The paper was published in the proceedings of the 12th Australia New Zealand Conference on Geomechanics and was edited by Graham Ramsey. The conference was held in Wellington, New Zealand, 22-25 February 2015.

Relative modulus improvement due to inclusion of geo-reinforcement within a gravel material

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ABSTRACT

The effectiveness of geo-reinforcement in terms of reducing the rutting depth of a trafficable surface is often reported in literature. However the quantification of this magnitude in regards to increases in measured stiffness parameters (Young's Modulus, *E*) is rarely reported. This study was completed to quantify the magnitude of change within a material's *in-situ* modulus value associated with the inclusion of typical reinforcement materials. This paper details the results of an *in-situ* testing study completed to quantify the effect that the installation of a single layer of three (3) types of geo-reinforcement (geotextile, geogrid or geocell) had on the composite stiffness of a loosely placed gravel material. In this study, *in-situ* modulus was measured via the use of a Light Falling Weight Deflectometer (LFWD), a quasi-static plate load test. The LFWD is a comparatively quick, non-destructive test that can be used for direct composite modulus estimation of the near-surface profile, either as a QA or investigative tool. Each of the three (3) types of geo-reinforcement considered was expected to apply a restraining force (albeit via different mechanisms) to the surrounding gravel which would result in stiffness increase exhibited by the composite arrangement. The results of the investigation suggested that the inclusion of geo-reinforcement could increase the composite modulus value by up to 100% in comparison to moduli values determined within non-reinforced material. However, the magnitude of observed modulus increase was found to be significantly dependent on the type of geo-reinforcement and depth of its installation within the gravel profile.

Keywords: Light Falling Weight Deflectometer (LFWD), Elastic modulus, subgrade, geogrid, geotextile

1 INTRODUCTION

This paper details a field testing study completed to quantify the effect that the installation of a single layer of geo-reinforcement – in the form of geotextile, geogrid or geocell materials – had on the composite stiffness of a loosely placed gravel material, measured as the *in-situ* Young's Modulus (*E*).

Literature suggests that the composite Young's Modulus value would increase with the addition of geo-reinforcement to a granular material unit. However, as different types of geo-reinforcement rely on different mechanisms to provide ground improvement this study aimed to quantify the improved in *E* values and produce a ranking on the effectiveness of each tested type of geo-reinforcement. In addition, by varying the depth at which the geo-reinforcement was placed within the gravel unit, the most effective depth of placement of the geo-reinforcement in providing a quantifiable improvement within a 'stiffness' measurement completed at the surface was assessed.

2 RATIONALE FOR STUDY

By necessity we, as design and construction engineers, often rely on manufacturer provided literature and data regarding the performance of geo-reinforcement products. However, although QA tests are required to be completed upon the reinforcement material itself during production, there is no formal testing requirement to prove, or even quantify, any improvement provided by such materials once they are installed within a soil mass.

Whilst we generally think of such improvement in terms of composite strength, there is also an improvement in modulus (i.e. reduction in material deformation under loading conditions). The effectiveness of geo-reinforcement in terms of reducing the 'rutting depth' of a trafficable surface after repeated loading cycles (e.g. wheel loading of pavement materials), or the ability of a geo-reinforced material to carry an increased number of traffic load repetitions is often reported in literature (e.g. Tensar, 2003). Similarly, geo-reinforcement manufacturers advocate the placement of a reinforcement layer either upon a subgrade soil material with low bearing capacities or as a constituent within a road pavement profile. The argument for their inclusion is that the geo-reinforcement will either reduce the required pavement / working platform thickness or the observed depth of rutting.

As the inclusion of a geo-reinforcement layer is identified as a way to improve the number of load repetitions that can be carried prior to pavement degradation or failure, their presence is presented a method of extending the life span of a pavement. However, actual quantification of the magnitude of any increase in measured stiffness parameters due to the inclusion of such reinforcement is rarely reported, and thus not directly available for altering material parameters adopted for design. This research focuses on a formal assessment of the variation in a stiffness parameter due to the inclusion of geo-reinforcement materials, quantified by the variation of the *in-situ* Young's Modulus (*E*) parameter obtained by testing utilising a Light Falling Weight Deflectometer (LFWD).

