IMPROVED TRACKBED PERFORMANCE OVER LOW STRENGTH FORMATION SOILS USING MECHANICALLY STABILISED LAYERS

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SUMMARY

When constructing rail track over low strength sub-grade soil, it is necessary to improve the support provided by this foundation soil to allow the required track geometry to be established and maintained. Techniques such as chemical stabilisation or excavation and replacement can be both time consuming and expensive.

The use of mechanically stabilised layers incorporating geogrids can allow a reduction in sub-ballast layer thickness resulting in reduced excavation and importation costs whilst providing required support levels to the subsequently placed ballast layer. Extensive investigation into the effectiveness of these geogrid mechanically stabilised granular layers has taken place over the last 30 years with the most recent research demonstrating the enhanced improvements provided by multi-axial hexagonal stabilisation geogrids.

This paper will describe the research undertaken to demonstrate these benefits and will discuss "live line" applications to illustrate practical application using project examples from around the world.

1 INTRODUCTION

Maintaining track geometry is beneficial to the timely operation of train services as well as reducing the need for expensive and disruptive track maintenance operations. The use of geogrids to improve trackbed stiffness and therefore assist in maintaining trackbed geometry has been a cost effective method adopted by engineers for around 30 years.(1)

The use of geogrids has been driven by extensive full scale research both in the laboratory and within "live line" sites which has confirmed the benefits of including integrally formed, "punched and drawn" geogrids within the trackbed structure. Much of this early work focused on biaxial geogrids, characterised by square apertures forming the geogrid structure, but has been further advanced with investigation into the relative performance of multiaxial hexagonal stabilisation geogrids, characterised by triangular apertures.(2)

Research programmes have examined the effect of geogrids in ballast where their benefits include reduced settlement rates, reduced traffic induced ballast degradation and extended ballast maintenance cycles.

However, the performance of geogrids has also been examined to assist engineers when they are engaged in constructing rail track over low bearing capacity sub-grade soils. This typically introduces the need to improve the foundation support required for the ballast layer. Solutions can involve time consuming chemical stabilisation of the sub-grade soils or excavation and replacement with sometimes thick layers of granular sub-ballast.

As an alternative to these techniques, a mechanically stabilised layer can be employed using multiaxial stabilisation geogrids, placed directly on the low strength formation without the need to remove existing soils.

2 RESEARCH BACKGROUND

As with other uses of geogrid in trafficked applications, it is difficult to quantify the benefits offered to a trackbed structure theoretically with results for one type of geogrid not easily transferred to another without similar full scale investigation. Gathering knowledge based on full scale performance assessment has been shown to provide geogrid manufacturers and designers with the confidence required to apply this technology to the benefit of their projects. As mentioned already, this research is extensive and initially focused on the use of punched and drawn biaxial geogrids. The following briefly examines this early research to set the scene for the improvements described later for the multiaxial hexagonal geogrids.

Various trial projects were used to demonstrate the benefits of geogrids in sub-ballast.

2.1 Deutsche Bahn, Cologne, Germany, Germany, 2003

The German Rail Authorities, Deutsche Bahn (DB) carried out a monitored project in 2003 where the inclusion of a punched and drawn biaxial geogrid was used to reduce the original 1.05m of gravel sub-ballast thickness by around one third to 700mm. It was of course important to maintain the target levels of support at the top of the selected sub-ballast required to place the ballast. The design was carried out using the Ev2 surface modulus methodology[3] with a target Ev2 at the top of the sub-ballast layer of 120MPa. The sub-grade had an in-situ Ev2 modulus of 10MPa.

