RAIL TRAFFICKING TESTING

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INTRODUCTION

A railway trackbed would appear to be an ideal structure for the use of geogrid reinforcement. Its principal component, ballast, is an unbound aggregate; its principal mode of deterioration is settlement (and differential settlement) due to permanent deformation within the ballast and underlying unbound layers. Furthermore, many railways require profile correction on an annual basis, sometimes more frequently than this – Fig. 1 shows examples – which demands the operation of expensive equipment – a tamping machine – and potential disruption to railway traffic. If the rate of settlement can be slowed down the benefit to the railway operator could be considerable. Since geogrid reinforcement is specifically intended to reduce permanent deformation within an unbound material, its use in railway trackbed is therefore logical.

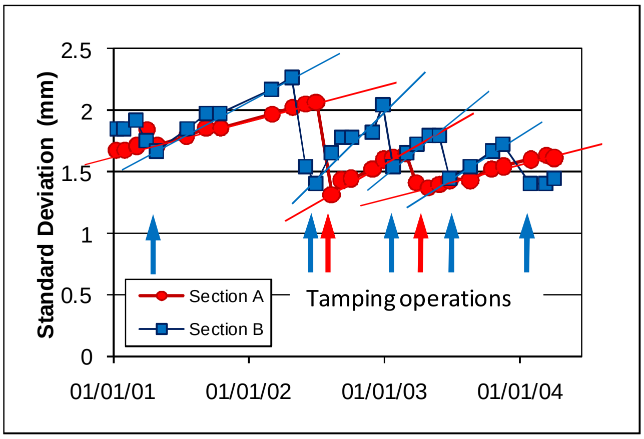

Figure 1. Measured rail profiles, East Coast Main Line

This paper will summarise an extensive set of tests carried out at the University of Nottingham, together with a trial on the West Coast Main Line in the UK. The results give a degree of confidence that the benefit of geogrid reinforcement is real rather than merely theoretical. The paper will then outline an approach to settlement and differential settlement prediction and conclude by suggesting the situations where geogrid reinforcement is most likely to be beneficial.

OPTIMISING GEOGRID DESIGN

Three approaches were taken to geogrid optimisation, comprising two different tests, a pull-out test and the so-called *composite element test*, and discrete element modelling of the pull-out test. Figure 2 shows a section through the composite element test, together with results relating to grid aperture size, Brown et al (2007b); Figure 3 illustrates the discrete element modelling of a pull-out test, McDowell et al (2006), together with results. In all cases it was found that an aperture in the 60-80mm range gave optimum performance (an aspect ratio of 1.2-1.6 with a 50mm ballast particle size).