A number of factors would likely influence the determined composite (material and geo-reinforcement) modulus value, including:

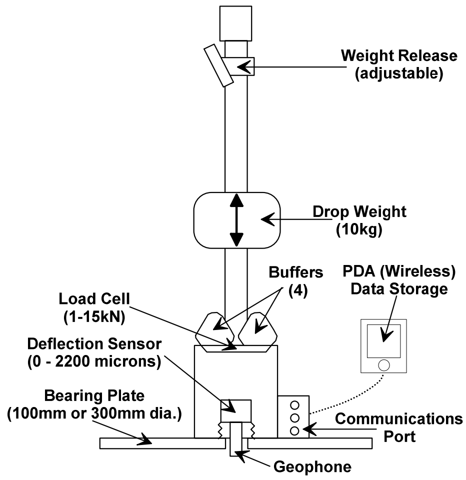
- Type of geo-reinforcement (strength or grade of material; orientation or arrangement of reinforcement elements)
- Depth of geo-reinforcement placement compared to testing location
- Magnitude of load to be placed upon the surface (as modulus is a stress dependent property)
- Type of fill material surrounding geo-reinforcement
- The number of load repetitions (modulus would likely degrade over lifetime of material)
- The stiffness of the underlying material
- The design life of the constructed element

The research summarised within this paper focuses primarily upon the first three (3) of these listed factors. This work provides a fundamental understanding of any stiffness gain due to the introduction of geo-reinforcement, and is independent of manufacturer produced literature.

3 METHODOLOGY

All field tests completed for this study adopted the same general methodology, whereby a single layer of geo-reinforcement (geotextile, geogrid or geocell) was placed within a mass of loosely packed gravel. For each of the constructed arrangements an *in-situ* Elastic (Young's) Modulus parameter, in the form of an E_{LFWD} value, was determined using the Prima 100 LFWD testing equipment.

(a)



(b)

Figure 1. Prima 100 LFWD; (a) during fieldwork and (b) in cross-section (after Fleming et. al., 2007)

3.1 Testing Equipment

In-situ testing to determine the Young's Modulus of the composite material (E_{LFWD}) was completed via the use of a Prima 100, a commercially available LFWD. This instrument, as shown in Figure 1, is a quasi-static plate load test, in which a sliding 10kg weight is manually raised upon a guide rod and dropped onto a rigid base plate instrumented with a load cell and velocity transducer. A load pulse is generated when the weight is dropped upon the rubber dampers, which passes through the rigid plate and into the ground as a uniform stress. The load cell and deflectometer measures the imparted force and deflection of the ground below the centre of the plate respectively.

As both force and deflection values are measured over the duration of the load pulse, the composite Young's Modulus (E_{LFWD}) over the zone of test influence can thus be derived by the classic static elastic theory (Boussinesq elastic half-space) equation, as shown in Equation 1. Previously identified limitations relating to use of static elastic theory for interpretation of LFWD results (which is a semi-dynamic test) are detailed in Fleming et. al. (2007, 2009), and include a phase lag between the timing of the observed peak force and maximum deflection values:

$$E_{LFWD} = [A \times P \times R \times (1 - \upsilon^2)] / d_0 \quad (1)$$

Where: A = Plate rigidity factor (π/2 for rigid plate); P = Maximum Contact Pressure; R = Radius of plate; υ = Poisson's Ratio; d_0 = Peak deflection

It is estimated that the Coefficient of Variation (CoV) of the calculated E_{LFWD} value for granular materials is approximately 15%, based on work published by Fleming et. al. (2009) and the estimation of repeatability from the data collected in this study. This CoV value includes equipment, procedural, operator and material variability, and compares favourably to traditional testing techniques, such as CBR testing (17 to 58%, as reported by Lee et. al, 1983) or field penetration tests such as the Dynamic Cone Penetrometer Test (DCP) and Standard Penetration Test (SPT) (both >50%, as reported by Mellish et. al., 2014 and Phoon and Kulhawy, 1999 respectively).