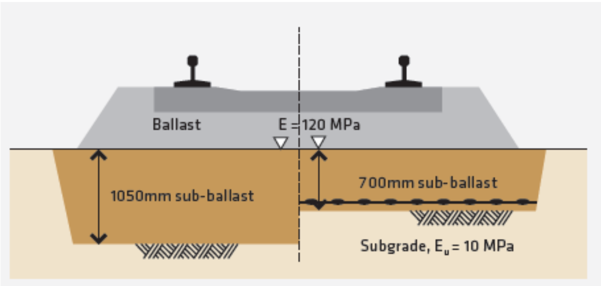

Figure 1: Comparison of non-stabilised and geogrid stabilised sub-ballast layers, Deutsche Bahn, Cologne, Germany, 2003

The reduced thickness of granular sub-ballast material used on this project lowered costs significantly with importation, excavation and construction times all reduced.

2.2 Bratislava-Trnava line, Slovakia, 1999

A further demonstration of the effectiveness of sub-ballast stabilisation with geogrids come from a trial section on track constructed on the Bratislava to Trnava line in Slovakia in 1999. The rail authority required a level of support to the ballast layer of at least 50MPa, again using the Ev2 modulus approach[3], in order to satisfy the standard for European corridors of a 160km/h line speed. The modulus of the existing sub-grade was variable but with a maximum modulus of 10MPa and so a sub-ballast layer was required and the opportunity was taken to assess the effect of including a geogrid.

Figure 2: Geogrid placed on geotextile directly on sub-grade soils awaiting sub-ballast installation, Bratislava to Trnava, Slovakia, 1999.

A design was carried out to determine appropriate sub-ballast thicknesses to meet the variable ground conditions and a series of plate loading tests were carried out on the site to examine the validity of the design along the line. The results are shown in Figure 3 and, as can be seen, all of the 12 tested sections exceeded the 50MPa target modulus.

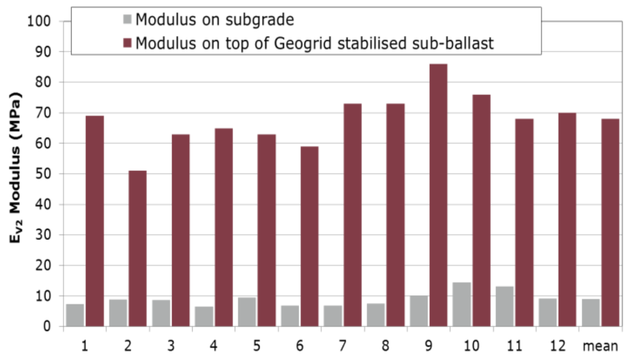

Figure 3: results of 12 plate load tests along the geogrid stabilised sections of the Bratislava to Trnava line, Slovakia, 1999.

3 ADVANCES IN GEOGRID TECHNOLOGY

Whilst this extensive and detailed work remains valuable, advancements in manufacturing “know-how” have allowed a pioneering geogrid manufacturer to improve these benefits still further with the introduction of multiaxial stabilisation geogrids, characterised by a distinct hexagonal structure and triangular apertures. Following the lead taken in the 1980’s, further extensive research programmes including full scale laboratory and “live line” investigation have been carried out to examine the performance of what are termed mechanically stabilised layers including hexagonal stabilisation geogrids. Results show that the previously described benefits associated with the older biaxial products have been enhanced by the multiaxial geogrids to allow railway engineers to benefit still further in trackbed applications.[3]

The following describes examples of this research into the performance of mechanically stabilised layer incorporating hexagonal stabilisation geogrids in sub-ballast applications.

4. THE STABILISATION FUNCTION

Recent legislation in Europe has resulted in the introduction of the distinct "stabilisation function" associated with multiaxial hexagonal geogrids which differs from the more traditional tensile strength based "reinforcement function" associated with other types of geogrid [4]. Geogrids operating as stabilisation geogrids are used to "….minimize deformations under trafficking, to improve bearing capacity and increase the design life of the granular layer in or under construction in roads, railway and other trafficked areas…." [5] Geogrid parameters associated with the stabilisation function are:

- Radial stiffness at 0.5% strain;
- Radial stiffness ratio;
- Junction efficiency; and
- Hexagon pitch (aperture size).

