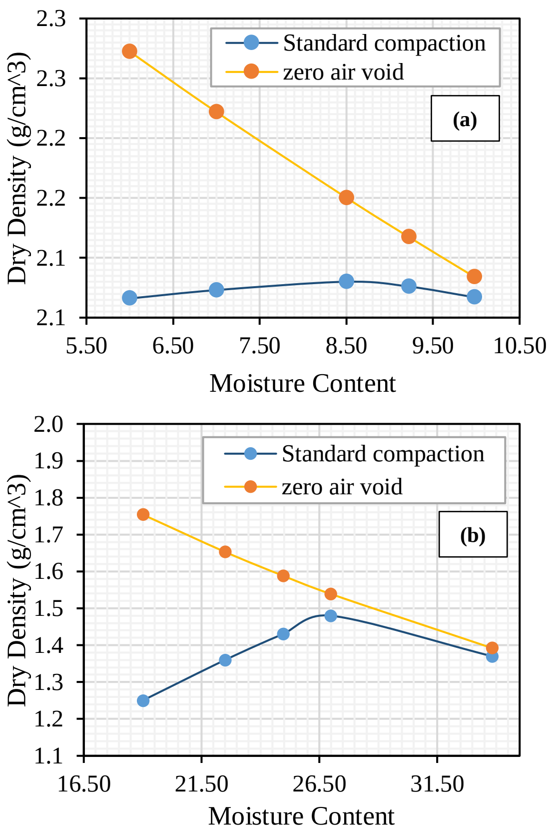


Fig.3 Compaction curve (a) Subbase materials; (b) Subgrade materials

Figure 3 shows the optimum moisture content (OMC) and maximum dry density (MDD) for subgrade and subbase materials. The subgrade soil has an OMC of 27.65% and a MDD of 1.48 g/cm³, while the subbase material demonstrated an OMC of 8.5% and a MDD of 2.08 g/cm³.

## 4. METHODOLOGY

This pullout test series assessed the interface friction properties of geocomposite materials in interaction with subbases and subgrade soils. These properties were employed to compute the pullout resistance of the geocomposite at the subgrade-subbase interface. The computed pullout resistance values were subsequently compared with experimental results to verify the reliability of the testing methodology and calculation procedures. The pullout test method followed, where possible, was ASTM D6706 [55]. A large direct shear apparatus, which can conduct a geogrid pullout test, was used in this study. The apparatus features two 100 kN load cells to measure vertical and horizontal forces; the setup includes two 50mm Linear Variable Displacement Transducers. Calibration entailed frequent verification of load cell accuracy and displacement readings with standard weights and precision gauges. Further, it consists of a manually adjustable shear box, and operations can be managed through a custom user interface developed by the manufacturer.

However, the large direct shear apparatus has intrinsic limitations, such as boundary effects caused by the finite dimensions of the pullout box, which may influence interface shear stress distribution at greater displacements. Additionally, the small sample size may impact particle-geosynthetic interactions, particularly with coarser materials. The manual operation of the shear box, although well-regulated, may create slight variations in displacement rates.

The schematic diagram in Fig. 4 illustrates the pullout test setup and the specimen dimensions are 150 mm (W) x 150 mm (L) x 200 mm (H). This configuration provided 70 mm of soil material on either side of the test specimen, while 30 mm thick, porous plates were placed at both top and bottom surfaces. Testing was conducted at a horizontal pull-out displacement rate of 1 mm/min across all normal stress levels.

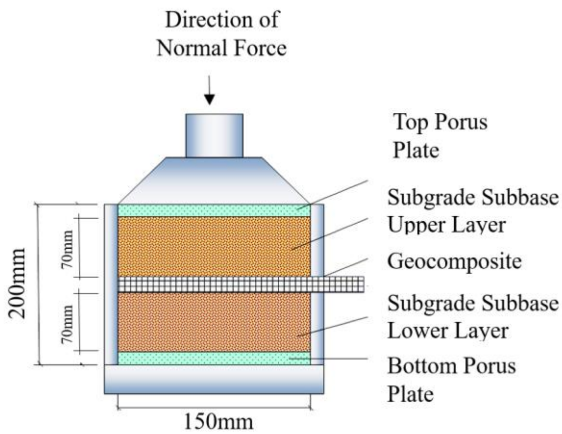


Fig.4 Pullout box test setup

The mechanical behaviour observed in geosynthetic-soil interactions during pullout testing can be explained through Mohr-Coulomb shear strength theory. According to this theory, shear stress at the geosynthetic-soil interface is primarily dependent on the effective normal stress, interface friction angle, and adhesion.