3.2 Materials and Expected Behaviour

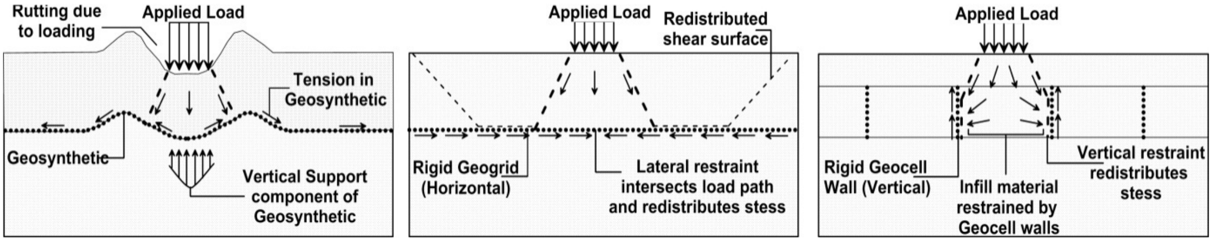
The study considered three (3) distinct types of geo-reinforcement; Bidim™ non-woven geotextiles, Tensar® geogrids™ and Geofabrics Australia's Ecoweb™ (geocell). In order to ascertain if the tensile strength of the geo-reinforcement affected the *in-situ* modulus, two (2) grades of both the geotextile – A29™ and A49™ – and geogrid – SS-30™ and TriAx™ – were independently tested. Accordingly, this study evaluated modulus increases associated with five (5) geo-reinforcement material variants.

The inclusion of a layer of geo-reinforcement within a gravel mass was expected to provide an increase in the measured modulus of the composite material via the application of a restraint to the free movement of loosely placed gravel. By the reduction or total restriction of movement of a portion of gravel material, any deformation observed at the surface was also be expected to decrease and, accordingly, the modulus value determined via monitoring surface deflections under measured loads would increase.

As presented in Figure 2, each of the three (3) types of geo-reinforcement tested (non-woven geotextile, geogrid, and geocell) were expected to provide a restraining force to the surrounding gravel via a different mechanism. The geotextile material would, upon loading, be expected to become a tensioned membrane and restrict the gravel material's movement; the geogrids would be expected to provide an interlocking membrane effect to laterally restrain the surrounding gravel material; whilst the geocell would provide a confinement effect to the material located within its vertical walls.

3.3 Test Arrangements and Procedure

For each geo-reinforcement test completed, a single layer of the geo-reinforcement was placed over 250mm of loosely packed gravel material within a 900mm by 565mm plastic container (i.e. rigid boundaries providing confinement to the gravel). The diameter of gravel varied between tests completed utilising geotextile reinforcement (5mm diameter gravel) or geogrid or geocell reinforcement (20mm diameter gravel).



(a) (b) (c)

Figure 2. Various boundary conditions through which geo-reinforcement materials provide restraining forces to the surrounding materials; (a) Geotextile tensioned membrane effect; (b) Geogrid confinement via horizontal constraint; and (c) Geocell (vertical) walls preventing material movement.

The installed geo-reinforcement was then subsequently covered with a defined thickness of the same gravel as used for the 250mm base layer. For the non-woven geotextile, tests were completed upon cover thicknesses of 0mm, 50mm, 150mm and 250mm. For other geo-reinforcements (geogrid and geocell), arrangements incorporating cover thicknesses of 50mm and 100mm were constructed. Table 1 presents a summary of each of the testing arrangements completed for this study, whilst Figure 3 presents the concept of the constructed arrangements completed for each type of geo-reinforcement.

After the construction of the geo-reinforced gravel mass, the *in-situ* composite stiffness was determined for each arrangement using the LFWD. For each arrangement, separate LFWD testing was completed utilising a 100mm and 300mm diameter rigid plate, and repeated for various (standardised) heights of weight drop. Due to the smaller diameter plate, a much higher stress was imparted by the rigid plate when the 100mm diameter plate was employed (refer Equation 1) – the 100mm diameter plate imparts a stress value approximately nine (9) times higher stress than that observed when using a corresponding weight drop height and a 300mm diameter plate.