Tensile strength properties of a geogrid have been shown to be poor indicators of expected performance under trafficking and this premise has been investigated and extended into understanding the benefits demonstrated by the multiaxial geogrids within the rail research described below.

Stabilisation relies upon the development of efficient particle confinement and the resulting mechanical interlock between the granular fill and the geogrid structure provides a "mechanically stabilised layer" or "MSL".

5. RESEARCH INTO STABILISATION OF SUB-BALLAST

Research into the performance of mechanically stabilised layer incorporating hexagonal stabilisation geogrids when applied as sub-ballast layers to improve bearing capacity is extensive. Performance has been assessed in both laboratory and "live line" conditions some of which is described below.

5.1 Comparative performance of geogrids within sub-ballast under cyclic loading

A programme of full scale cyclic load testing was carried out using apparatus at the Czech Technical University in Prague, Czech Republic. The testing was used to evaluate the performance difference between a biaxial geogrid and a hexagonal stabilisation geogrid.

5.1.1 Test set up

The tests were carried out using a steel box of 2.0 x 1.0 x 0.8m in size, consisting of welded steel sections with removable walls from wooden baulks at 100 x 150 mm in section. To minimize the friction of the sleeper bed against the box walls, the wooden walls were lined with a galvanized sheet 0.55 thick. The box bottom and walls were further covered with a thin foil to prevent desiccation of the brick clay.

5.1.2 – Subgrade clay

Brick clay blocks were laid onto the bottom of the test box in two layers to form a clay sub-grade 280mm in thickness. Each layer was compacted with a manual vibration device for 25 minutes, ensuring a consistent compaction level.

Figure 4: Clay sub-grade being placed and compacted, Czech Technical University, Prague, 2009

5.1.3 – Geogrids included

A non-woven separation geotextile layer was placed on the clay subgrade layer to avoid any short term mixing between the clay and sub-ballast. Two types of rigid monolithic geogrid were used, each placed on the geotextile layer:

- A biaxial geogrid ref: Tensar SS30 – 30kN/m biaxial tensile strength and aperture size of 39mm x 39mm
- A multi-axial hexagonal geogrid ref: Tensar TriAx TX160 – stabilisation geogrid – hexagon pitch 80mm.

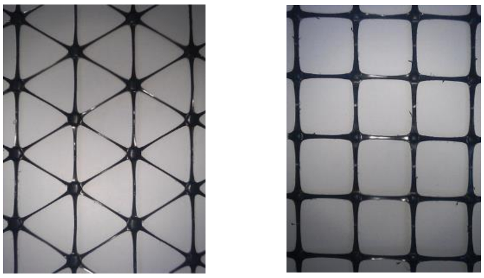

Figure 5: Plan view of hexagonal stabilisation geogrid (left) and biaxial geogrid (right)

5.1.4 – Trackbed construction

A granular layer consisting a 0/32mm locally sourced gravel was placed and compacted to achieve a 150mm thick sub-ballast layer. This material was placed directly on top of each geogrid for each of the tests carried out. A course graded – 32/63mm - 300mm thick locally sourced ballast stone was then placed and compacted on top of the sub-ballast to complete the overall trackbed thickness.

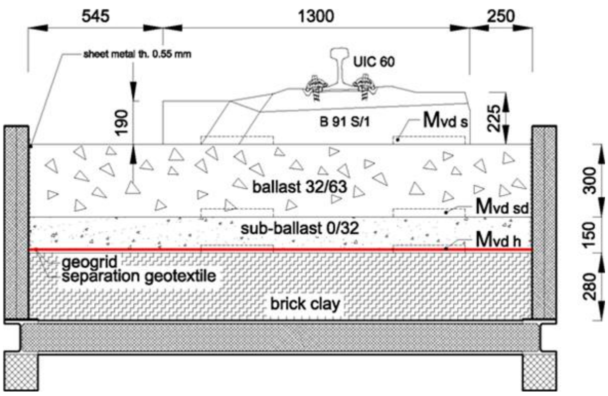

Figure 6: Test set up for full scale cyclic loading with geogrids in sub-ballast at Czech Technical University, Prague

