Horton, M, Connolly, DP and Yu, Z

Rail trackbed and performance testing of stabilised sub-ballast in normal and high-speed environments

Article

Horton, M, Connolly, DP and Yu, Z (2017) Rail trackbed and performance testing of stabilised sub-ballast in normal and high-speed environments. Procedia Engineering, 189. ISSN 1877-7058

Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 189 (2017) 924 – 931

Procedia Engineering

www.elsevier.com/locate/procedia

Transportation Geotechnics and Geoecology, TGG 2017, 17-19 May 2017, Saint Petersburg, Russia

Rail trackbed and performance testing of stabilised sub-ballast in normal and high-speed environments

M Horton[a*], D P Connolly[b] and Z Yu[b]

[a] *Tensar Internatioal Ltd, Shadworth Business Park, Blaskburn BB1 2QX , UK*
[b] *Heriot-Watt University,Edinburgh Campus, Edinburgh, EH14 4AS, UK*

Abstract

The ability of geogrids to preserve track alignment within a high-speed rail environment at close to critical velocity is somewhat uncertain; testing in a controlled environment can be problematic. This paper presents the results from a new 'true triaxial' test apparatus that overcomes some of these problems.

In 'normal'-speed rail environments, geogrids have been used for many years to stabilise and enhance the performance of sub-ballast to maintain both vertical and horizontal alignment and increase the interval between maintenance events. This has been reflected in controlled testing conducted in both the laboratory, in the field and under heavy loading.

To look at this issue for high-speed rail and to make comparisons between track alignment preservation in normal and high-speed environments, a new 'true triaxial' test apparatus (GeoTT) has been developed at Heriot Watt University that can subject railway sub-ballast to forces in all 6 directions, mimicking the principle stress rotation that has been implicated in track alignment deterioration subjected to high speed train traffic.

The use of this apparatus, where the rams are programmed using force-time histories developed from 3D finite element models, allows sub-ballast performance to be evaluated for the fraction of the time and cost that would be necessary for full scale testing. A comparison is made between existing testing results from 'normal-speed' testing and the new high speed simulations that indicate the continued potential for geogrids to continue to aid track performance in much more critical environments.

Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology

Keywords: Rail; high speed;sub-ballast;true-traixial;stress rotation; stabilisation, geogrid

*Corresponding author. Tel.: +44 1254 262431; fax: +44 1254 266868 E-mail address: mhorton@tensar.co.uk

1877-7058
Peer-review under responsibility of the scientific committee of the International conference on Transportation Geotechnics and Geoecology
doi:10.1016/j.proeng.2017.05.143

1. Introduction

Punched and drawn polymeric geogrids have been used for more than 30 years to stabilise sub-ballast in railway applications. Records from live line monitoring are relatively few and far between compared with other applications where such geogrids are used but there is a growing body of evidence to support the performance enhancement that these geogrids offer in stabilising the sub-ballast layers, both from the laboratory and in the field. More recently, interest in the ability of geogrids to stabilise sub-ballast in high-speed rail applications (greater than 300 km/h) has grown. However, the performance of geogrids is much more difficult to test in a controlled environment at such speeds and has led to the development of new soils testing apparatus that is able to subject a soil sample to forces in six directions, mimicking the forces that soil will experience during high-speed train traffic.

2. Previous Work

Originally stabilisation of track bed aggregates was provided by biaxial punched and drawn geogrids [1,2,3], but the more recent development of multi-axial punched and drawn stabilisation geogrids have demonstrated further improved performance [4][5].

The laboratory simulation of long-term geogrid performance has proven to be a cost-effective alternative to field testing. Raymond [6,7] used a compression test tank to show that ballasted track underwent reduced settlement when reinforced by geosynthetic materials. Similarly, using a variety of different sized test boxes, McDowell and Stickley [8], Horníček et al. [9] and Ruiken et al. [10] showed that geogrid reduced permanent settlement significantly.

3. A comparison of biaxial geogrid and hexagonal geogrid-stabilised sub-ballast – laboratory testing at ‘normal’ speed

Tests undertaken at the Czech Technical University in Prague in 2009 [4][5] used geogrid to stabilise sub-ballast (see Figure 1) over a brick clay with an Ev2 value of approx. 35MPa (approx.7% CBR).

