Behaviour of biaxial geogrids in unpaved roads – research from Ireland

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ABSTRACT: Biaxial geogrids are often used to reinforce unpaved roads over low strength subgrades. By allowing the unsuitable subgrade to remain in place and allowing for reduced road thicknesses, substantial reductions in cost and improvements in performance can be achieved. This paper reviews research undertaken at Technological University Dublin where small model testing boxes and instrumented geogrids have been used in combination with representative samples of weak subgrades and high-quality granular fill to simulate the response of biaxial geogrids to monotonic and cyclic plate loading. It was found that the tensile strain measured in the geogrid under test was only a small fraction of the geogrid's ultimate tensile strain, indicating that the ultimate strength of the geogrid is less important than its interaction with the fill. The magnitude of loading was found to have a more significant effect on displacement than the number of load cycles suffered. It was also found that increasing the number of geogrids in the road had a very significant impact on strain and displacement suffered.

1 INTRODUCTION

Geotextiles and geogrids, have been used in the reinforcement of unpaved temporary access roads over low-strength unsuitable subgrades. When unsuitable subgrades are left in place and the correct geosynthetics are used, it can lead to reductions in cost, improved performance, reduction of rutting, and an increased service life of the unpaved access roads (Keller, 2016).

Unpaved roads are generally constructed by placing one or more layers of high-quality granular fill over a natural subgrade. When one or more layers of geotextile or geogrid is placed between the subgrade and the granular fill as a separator and/or reinforcement, an improved road base can be achieved. A typical reinforced unpaved road cross section is shown in Figure 1.

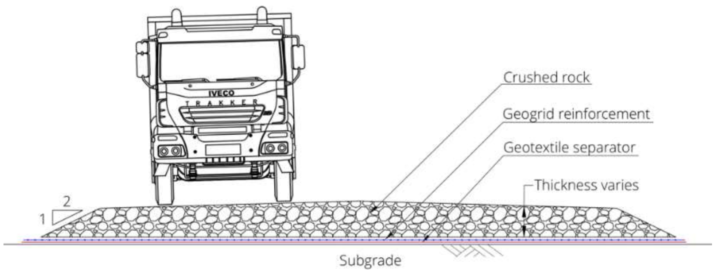

Figure 1. Typical unpaved road cross section.

Many design methods have been proposed for unreinforced and reinforced unpaved roads over the years. A significant body of field test data, where unreinforced unpaved roads and airfields were tested under known loadings, was published by (Hammitt, 1970). Various authors have developed design methods based on these and other data (Giroud and Noiray, 1981, Milligan et al., 1989a, 1989b, Jewell, 1996, Giroud & Han, 2004a, 2004b). The majority of these methods take account of the confinement and lateral restraint of the granular particles which interlock with the ribs of the geogrid (Giroud, 2009) rather than the "tensioned membrane" effect which requires larger deformation than those typically tolerated for road ways.

The Giroud & Han (2004a, 2004b) design method has been widely used to design unpaved roads using bixial geogrids in Ireland. Several case histories are presented in Reilly & Nell (2018). Calvarno et al. (2016) report on an analysis of the Giroud & Han design method alongside the more recent Leng & Gabr procedure. The Giroud & Han design method predicted a greater design road thickness than the Leng & Gabr procedure. The field testing found that the Giroud & Han and Leng & Gabr designs formed upper and lower bounds respectively to the measured performance of a road on a subgrade for CBR = 1.3%.

Jas et al. (2015a, 2015b) used discrete element modelling, calibrated with laboratory testing in a 1.0m (L) x 1.0m (W) box, to show the response of a geogrid in an unpaved road on a weak subgrade to loading due to a passing wheel. The actual tensile stress and strain in the geogrid was very small (less than 0.3 kN/m and around 0.5% respectively) and a small fraction of the geogrid's ultimate capacity, achieved at around 6% strain. It was concluded that the confinement of the granular particles in the apertures of the geogrid result in a residual stress in the first 8 to 10 cm above the geogrid.