A series of pull-out tests were conducted on geocomposites under varying normal stress levels (50 kPa, 100 kPa, 200 kPa, and 400 kPa) across three distinct interface conditions: subgrade-Geocomposite-subgrade, subbase-Geocomposite - subbase, and subbase-Geocomposite-subgrade. To evaluate the interface shear strength properties of the geosynthetics with both the subgrade and subbase materials, a series of tests were conducted in which the subgrade was placed above and below the geocomposite samples. A similar test series was also performed with the other two configurations.

Pull-out load and horizontal displacement plots were used to determine the peak pull-out load for a given vertical stress. The pull-out shear strength (Peak pull-out shear stress) at a constant normal stress was calculated by dividing the peak pull-out force by the effective contact area, which was twice the geocomposite sample's plan area due to the two contact surfaces. The peak pull-out shear stress values were then plotted against the corresponding vertical normal stress values, and the interface friction angle and adhesion were obtained by fitting the data to a linear trendline.

The measured interface shear strength properties between the geocomposite and subgrade soil/base layer materials were used to estimate the peak pull-out force when the geocomposite is pulled by placing it between subgrade soil and subbase gravel. These estimated values were then compared with experimental results to validate and verify the experimental procedure for determining the geocomposite interface shear strength properties. When the soft subgrade is typically placed on top of the soft subgrade, followed by a capping gravel layer to improve the subgrade.

## 5. RESULTS AND DISCUSSIONS

Figures 5(a) and 5(b) show the pull-out horizontal) load versus horizontal displacement behaviour when the geocomposite was embedded in subbase material (subbase-subbase) and subgrade material (subgrade-subgrade), respectively. Furthermore, it was subjected to pull-out under various constant vertical stresses. The pull-out resistance shows an increasing trend with the vertical (normal) stress increases. When there is no distinct peak in the horizontal load (peak pull-out force), the maximum pull-out load within 25 mm of horizontal displacement is considered the peak horizontal (pull-out) load. This peak load was then divided by the effective contact area to calculate the peak shear stress for the corresponding vertical (normal) stress. Following the same methodology, four pull-out tests were conducted by embedding the geocomposite in subgrade soil (subgrade subgrade) under the same constant vertical stresses. The peak pull-out (horizontal) shear stress for each vertical stress was calculated using the same procedure applied to the subbase-subbase tests.

Figure 6 demonstrates the peak interface shear stress variation with normal vertical stress increased when the geocomposite was pulled out after being embedded in subbase gravel (subbase-subbase) and subgrade soil (subgrade-subgrade). Each dataset was fitted to a linear trendline to determine the interface friction angle (slope of the line) and adhesion (Y-axis intercept), with the corresponding values in Table 2.

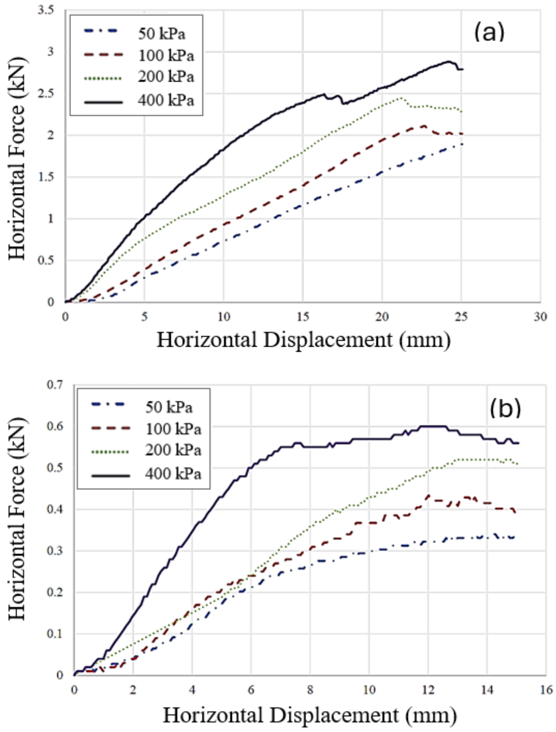


Fig.5 Relationship between the pull-out (horizontal) load vs horizontal displacement for geocomposite (a) (subbase-subbase); (b) subgrade- subgrade)