For each of the eight (8) LFWD tests (i.e. loading arrangements) completed upon each composite arrangement, four (4) standardised weight drop heights were utilised for tests completed with the 100mm and 300mm diameter rigid plate (weight drop heights of 210, 420, 630 and 785mm). Tests involved the completion of a series of weight drops ($n \geq 10$) from each standardised drop height, such that any 'seating' and 'outlier' values could be identified within the recorded dataset. The equipment and methodology of LFWD testing was in accordance with relevant international standards and recommendations (e.g. ASTM-2835, IAN 73/06).

Table 1: Geo-reinforcement material and gravel (diameter and thickness) variants

Geo-Reinforcement Inclusion		Gravel Dia. (mm)	Gravel Thickness (mm)	
Type	**Name / Class**		**Base**	**Cover**
NIL (Unreinforced)	N/A	5	250	N/A
	N/A	20		
Geotextile	Bidim A29	5		0, 50 150 250
	Bidim A49	5		
Geogrid	Tensar SS-30	20		50, 100
	Tensar TriAx	20		
Geocell	EcoCell (90mm depth)	20		

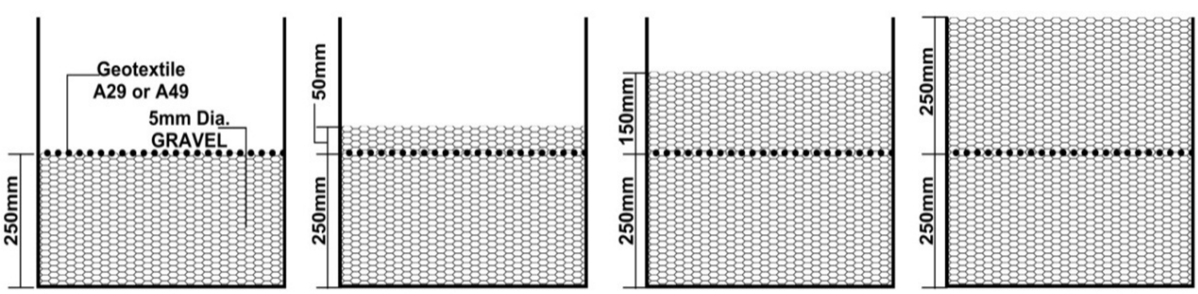


Figure 3. Concept of tested material arrangements (geotextile variation shown)

4 RESULTS AND DISCUSSION

For each LFWD weight drop height and constructed geo-reinforced arrangement, a standardised data inspection and filtering process was applied and an *in-situ* modulus value (E_{LFWD}) value determined. The filtering process included the removal of seating blows and data outliers, as per previously published methodologies (e.g. ASTM-2835, IAN 73/06).

Prior to the influence of any geo-reinforcement, the general relationship between test stress and modulus was expected to be linear, as presented in Figure 4. In order to allow a direct correlation between each of the tested material arrangements, the reported E_{LFWD} values were interpolated to standardised test stress values. These stress values – 50kPa, 75kPa and 100kPa for the 300mm diameter rigid plate and 500kPa, 750kPa and 900kPa for the 100mm diameter rigid plate – are within the expected test stress ranges, as shown in annotations included in Figure 4.