2 RESEARCH ACTIVITIES

2.1 *Research at Technological University Dublin (TU Dublin)*

This paper reviews research conducted by Rutkauskas (2018), Aladwani (2019), and Flaherty (2020) under the supervision of the first author at TU Dublin. Two designs of model testing boxes and instrumented biaxial geogrids (Thrace TG3030S) were used in combination with representative samples of weak subgrades and granular fill to simulate the response of biaxial geogrids to monotonic and cyclic plate loading. Testing was carried out with different subgrades, varied loading intensities and cycles and varying numbers of geogrids. The granular fill "Clause 804" and a well graded 0/31.5mm crushed rock fill was used. (Travers & Wyse, 2022).

2.2 *Instrumented geogrid with foam subgrade*

Rutkauskas (2018) carried out research involving instrumenting the geogrid with strain gauges to show how the geogrid responded to loading when placed in contact with a weak subgrade (in this case replicated by a foam) and covered by a surcharge of crushed rock, as would be the case in an unpaved road. The timber test box was 0.6m (L) x 0.6m (W) x 0.6m (H). Strain gauges were placed around one junction, located approximately midway in the left-right sense of the geogrid, and at the one third location in the up-down sense of the geogrid. Loading was applied monotonically using a 100mm x 100mm steel plate actuated by a hydraulic ram fitted with a load cell. Tests were carried out as follows:

- No geogrid, 300mm crushed rock directly on the subgrade
- One layer of geogrid on the subgrade, 300mm crushed rock over

- One layer of geogrid on the subgrade, one layer of geogrid mid-height of the crushed rock

A cross section of the test apparatus is shown in Figure 2.

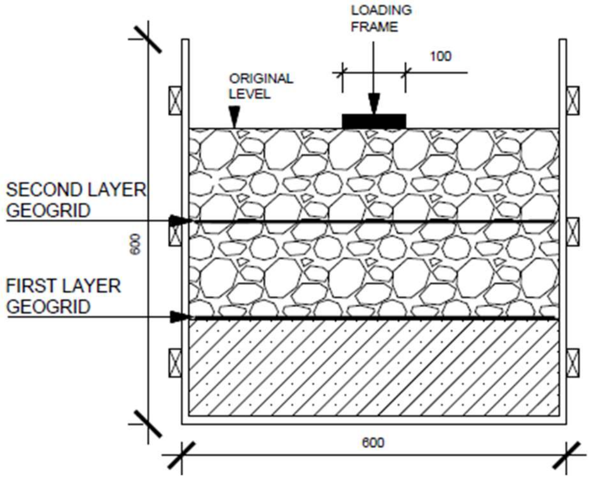

Figure 2. Testing arrangement for two layers of geogrid. For tests with one layer, the second layer of geogrid was omitted while material thicknesses remained the same (Rutkauskas, 2018).

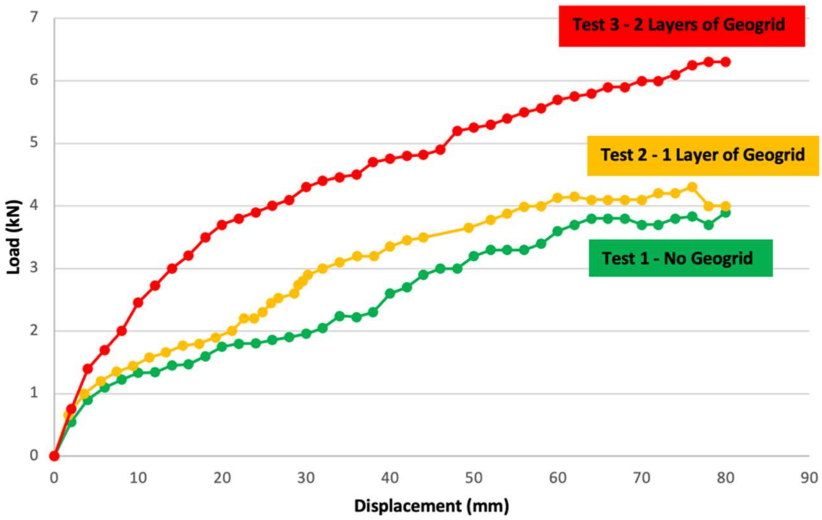

Figure 3. Loading vs displacement for no geogrid, one layer of geogrid, and two layers of geogrid. (Rutkauskas, 2018).