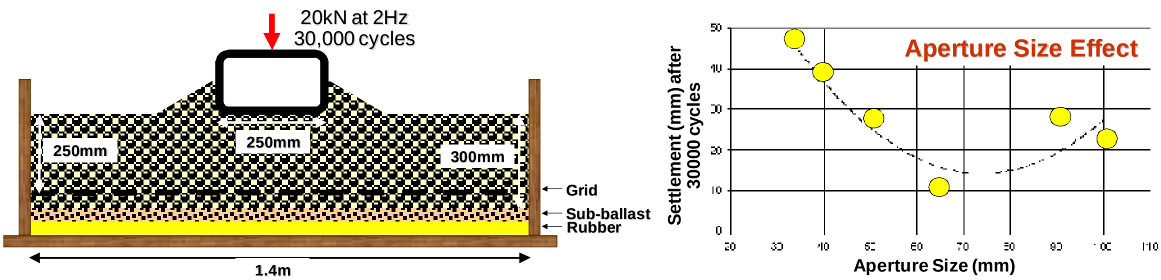

Figure 2. The composite element test

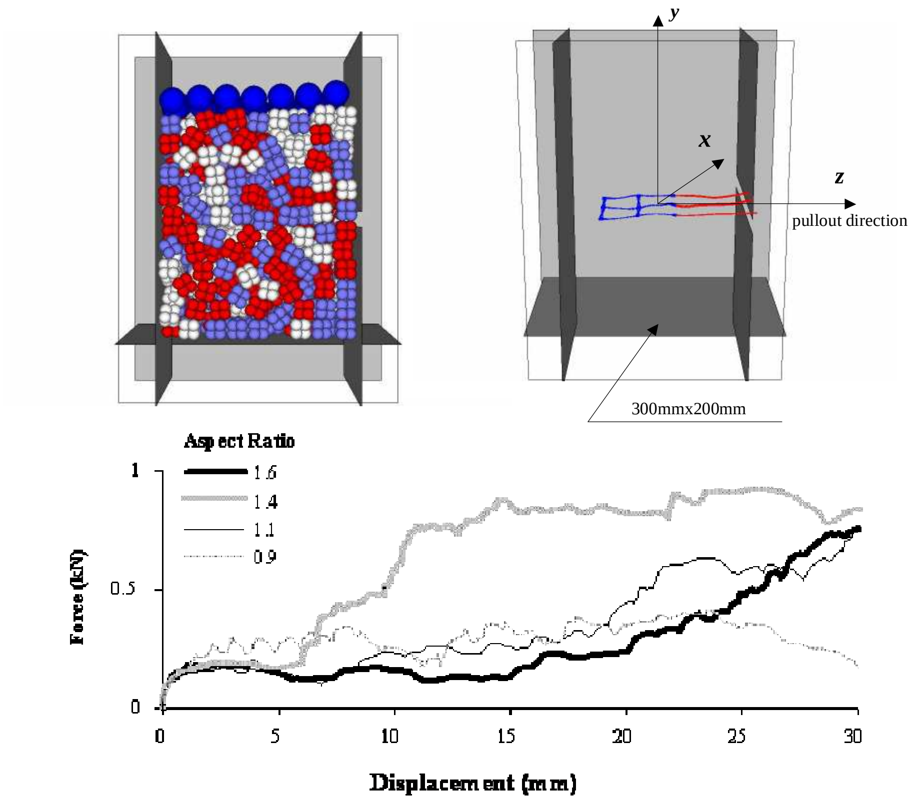

Figure 3. The pull-out test

Comparisons in the composite element test between Tensar products and a grid made of rounded steel bar, Brown et al (2007b) revealed two further intuitively reasonable findings. The first was that high geogrid stiffness was beneficial; the second was that an angular rib profile was essential. Following an economic appraisal of the options it was decided to utilise a Tensar SSLA30 geogrid in future trials.

QUANTIFYING THE EFFECT OF GEOGRID

The composite element test has proved an excellent tool in discriminating between geogrid types. It has also provided data to assist in development of trackbed modelling techniques. However, it is not fully simulative of a real trackbed and the resulting settlements are therefore not directly applicable to the field. For this reason a larger *railway test facility* (Brown et al, 2007a) was also used. This facility, shown in Fig. 4, consists of three railway sleepers, bedded realistically in ballast, which in turn overlies about 800mm of silty soil. The soil can be prepared at a desired moisture content, which determines the stiffness of response to load. For the tests described here the stiffness, as measured by a dynamic plate test, was approximately 15MPa. The soil was overlain by a geosynthetic fabric in order to maintain separation between ballast and soil. The ballast thickness used was 300mm to the underside of the sleepers.

Loading was achieved through three independently controlled actuators and distributed to the rail seat areas of the sleepers via spreader beams. In these tests the maximum load used was 95kN. The loading was staggered between the three sleepers to simulate the passage of a train at a speed of about 17mph. Further details can be found in Brown et al (2007a). It should be noted that a load of 95kN to a single sleeper is equivalent to an axle load of 200-250kN because in reality the rail spreads the load between adjacent sleepers. The efficiency of this load-spreading is a function of both the rail stiffness in bending and also the stiffness of the underlying trackbed.

Figure 5 presents settlement data from four tests, two including Tensar SSLA30 geogrid and two without. There was a slight difference between the two reinforced tests; in Test 2 the geogrid was placed above a single layer of ballast stones covering the geosynthetic fabric, while in Test 3 it was placed directly above the fabric. It was also noted that the soil stiffness appeared to increase slightly between tests despite the fact that moisture content was maintained at a similar level each time and this is thought to have been responsible for the improved performance in Test 4 compared to Test 1. The final difference to note is that Tests 3 and 4 included a tamping operation after 500,000 load applications, utilising a purpose-built tamper unit intended to replicate the tamping action found on site.