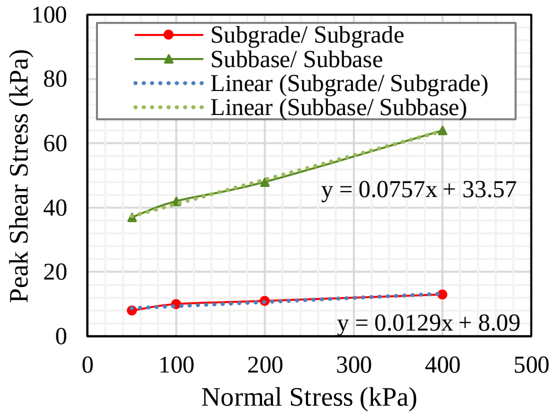


Fig.6 Normal and peak shear stress for geocomposite pullout testing

Table 2. Interface shear strength properties for geocomposite

| Property | Subgrade - Subgrade | Subbase - Subbase |
|---|---|---|
| Interface Friction Angle, δ (degrees) | 0.74 | 4.33 |
| Adhesion, $c_\alpha$ (kPa) | 8.09 | 33.57 |

Four pull-out tests were conducted by placing geocomposite between subbase material (above) and subgrade soil (below) (subbase-subgrade) under vertical normal stresses. The peak horizontal load was plotted against the corresponding normal stress, as shown in Figure 7 (Measured). The peak pull-out (horizontal) force ($F_{Pull}$) for the geocomposite embedded between subbase gravel and subgrade soil was then calculated using the following formula (1):

$$F_{pull} = A\left((\sigma tan(\delta) + c_{\alpha})_{subbase} + (\sigma tan(\delta) + c_{\alpha})_{subgrade}\right) \quad (1)$$

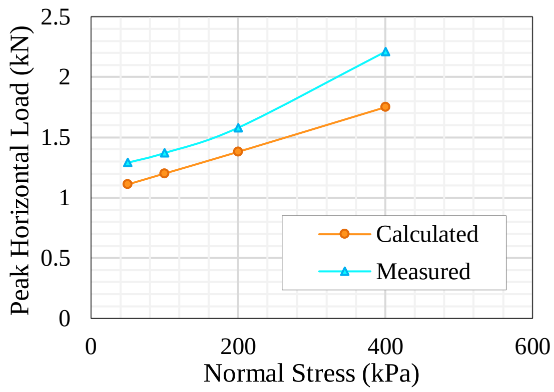


Fig.7 Comparison of measured and calculated peak pull-out loads at varying normal stress for geocomposite pull-out (subbase-subgrade)

The measured peak pull-out load is approximately 15% higher than the calculated value at the same normal (vertical) stress. This discrepancy can be attributed mainly to non-uniform stress distributions arising from localised interactions at geosynthetic apertures and soil particle heterogeneity, unlike the uniform stresses assumed theoretically. Similar deviations were reported in previous studies, such as those by Farrag et al. [49], who identified that soil-geosynthetic interlocking and non-uniform boundary stresses contribute significantly to higher measured resistance. Despite these variations, the consistently higher measured values suggest an inherent safety factor in the design process. Therefore, it is recommended that the pull-out force calculated using Equation (1) be multiplied by 1.15 to account for these discrepancies and provide more realistic estimates.

## 6. CONCLUSION

The following conclusions were made based on the findings of this study.

- The research revealed that geocomposite samples with maximum pullout resistance increased as horizontal displacement and normal stress increased.
- The reasonable agreement between the measured and estimated pull-out peak forces in the subgrade-subbase scenario verifies the accuracy and reliability of the proposed test method in determining interface properties.
- It seems that the Mohr-Coulom friction theory can be applied to estimate the interface friction with reasonable accuracy.
- Geocomposites enhance shear resistance and offer potential economic and environmental benefits, but long-term performance under cyclic loading and cost-effectiveness require further investigation.

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