The load carrying capacity at 40mm defection was increased by 29% for one layer and 83% for two layers, and at 75mm deflection by 29% for one layer and 61% for two layers. Figure 3.

At the end of the test phase at 80kN loading, the plate penetrated the fill by a lesser amount when reinforced; plate penetration was reduced by 5% for one layer and 13% for two layers. Finally, the tensile strain measured was less than 0.31% at the end of the test phase at 80kN for both reinforced cases. For the case with two layers of geogrid, strains measured in the geogrid at mid height were smaller than the strains measured in the geogrid placed on the subgrade (0.13% vs 0.31%. Compression strain was measured in some strain gauges.

The results showed that the tensile strain measured in the geogrid was only a small fraction of the geogrid's ultimate tensile strain. The tensile force per meter in the geogrid was found to be 1.86kN/m for the test with one layer and 2.0kN/m for the test with two layers. These forces are only 6.2% and 6.67% respectively of the ultimate tensile strength of the geogrid of 30kN/m. This finding corresponds with the findings of Jas et al. (2015a, 2015b).

2.3 *Instrumented geogrid with natural soil subgrade*

Aladwani (2019 built on lessons learned by Rutkauskas (2018. A rigid model testing box and a real soft soil (peat) rather than a foam. Up to four layers of geogrid were utilized in the test.

The testing box was 0.7m (L) x 0.7m (W) x 0.7m (H) and fabricated from mild steel. A peat sub-grade obtained from a peatland in the midlands of Ireland was used. The peat's properties were: Von Post H5, unusually low moisture content of 10.5%, and lab vane strength 4.5kPa. The peat was placed in 150mm thick layers before each test. Testing proceeded to a displacement of 120mm rather than 80mm. The testing arrangement is shown in Figure 4.

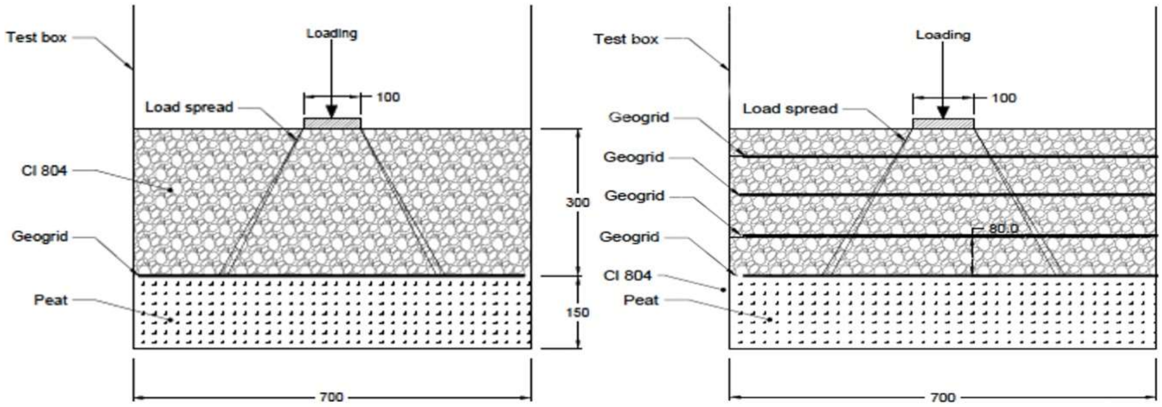

Figure 4. Testing arrangement (Aladwani, 2019).

Results of the testing showed that multiple layers of geogrid, as expected, increased the loading sustainable for a given displacement, as per Rutkauskas (2018). The load carrying capacity at 60mm defection was increased by 245% by increasing geogrid layers from one to four, and at 120mm deflection by 516% for four layers.

At the end of the test phase at 120mm displacement, the loading plate penetrated the fill by a lesser amount when reinforced with four layers as against one layer; plate penetration was reduced by 21% for four layers.

The strain gauge readings were between 0.25% and 0.6% at the end of the test phase at 120mm displacement for both reinforced cases. The greater tensile strain measured by Aladwani as against the strain measured by Rutkauskas is explained by the greater displacement of the loading plate (120mm vs 80mm) and the use of soft peat as a subgrade. Again, compression strain was measured in some strain gauges. The results showed that the tensile strain measured in the geogrid (0.25 to 0.6%) was a small fraction of the geogrid's ultimate tensile strain of 9 to 12%.