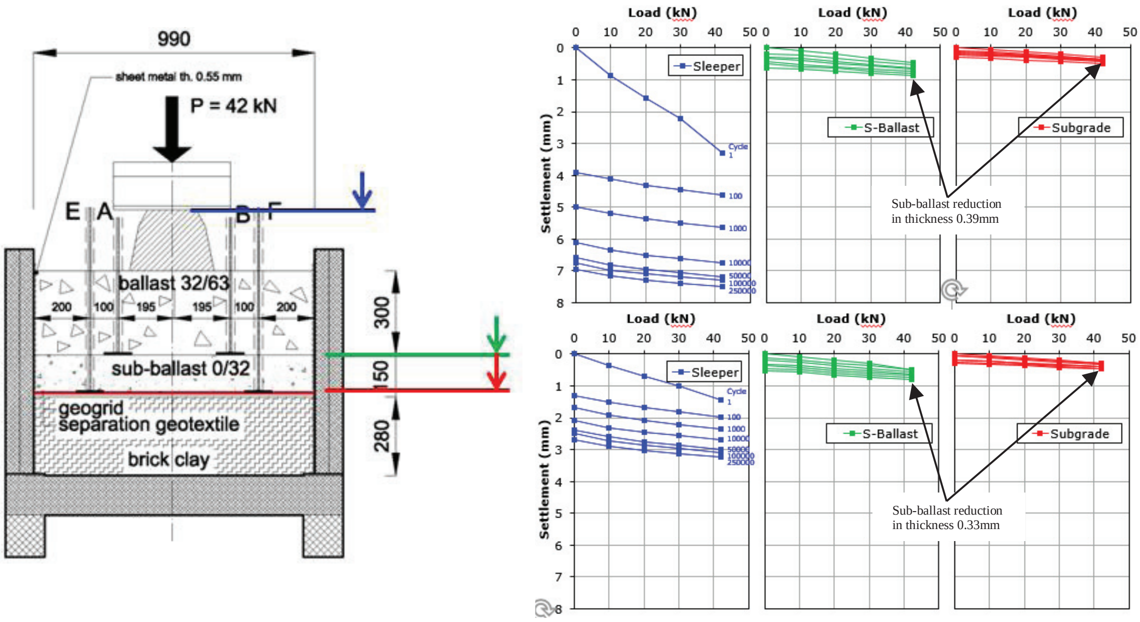


Figure 1 – Test setup at Czech Technical University, Prague (left) and settlement results (right) for SS30 biaxial geogrid (top) and TX160 hexagonal geogrid (bottom) showing marked difference in settlement of ballast over 250,000 cycles of a 42kN load.

This testing showed a significant difference in performance between a biaxial geogrid (Tensar SS30) and a hexagonal geogrid with triangular apertures (TriAx TX160) when tested under cyclic loading of 0 to 42 kN up to

250,000 cycles. Settlement beneath the sleeper was reduced by more than 50% with minimal settlement at the sub-ballast and formation surface in both tests. The reduction in sub-ballast thickness during loading was, however, very similar in both tests with the hexagon geogrid stabilised test showing a slight improvement (0.33mm) over the biaxial geogrid (0.39mm) a difference of about 7%. However, this testing did not include a control and this prevents some direct comparison with later testing.

4. Control vs hexagonal geogrid stabilised sub-ballast -laboratory testing normal speed

As part of a testing programme at PNF in St Petersburg 2013, Belyaev and Ashpiz [11] used a 25 tonne, 10Hz vibrating surcharge on a full-scale rail section (Figure 2 left) to look at, amongst other things, performance improvement available in terms of track settlement from stabilising sub-ballast. A control test was conducted using a sandy clay with an Ev2 value of 26Mpa (approx. 6.4% CBR) overlain by 0.2m of sand, 0.4m sub-ballast and 0.4m of ballast and compared with a similar makeup but with only 0.2m of TX170-stabilised sub-ballast. The Ev2 at the top of the non-stabilised sub-ballast was 70Mpa but on the reduced thickness of stabilised sub-ballast was found to be 107Mpa, despite being only half the thickness (see Figure 3 right).