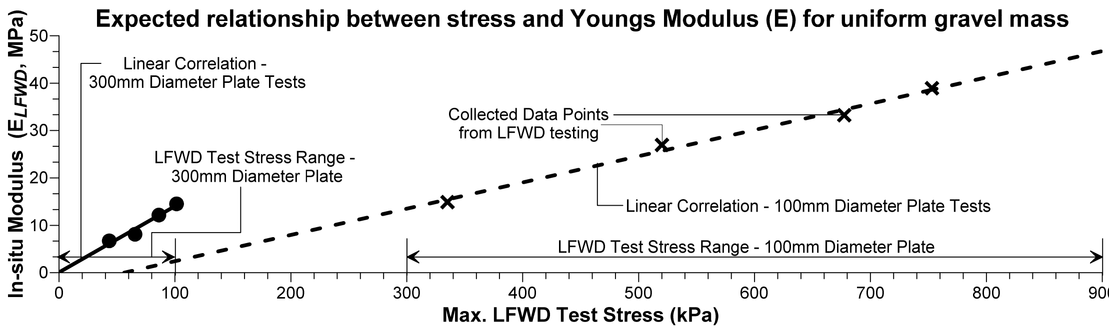
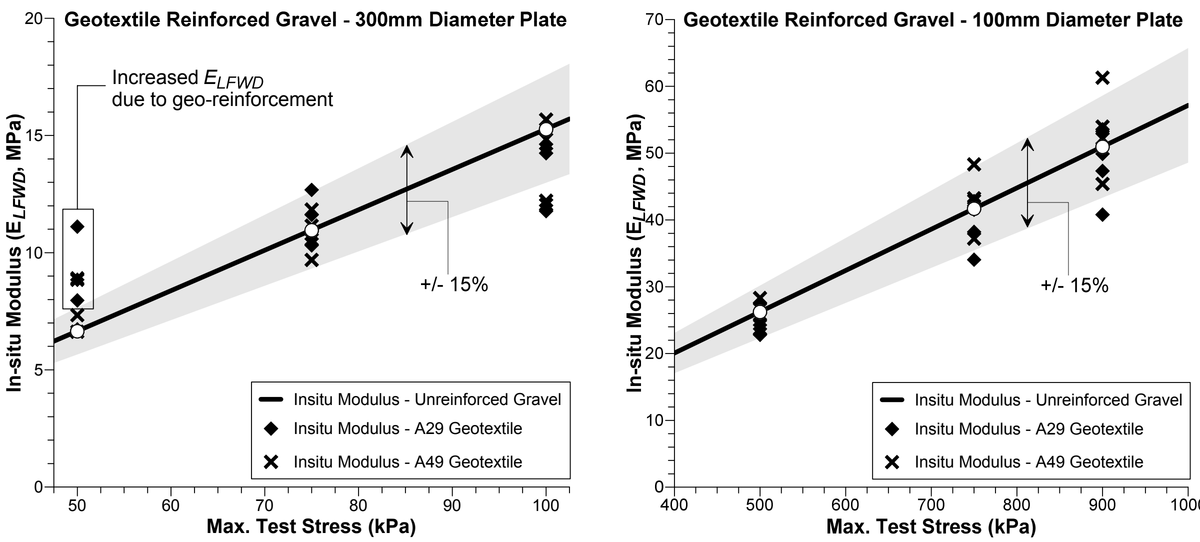


Figure 4. Expected linear relationship between observed E_{LFWD} values and max. test stress for uniform material within LFWD zone of influence. Note significant change of stress based on utilised plate dia.

Assessment of the effect of the layer of geo-reinforcement was undertaken by direct comparison between the corresponding standardised E_{LFWD} values determined for the reinforced and unreinforced arrangements. In line with previous recommendations (Fleming et. al., 2009), and based on the CoV values determined in this study, a E_{LFWD} value within 15% of the unreinforced ('baseline') value was considered to represent no *in-situ* modulus change.

4.1 Non-Woven Geotextile

Figure 5 displays the E_{LFWD} values derived for each of the tests completed upon the non-woven geotextile materials using (a) a 300mm diameter rigid plate; and (b) a 100mm diameter rigid plate. As seen in these results the only observable increased E_{LFWD} modulus values occurred at tests conducted with lowest stress magnitude (σ < 60kPa). The stiffness results obtained from tests completed with the



(a) *(b)*

Figure 5. E_{LFWD} values with geotextile inclusions compared to unreinforced gravel. (a) E_{LFWD} values obtained using a 300mm diameter plate; (b) E_{LFWD} values obtained using a 100mm diameter plate.

100mm diameter plate appear to be relatively consistent with the E_{LFWD} values calculated for the unreinforced arrangements (refer Figure 5b), in which with the majority of results (20 of 24 tests, 84%) plotted within the accepted range of E_{LFWD} variation (±15%).