2.4 *Instrumented geogrid with natural soil subgrade subjected to cyclic loading*

Flaherty (2020) built on the previous two studies by introducing cyclic loading conditions to the testing regime. Cyclic loading was intended to replicate traffic passing over the surface which gave a more accurate indication of how the geogrid will perform in a typical unpaved road.

The testing equipment and arrangement were largely the same as used by Aladwani (2019), except that a sheet of non-woven geotextile was introduced to separate the peat from the crushed rock. The peat was compacted in 150mm thick layers and has a moisture content of 75% and lab vane strength 9.4kPa.

Tests were carried out as follows:

- One layer of geosynthetic, one layer of geogrid
- One layer of geosynthetic, two layers of geogrid
- One layer of geosynthetic, three layers of geogrid

The cyclic loading regime involved increasing the load intensity from 5kN to 25kN in increments of 5kN. For each 5kN loading phase, four load cycles were applied. Vertical deformation of 120mm was considered as failure. Loading was applied at a rate of 0.5kN per second. Graphs of load vs displacement are shown in Figure 5, Figure 6, and Figure 7.

The results showed that load magnitude has a greater influence on displacement than the number of load cycles. The most significant increases in displacement occured when the load magnitude was increased by 5kN at the start of each new loading phase. After the initial increase, the displacement reduced and became more uniform throughout the remainder of each loading phase. The test with three layers of geogrid had the lowest maximum average increase in displacement due to additional load, indicating that increasing the number of geogrid layers improves the roads ability to resist temporary and permanent deformation.

During the unloading phase of each loading cycle, both the displacement and the strain in the bottom layer of geogrid demonstrated the ability to recover. The average strain recovery was 97.5%, and the average displacement recovery was 63%. Displacement recovery was greater as the number of geogrid layers increased, indicating that increasing the number of layers of geogrid will help to reduce temporary and permanent deformation and thus increase the life of the road.

The highest strains were recorded at 40mm from the centre of the geogrid, which was directly under the plate load. This suggests that the lateral confinement of the aggregates results in a higher strain under the wheel load. Further research is required to clarify the mechanism causing this.

The results also indicated that lateral confinement occurs earlier when the number of geogrid layers increase. This could be as a result of the top layer of geogrid being closer to the plate load. Further research is required to determine the optimum placement of the geogrid.

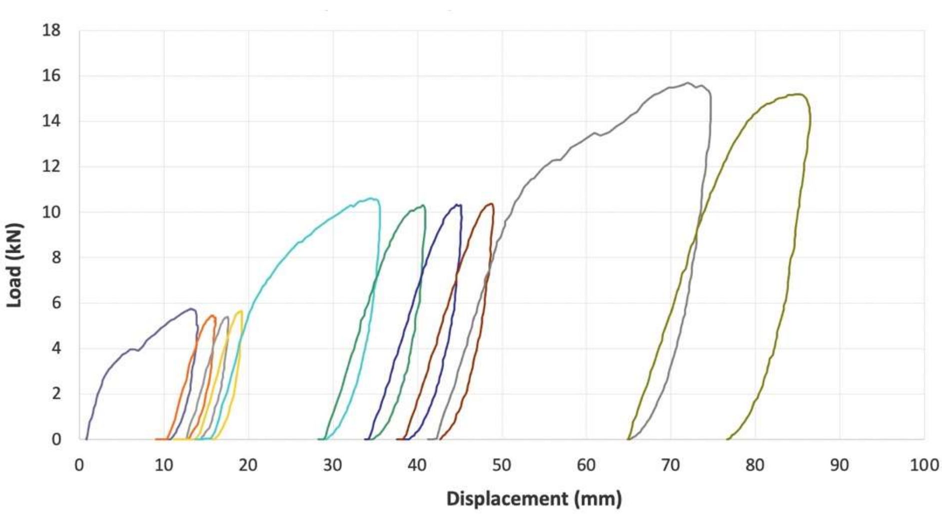

Figure 5. One layer of geogrid – displacement vs load (Flaherty, 2020).