5.1.5 – Load application

Cyclic loading was applied using an actuator positioned on a "half sleeper" section through a 500mm length of UIC 60 steel rail section. Loading cycled at a frequency of 3Hz up to a load of 42kN. Each test set up was subjected to 250,000 load cycles with intermitted measurements taken at 100, 1,000, 10,000, 50,000, 100,000 and 250,000 intervals.

Figure 7: Completed tests section showing sleeper and rail section under load actuator, Czech Technical University, Prague

5.1.6 – Measurements and results

Settlement at the top of the sleeper section was monitored throughout the cyclic loading. The test results in Figure 8 showed that the majority of the settlement was due to loss of ballast thickness below the sleeper but the measured settlement of the sleeper was significantly smaller with multiaxial geogrid stabilising the sub-ballast when compared with the section containing the biaxial geogrid, even after taking into account the initial settlement due to bedding in of the sleeper.

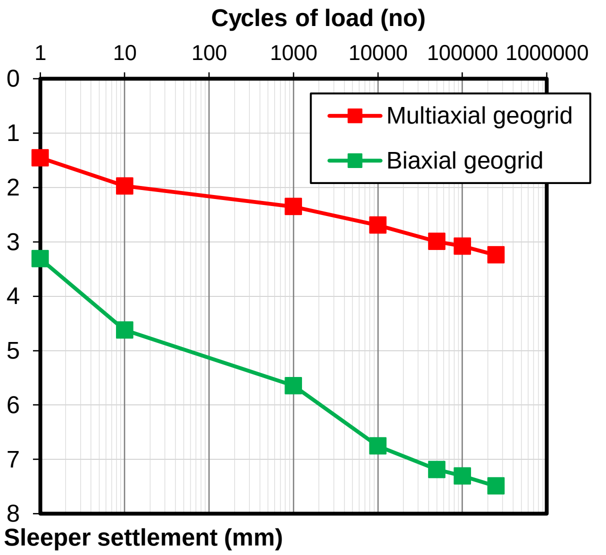

Figure 8: Comparison of measured sleeper settlements after 250,000 load cycles, Czech Technical University, Prague

As well as settlement measurements, static deformation modulus values were measured at the top of the sub-ballast and ballast layers after each test in accordance with local Czech rail procedures – SZCD S4. Each layer of construction, the subgrade, sub-ballast and ballast was subjected to a static load applied through a steel plate positioned on the centreline of sleeper and rail – 0.1MPa was applied to the subgrade, 0.2MPa to the sub-ballast layer and 0.4MPa to the ballast. An identical set of tests was carried out on each layer, in reverse order, whilst dismantling the tests. A total of 6 load tests were carried out for each structure. Settlement measurements under these loads were taken to allow modulus values to be determined.

Test section	Biaxial geogrid	Hexagonal geogrid	Variance
Static deformation modulus on ballast surface after cyclic loading (MPa)	110.2	116.9	+6.1%
Static deformation modulus on sub-ballast surface after cyclic loading (MPa)	48.2	55.6	+15.3%

Figure 9: Improvement in static deformation modulus values by including hexagonal stabilisation geogrid in sub-ballast in trackbed construction, Prague.

The results obtained showed an improved trackbed performance when the hexagonal stabilisation geogrid was included in the sub-ballast layer compared with the same tests including the 30kN/m biaxial product. Settlement was reduced and the resulting "load capacity" was increased.