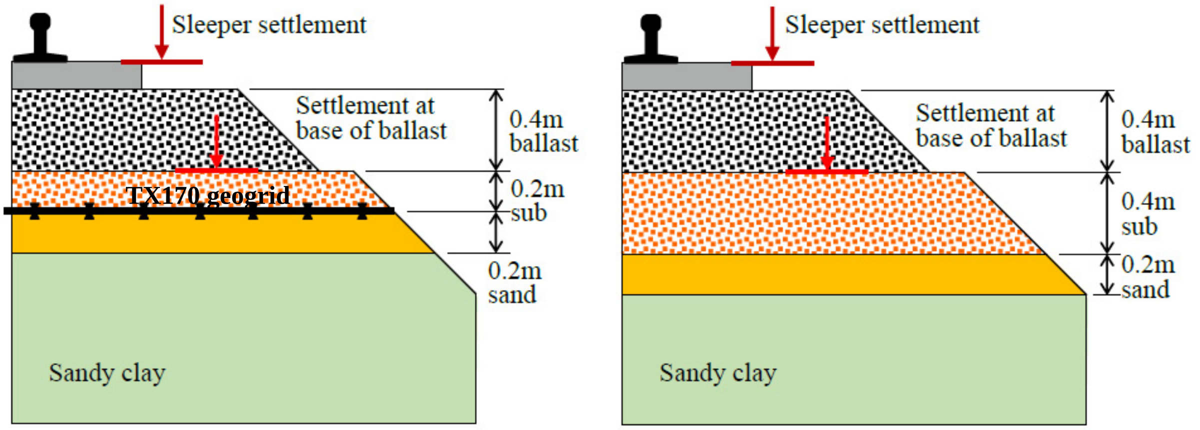


Figure 2. Test setup for stabilised sub-ballast testing at PNF St Petersburg, stabilised with TX170 (left) and control (right). Note that the Ev2 value on the surface of the stabilised sub-ballast is increased by 56% despite the reduced sub-ballast thickness

Figure 3. 25t vibratory load mounted on test rails in full size testing at PNF St Petersburg

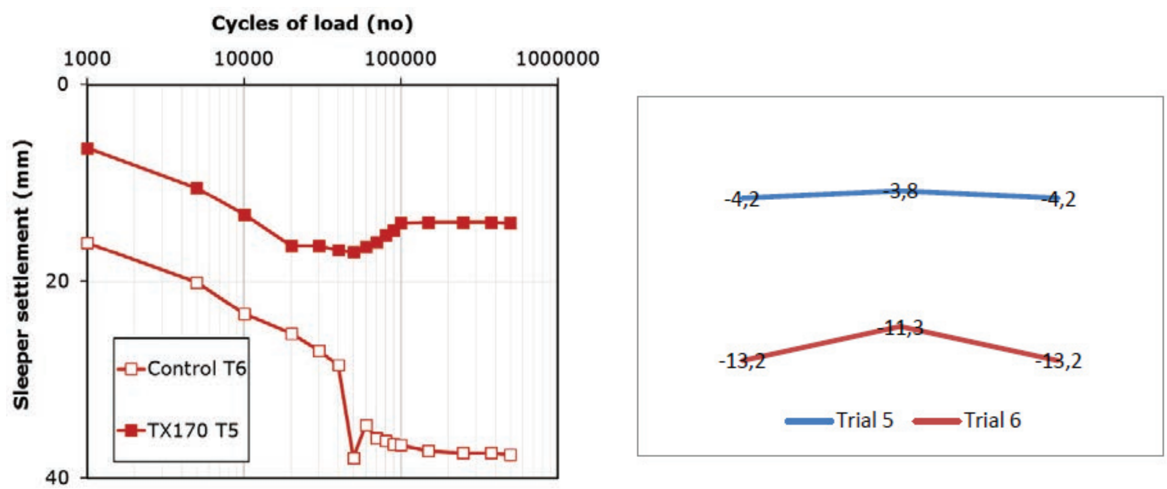


Figure 4. Sleeper settlement curves for PNF St Petersburg testing (left) showing improved retention of track level with TriAx- stabilised sub-ballast and settlement within the sub-ballast layer (right) for the same tests. Note that the settlement of the sub-ballast may include some settlement in formation level

After 500k cycles of the 25tonne vibratory load, it was found that settlement of the geogrid-stabilised sub-ballast layer was significantly reduced by over 62.5% compared to the non-stabilised control layer (see figure 4 left) despite the stabilised sub-ballast layer being only 50% of the thickness of the control sample indicating that geogrid stabilisation has significant potential for reducing maintenance costs. It is interesting to note that in both cases, most of the settlement is within the ballast layer itself and shows the benefit in stiffening the sub-ballast layer to help prevent ballast movement and ballast particle degradation, helping to maintain both line and level.