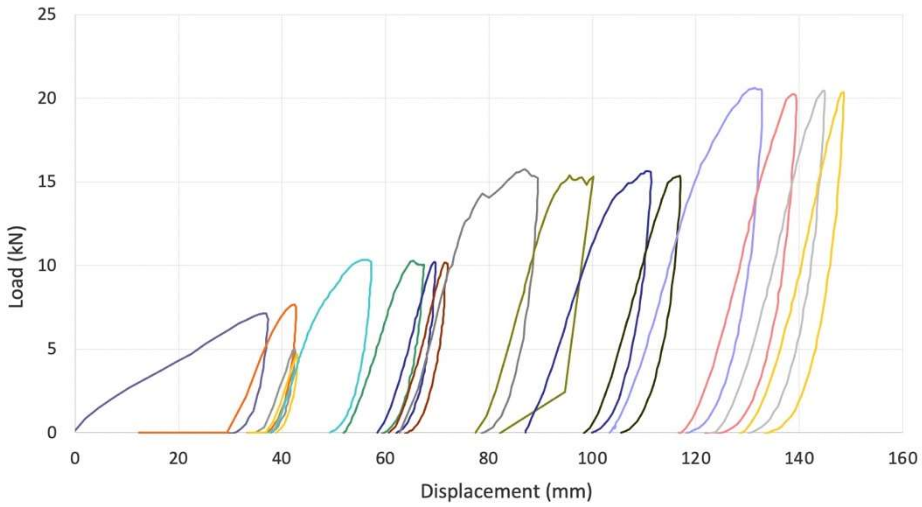

Figure 6. Two layers of geogrid – displacement vs load (Flaherty, 2020).

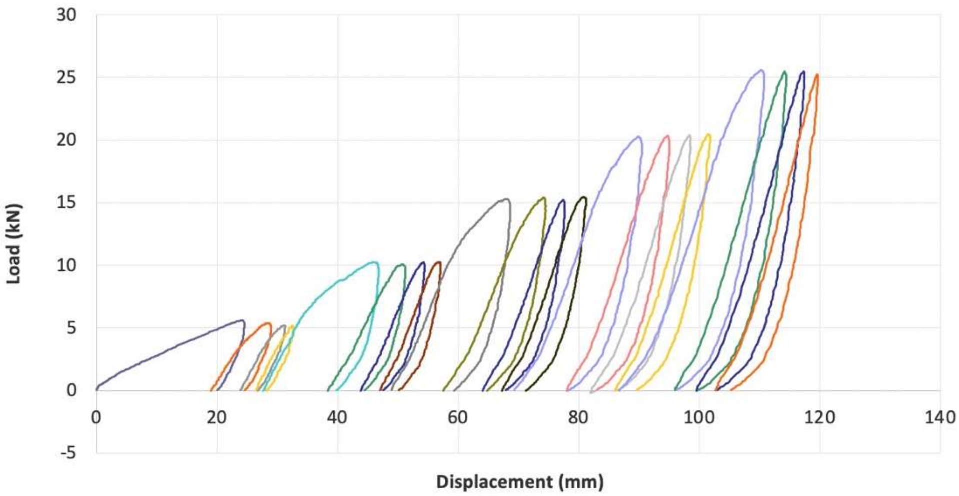

Figure 7. Four layers of geogrid – displacement vs load (Flaherty, 2020).

3 CONCLUSION

Conclusions drawn from the work are as follows:

- Small model testing boxes and instrumented geogrids were used successfully in combination with representative samples of weak subgrades and high-quality granular fill to simulate the response of biaxial geogrids to monotonic and cyclic plate loading.
- It was found that the tensile strain measured in the geogrid under test was only a small fraction of the geogrid's ultimate tensile strain, indicating that the ultimate tensile strength of the geogrid is less important than its interaction with the fill.
- The magnitude of loading was found to have a more significant effect on road surface displacement than the number of load cycles suffered.
- It was also found that increasing the number of geogrids in the model unpaved road had a very significant positive impact on the strain and displacement suffered.
- Further research is required to relate the thickness of the unpaved road in testing to design thicknesses from the design methods commonly in use.
- Further work will also use increased loading cycles and a larger testing box.

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