Within the range of test stresses that displayed improvement due to the inclusion of a geotextile layer (i.e. σ < 60kPa), the magnitude of modulus improvement was observed to vary up to a maximum of 67%. As presented in Figure 6, there appeared to be an initial increase in E_{LFWD} values when LFWD testing was completed directly upon the geotextile material, whereby E_{LFWD} values increased by 20% to 33% over the corresponding unreinforced material moduli. Although this increase disappeared when 50mm of gravel cover was placed upon the material, once at least 150mm of gravel cover was installed an improvement above baseline modulus values was again repeatedly observed, with the magnitude of modulus improvement increasing with depth of gravel cover. The strength class of geotextile did not always reflect the magnitude of observed E_{LFWD} improvement, with the lower strength geotextile (A29) providing higher E_{LFWD} values (by up to 33%) than the corresponding tests conducted with high strength (A49) geotextile installed and at least 150mm of cover placed.

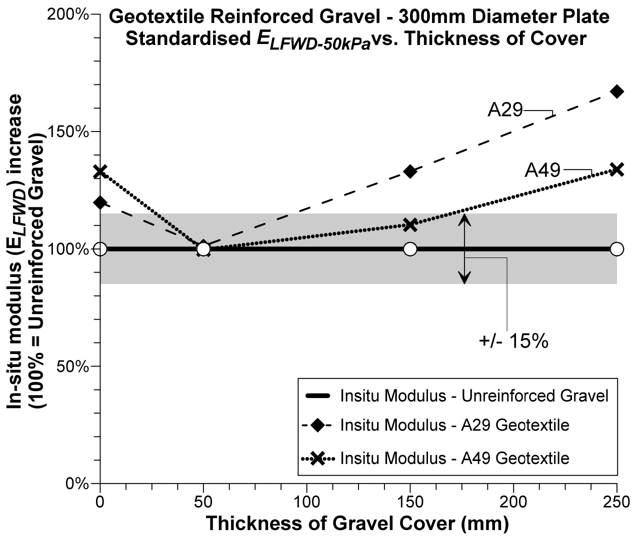


Figure 6. Increase (%) of standardised in-situ modulus ($E_{LFWD-50kPa}$) based on gravel cover thickness for 50kPa tests completed upon geotextile reinforced and unreinforced 5mm gravel (loosely placed).

These results confirmed that non-woven geotextile products should be used solely to provide a separation or filtration function, rather than for any reinforcement purpose. Any modulus increase due to the inclusion of such a material appeared to be limited to the low stress test state (σ < 60kPa) and within low modulus values ($E_{LFWD} \leq$ 10MPa). This was interpreted to indicate that at higher test stress values ($\sigma \geq$ 60kPa) a bearing capacity failure of the composite arrangement likely resulted, in which the non-woven geotextile was, along with the surrounding gravel, significantly displaced and thus not able to provide any material confining effect. Visual observations supported this interpretation, in which the deformation created within the gravel arising from LFWD testing was significantly deeper when the 100mm diameter plate was used (in comparison to the 300mm diameter plate). Tests completed with the wider (300mm) plate produced a uniform, 20mm deep depression across the full LFWD footprint whilst other (100mm) tests produced a deeper, conical depression / heaved surface.

4.2 Geogrid and Geocell

The same method of result analysis was adopted for tests completed upon the geogrid and geocell reinforcement materials. Figure 7 plots the calculated E_{LFWD} values for each of the geogrid and geocell arrangements tested. As per the geotextile results, no modulus improvement due to the inclusion of geo-reinforcement was observed in the tests involving the 100mm diameter plate or the higher stress state associated with the 300mm diameter plate (i.e. $\sigma \geq$ 85kPa).