Settlement beams were incorporated within the stabilised sub-ballast itself and these indicated that at this level, settlement of just over 4mm on average was recorded (T/Trial 5) and 12.6mm for the non-stabilised (but thicker) sub-ballast case (T/Trial 6); a reduction by some 60% (Figure 4 right) for the stabilised case. However, instrumentation was not present at the top and bottom of this layer and this may not represent the settlement of the sub-ballast layer alone.

5. Control vs hexagonal geogrid-stabilised sub-ballast – laboratory testing - high speed simulation.

When trains travel at speeds comparable to the natural wave speed of the underlying soil, track displacements are magnified. This results in elevated stress levels within both track and soil, both horizontally and vertically, thus causing rapid track deterioration. Whilst the examples above have shown the benefit of increasing lateral confinement on sub-ballast layers by incorporating geogrid, the ability of geogrids to provide similar confinement for lines running at elevated speeds are unclear. It is difficult to simulate rapid rotation of the principle stress direction and it has been shown in the past that this has a significant influence on the soil behavior [12,13,14,15,16,17].

In order to overcome this issue and faithfully simulate behaviour of the track, a true triaxial test rig has been developed (Geo TT) at Heriot Watt University in Edinburgh, UK. The rig has 6 independently actuated hydraulic rams that allow the generation of force patterns closer to those experienced on high speed rail lines.

5.1. Test-set-up

The GeoTT consists of 6 independent hydraulic rams; 2 for each Cartesian plane, mounted in a rigid steel frame (see Figure 5 left). The test sample is placed inside a bespoke steel cage with dimensions 560 x 560 x 560mm and capable of housing large samples of track materials. The sample-holding cage has reinforced circular apertures to permit the entry of the loading rams which then impose load on the sample via an independent loading plate within the cage. The cage is suspended from the loading frame by means of wire ropes.

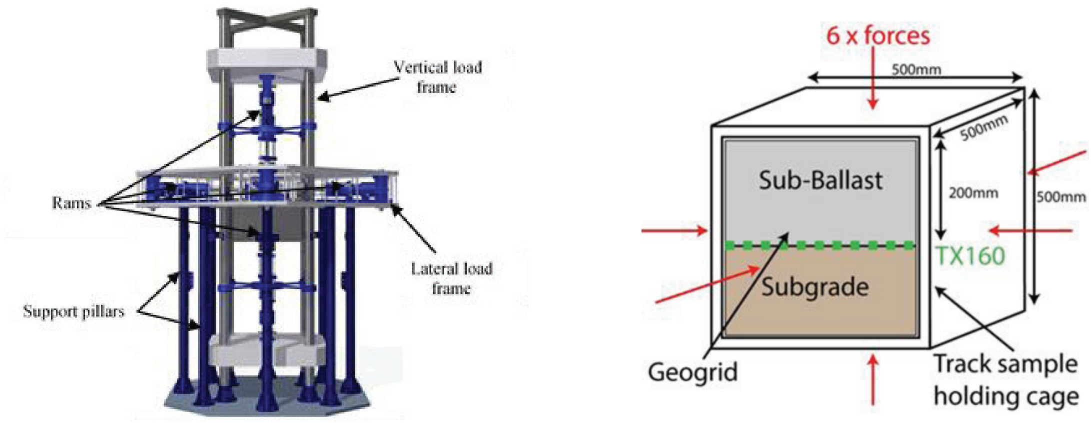


Figure 5. GeoTT test rig schematic (left) and test setup for stabilised sub-ballast over soft subgrade test.

Sub-ballast material used in test complied with Cl 603 (Type 1 sub-base) of the UK Specification for Highway works and consisted of a hard, angular dolerite material. The grading curve for this material [18] is shown in Figure 6 (left).