5.2 Field Testing of Hexagonal Stabilisation Geogrid in Sub-ballast

Comparative performance of sub-ballast layers with different types of geogrid on a live line were carried out on existing rail tracks at a coal powered electricity generation facility in Wilsonville, Alabama, USA. (5)

Figure 10: Rail track in use, Wilsonville, Alabama, USA

Biaxial and hexagonal geogrids were included under different stretches of track with a consistent overall construction applied. In each case, the geogrid was placed directly on a compacted sub-grade and under 200mm of sub-ballast which was in turn overlain by 250mm of ballast. The test consisted of three sections containing geogrid with one further section acting as a control.

Pressure cells were placed on top of the sub-grade to measure the stress on the sub-grade directly under the line of the tracks. One pressure cells was installed for each test section.

Track settlement was monitored by surveying a series of mini-prisms mounted to every third rail sleeper

Results and discussion

Monitoring took place over a seven month period between September 2011 and April 2012. Comparison of the earth pressure cell measurements over this time period clearly showed that sub-grade pressures in geogrid stabilised sections were lower than in the non-stabilised control section. This indicates than the geogrids better distribute the imposed traffic loads by increasing the area of influence on the sub-grade. Further, these pressures were found to be at their lowest in the section including the hexagonal geogrid when compared with the biaxial geogrid section. Lower sub-grade pressures typically correspond to higher track stiffness and so the trackbed stabilised with the hexagonal stabilisation geogrid would be expected to exhibit higher track stiffness than similar sections containing biaxial geogrids or no geogrid at all.

5.3. Railway reconstruction, Bratislava, Slovakia.

The complete reconstruction of trackbed was required to allow operational speeds to be increased for a major European rail corridor. The original track quality had deteriorated due to areas of weak formation soils and although there was a requirement to excavate and remove some of the existing formation soils, the inclusion of a multiaxial geogrid in the sub-ballast layer reduced excavation volumes significantly.

The use of a large aperture multiaxial geogrid allowed the project to recycle the original ballast material to act as a new sub-ballast layer reducing the amount of imported fill.

Figure 11: Hexagonal stabilisation geogrid installed awaiting recycled sub-ballast, Bratislava, Slovakia.

5.4 Turnout reconstruction, Kaapmuiden, South Africa.

Engineers had a limited track possession time to reconstruct an important "turnout and scissors" crossing on a key junction of the busy Transnet freight rail route to the South African border with Mozambique. The standard reconstruction methodology included the installation of a 400mm thick imported granular sub-ballast layer.

To save costs and importantly in a short track possession time, the project Engineers examined ways of making the reconstruction operations more efficient and cost effective. Based on the knowledge gathered and demonstrated on the benefits of including geogrids within trackbed, a mechanically stabilised layer incorporating a hexagonal stabilisation geogrid was evaluated and adopted as part of the reconstruction works and allowed the sub-ballast thickness to be halved to 200mm.

As well as halving costs of importing the sub-ballast fill, excavation quantities were reduced and construction times were significantly reduced. Reduced excavation also meant that there was a reduced risk of contractors damaging cables and other services buried under the area being reconstructed.

Hexagonal stabilisation geogrids have been used extensively in rail projects around the world since their introduction in 2007.

Figure 12: Multiaxial geogrid installation, Kaapmuiden, South Africa, 2011

6 CONCLUSIONS

Using geogrids to increase trackbed stiffness and therefore enhance long term performance of the railway line positioned above is established with extensive research and associated geogrid development. The method of evaluating the potential benefits of different types of geogrid can only realistically be based on the full scale assessment from both laboratory testing and "live line" investigations. Research into the relative performance of biaxial geogrids and the more recently introduced hexagonal stabilisation geogrids indicates that assessing a product based on simple product parameters alone will not provide an accurate prediction of performance of the resulting trackbed structure.

This innovative geogrid technology has been shown to outperform earlier products to offer rail engineers even more opportunity to build value into their projects. Research into the performance of these products continues to demonstrate and quantify their benefits yet further. [7]

7 ACKNOWLEDGEMENTS

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