For the tests in which modulus increases were noted (i.e. σ < 85kPa), both the magnitude of E_{LFWD} increase and depth to which increases above the unreinforced E values continue appears to be reinforcement material type specific. When 50mm gravel cover was installed, only the tests imparting the lowest stress (50kPa) displayed improved E values. However, once 100mm gravel was installed,

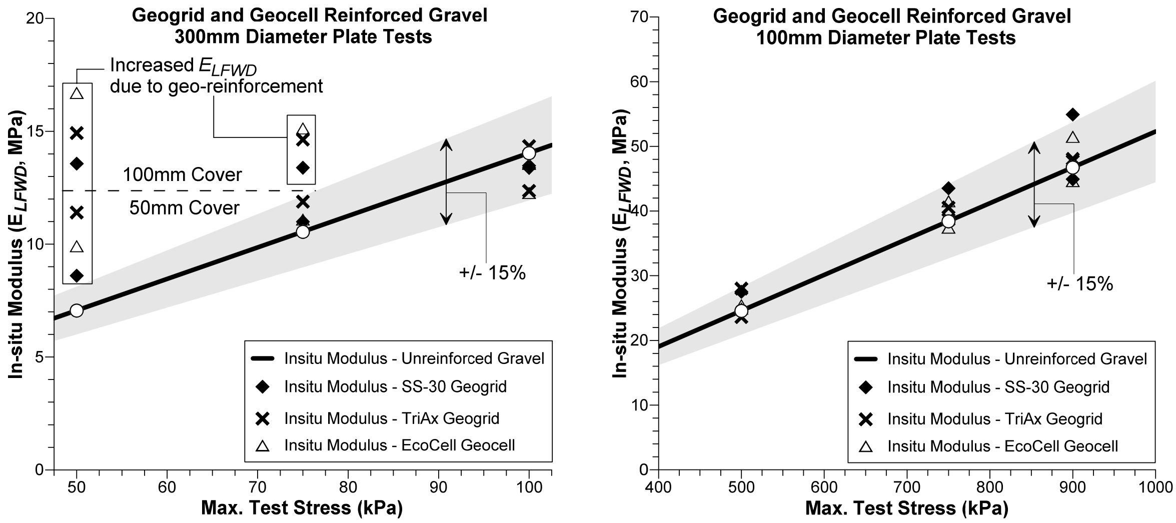


Figure 7. E_{LFWD} values with geogrid and geocell inclusions, compared to unreinforced material. (a) obtained using a 300mm diameter plate; and (b) obtained using a 100mm diameter plate.

increased *E* values were observed in both the 50kPa and 75kPa standardised E_{LFWD} values, with the 50kPa values indicating greater improvement than that observed in the 50mm cover tests. This suggests that the magnitude of the stiffening response to geo-reinforcement inclusions increases with the depth of burial. However, due to the limited thickness of gravel cover included in this study (max. 100mm thick gravel cover), the optimum depth at which the geo-reinforcement could be installed to observe the maximum *E* increase in surface based testing was unable to be quantified.

As shown in Figure 8, the effect of the inclusion of a geogrid or geocell as a geo-reinforcement layer fundamentally alters the linear relationship between the *in-situ* modulus (E_{LFWD}) and imparted stress magnitude (as previously presented in Figure 4). Instead, the reinforced composite mass effectively increases the modulus towards a constant E_{LFWD} value (as evidenced by the sub-horizontal lines to the left of the graphs in Figure 8) until the imparted stress level increases and the altered relationship intersects the unreinforced gravel's linear relationship. Beyond this intersection (right hand side of graphs in Figure 8) no difference between the reinforced and unreinforced E_{LFWD} value was observed.