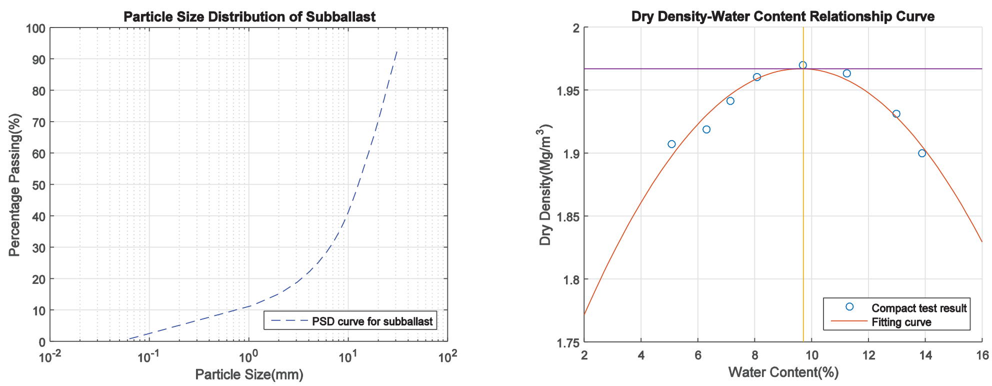
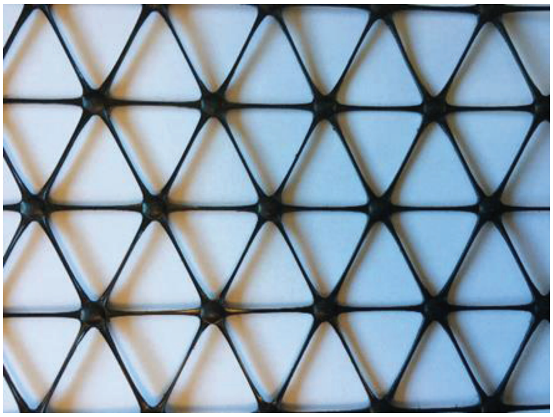


Figure 6 Grading curve for sub-ballast aggregate use in GeoTT testing (left) and dry density/moisture content curve for manufactured clay subgrade (right).

The subgrade used in this testing was manufactured using 80% kaolin (Imerys Polwhite E) clay and 20% sharp sand with a 9.7% moisture content (optimum moisture content, [18] shown in Figure 6 right). This gave an approximate CBR of 3% when compacted and measured using a MEXE cone penetrometer.

To construct each sample, subgrade the manufactured subgrade of 300mm thick was compacted in accordance with British Standards [19] using a vibrating plate. Once complete, sub-ballast with thickness of 200mm was placed compacted for 5 minutes to a density of 1885 kg/m3.

For the geogrid stabilised test, a single hexagonal structure TX160 geogrid layer was placed at the interface of the subgrade and the subgrade (Figure 7) oriented so that the manufactured direction of the geogrid was perpendicular to the direction of simulated train passage.



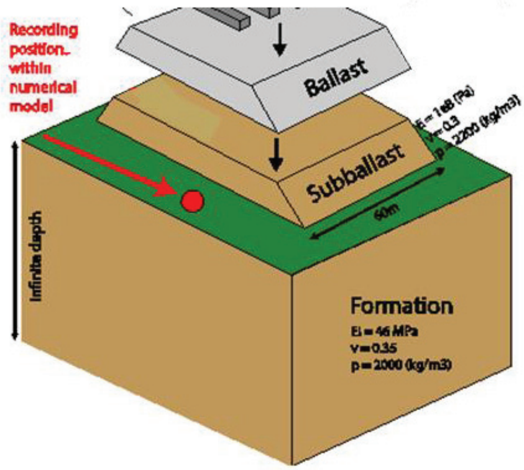


Figure 7. TriAx TX160 geogrid used in GeoTT simulation (left) and recording position for horizontal forces and soil numerical properties (right).

5.2. Computer simulations – force-time histories

Computer simulations were used to generate the force time histories that would be applied to the GeoTT hydraulic rams. Three-dimension finite element modelling was used to generate stress time histories (based upon an 18-tonne axle load travelling at 294km/h) which could then be converted to force histories were calculated at the sub-ballast-subgrade interface as follows*:*

Vertical and horizontal directions

Using the results from a 3D finite element model, the mean maximum nodal stresses sampled at the sub-ballast-subgrade interface are:

Vertical stress=24.23 kPa
Parallel stress=24.10 kPa
Perpendicular stress=6.59 kPa

Therefore, multiplying by the cage wall area and accounting for confining stresses gives the forces required to excite the sample in the lab:

Vertical force=7.08 kN
Parallel force=7.06 kN
Perpendicular force=4.25 kN

The soil numerical modelling properties were chosen to simulate the passage of a high-speed train moving at 300 km/h over a soft subgrade (at 93% of the critical velocity). Track properties and general model configuration are shown in Figure 7:

5.3. Results of GeoTT testing

Settlement curves in the three Cartesian directions are shown in Figure 8 and results against the non-stabilised case summarised in Table 1.

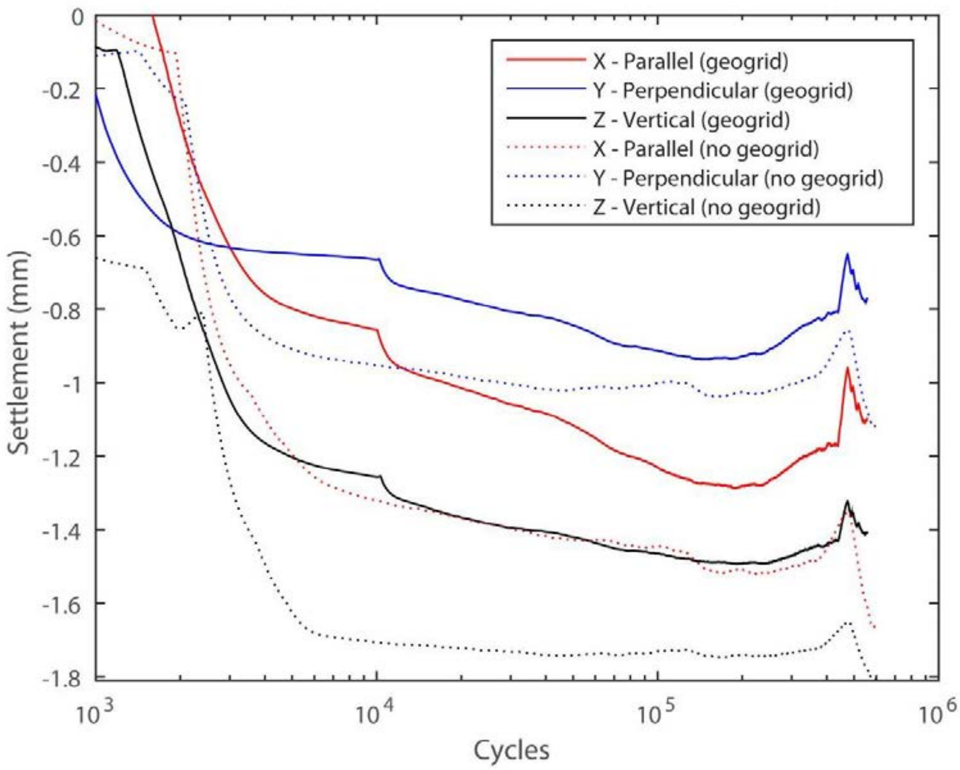


Figure 8 Settlement curves for sub-ballast/subgrade settlement

The following observations can be made:

- The vertical direction showed the largest settlement and the direction perpendicular to the track exhibited the lowest in both geogrid stabilised and non-stabilised tests
- Settlements were in the order of ≈0.9-1.5mm when geogrid was present, and ≈1-1.7mm when it was not.
- The geogrid results showed a marked improvement in performance. The average improvement was 18%, 13%, 16% in the X, Y and Z directions respectively (Table 1)
- Dilation occurred after approximately 4.5×10^5 cycles. This was most likely because the subgrade was formed from a sandy-clay mix with dilation occurring at this level.
- Comparing the vertical settlement with previous low speed testing, the settlements within and at sub-ballast level are a similar magnitude to those observed during previous low speed testing and indicates the potential for sub-ballast stabilisation to improve the performance of track in high speed rail conditions over soft subgrades. This testing was conducted on much softer subgrade than the previous low speed testing.