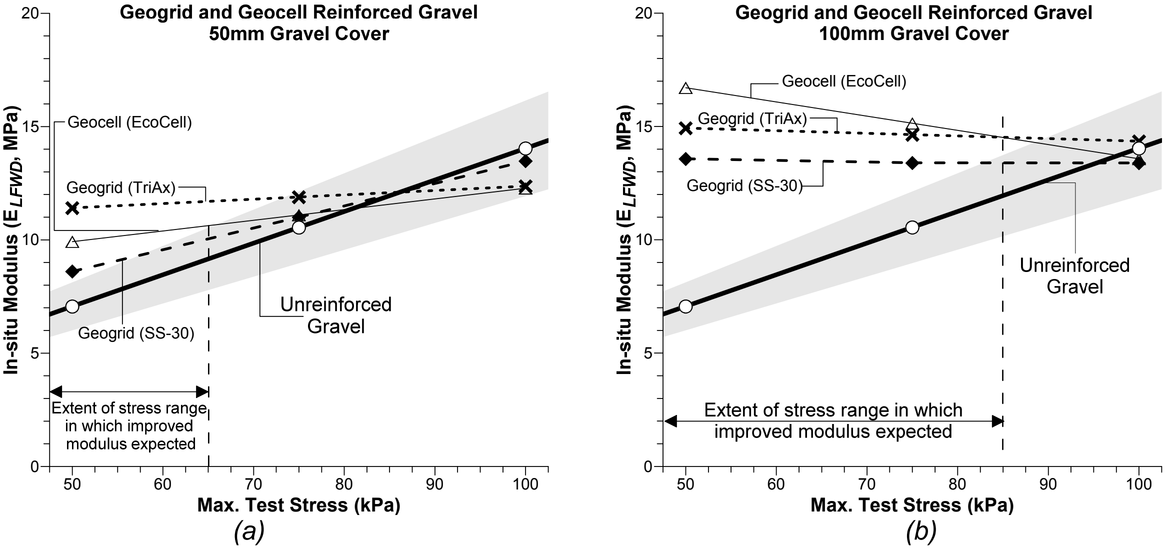


Figure 8. E_{LFWD} values based on type of geogrid and geocell inclusion, compared to unreinforced material; (a) For 50mm gravel cover; and (b) For 100mm gravel cover (tested using 300mm dia. plate).

Of the two (2) geogrids types tested, the TriAx reinforcement consistently outperformed the SS-30 geogrid, always returning a superior E_{LFWD} in the results that demonstrated a modulus improvement from the corresponding unreinforced arrangements (i.e. σ < 85kPa). The TriAx reinforcement layer demonstrated a modulus increase of up to 111% compared to the 'baseline' E_{LFWD} values, whilst the

SS-30 geogrid showed a maximum of 92% improvement. Similarly, in tests completed using 50mm gravel cover the TriAx reinforcement returned $E_{LFWD-50kPa}$ values up to a 32% higher than the corresponding SS-30 arrangement value.

The geocell demonstrated the highest observed modulus improvement of the study once 100mm of gravel had been placed over the reinforcement cell, with a maximum E_{LFWD} improvement of 137% observed in $E_{LFWD-50kPa}$ values. This modulus improvement was 26% greater than the corresponding testing completed with TriAx geogrid, and was interpreted to imply that the vertical walls of the geocell were more effective at providing material confinement (or affects a greater area of gravel material) than the rigidity provided by mechanical interlock associated with horizontally orientated geogrids.

5 CONCLUSIONS

This independent study assessed the relative improvement in *in-situ* stiffness when various types of geo-reinforcement products were incorporated into loosely placed gravel. A Light Falling Weight Deflectometer (LFWD) was used to measure the *in-situ* modulus and, based on the results of these tests the following conclusions were made:

- As applied shear stress increased, observable improvements in *in-situ* modulus reduced. In the case of geotextiles a test stress value above 60kPa demonstrated no increase to *in-situ* modulus. For the geogrid and geocell materials tested this cut-off value increased to 85kPa.
- Inclusion of geotextile was observed to have the smallest effect on the *in-situ* modulus improvement. A maximum improvement of 67% was observed in testing involving geotextiles.
- The inclusion of a layer of geogrid improved *in-situ* modulus values by up to 111%. The type of geogrid installed affected the magnitude of modulus increase, with the TriAx geogrid consistently outperforming the SS-30 (biaxial) geogrid (by up to 32% greater improvement).
- Of the tested geo-reinforcements, the inclusion of a single geocell provided the greatest increase to the surface measured *in-situ* moduli. The maximum *in-situ* modulus improvement observed (137%) was found when the geocell was installed under 100mm of gravel cover.
- Observed *in-situ* moduli improvement was greatest when cover gravel depth was maximised. To determine the optimal location to install reinforcement within a material profile, such that maximised *in-situ* modulus improvement is observed at surface level, requires additional trials.

6 ACKNOWLEDGEMENTS

The authors would like to acknowledge Geofabrics Australasia for the provision of the geo-reinforcement products used for the completion of this study.

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