- It was noted that there was no visible damage to the geogrid during the 500k cycles imposed. This suggests a useful service life well in excess of that simulated during this testing.

Table 1. Settlement Results from GeoTT stabilised sub-ballast testing vs non-stabilised

	Av. Settlement improvement after 500k cycles (%)
X direction (parallel to train travel)	18.11
Y direction (perpendicular to train travel	12.69
Z direction (vertical)	15.51

Conclusions

This paper describes tests to determine the potential of hexagonal structure geogrids with triangular apertures to stabilise sub-ballasted track operating at normal track speeds and at close to critical velocity. Normal speed testing has shown that vertical track alignment is improved by incorporating a geogrid at the sub-ballast/formation interface. More recent testing using a new true triaxial test rig (GeoTT) which uses numerical simulations of high speed track stresses to excite track samples placed inside the testing rig at Heriot Watt University for 500k cycles has shown that significant benefits may be obtained by using hexagonal structure geogrids in high speed track sub-ballast on poor subgrades.

References

[1] M. Matharu, Geogrids cut ballast settlement rate on soft sub-structures, Railway Gazette International March 1994.
[2] C.G. Jenner, The Use of Geosynthetics in Railways, geosynthetics – Recent Developments, 2006.
[3] P. Sharp, M. Brough and J. Dixon, Geogrid Trials at Coppull Moor on the West Coast Main Line, Railroad Conference, 2006.
[4] J Cook and L Horníček, The Performance of new generation geogrids within Trackbed under Cyclic Loading.
[5] J Cook, J. Buckley, M Dobie and R. Bhavsar, The use of Multi-Axial Geogrids in Rail Trackbed Stabilisation, IHHA Conference, Perth Australia, 2015.
[6] G. P. Raymond, Reinforced ballast behaviour subjected to repeated load, Geotextiles and Geomembranes, 20(1), pp. 39–61, 2002.
[7] G. Raymond and I Ismail, The effects of geogrid reinforcement on unbound aggregates, Geotextiles and Geomembranes, 21(6), pp. 355–380, 2003.
[8] G. McDowell and P. Stickley, Performance of geogrid-reinforced ballast, Ground Engineering, 2006.
[9] L. Horníček, P. Tyc, and M Lidmila, An investigation of the effect of under-ballast reinforcing geogrids in laboratory and operating conditions, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 224(4), pp. 269–277, 2010
[10] A. Ruiken, M. Ziegler, L. Vollmert and I Duzic, Recent findings about the confining effect of geogrids from large scale laboratory testing, in 9th International Conference on Geosynthetics. Brazil, pp. 3–6. 2010
[11] M Horton, V.S. Balyaev and ES Ashpiz, Comparative Full-Scale Loading Trials on Trackbed with and Without Geogrid Stabilisation, Railway Engineering 2015, Edinburgh, 2015.
[12] T.L. Yond, Compaction of sands by repeated shearh straining, Journal of the Soil Mechnaics and Foundations Division, 98(7), pp 709-725.
[13]. P Ansell, and S.F. Brown, A cyclic simple shear apparatus for dry granular materials, ASTM Geotechnical Testing Journal, 1(2), 1978
[14] F. W. K. Chan, Permanent deformation resistance of granular layers in pavements. University of Nottingham. 1990
[15] F. Lekarp, U. Isacsson, and A. Dawson, State of the art. I: Resilient response of unbound aggregates', Journal of Transportation Engineering, 126(1), pp. 66–75, 2000
[16] W. Powrie, L.A. Yang and C.R.I Clayton, Stress changes in the ground below ballasted railway track during train passage, Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 221(2), pp. 247–262, 2007
[17] P.J. Gräbe and C.R.I Clayton, Effects of principal stress rotation on resilient behavior in rail track foundations, Journal of geotechnical and geoenvironmental Engineering, 2013
[18] British Standards Institution, Methods of test for soils for civil engineering purposes. Classification tests, *BS 1377-2:1990*.
[19] British Standards Institution, Methods of test for soils for civil engineering purposes. Compaction-related tests, *BS 1377-4:1990*.