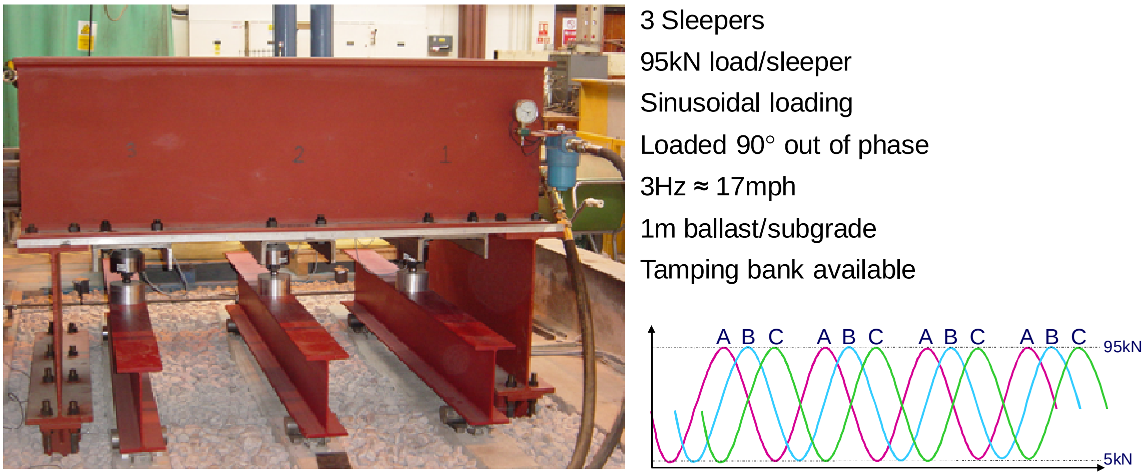

Figure 4. The Nottingham railway test facility

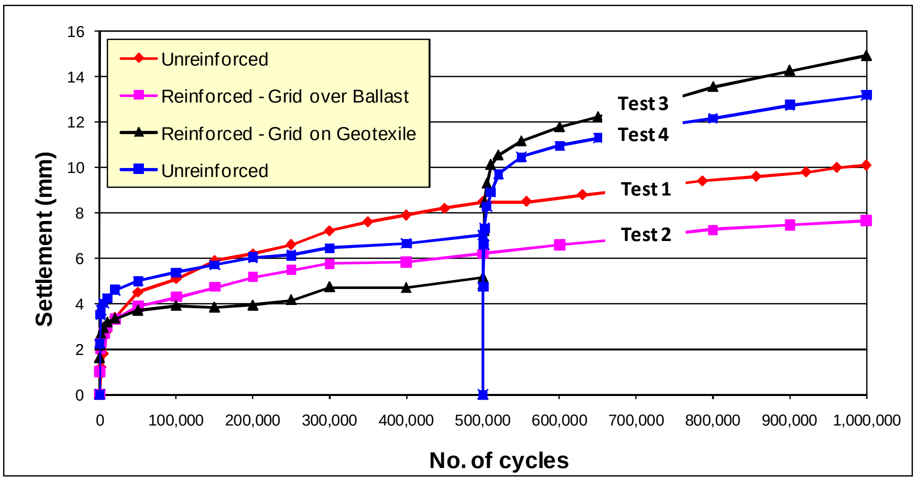

Figure 5. Settlement data – railway test facility

The clear conclusion from Fig. 5 is that geogrid reinforcement has discernible benefit, in this case amounting to an extension of life by a factor of at least 2 at a given level of settlement. There is no significant difference between Tests 2 and 3, which implies that the geogrid can be placed at the base of the ballast layer, the most convenient location in practice.

FIELD APPLICATION

The fact that geogrid reinforcement inhibits the development of settlement under laboratory conditions does not prove that it will be able to inhibit differential settlement in a real trackbed. A trial was therefore carried out by Network Rail at a site on the West Coast Main Line in Lancashire, Sharpe et al (2006). The trial was over a length of 1100 yards, i.e. five 220-yard sections. All five sections were renewed by removing existing ballast, placing a geosynthetic fabric as a separator, and then rebuilding the track using fresh ballast. In two sections Tensar SSLA30 geogrid was placed directly over the fabric; the other three sections were unreinforced. Historically the performance of all five sections had been poor, requiring regular maintenance; however the two sections where the geogrid was used had been the poorest. This was evident from historical records of track vertical alignment, and it was subsequently shown by means of a Falling Weight Deflectometer survey that the ground beneath the reinforced sections was less stiff than elsewhere.

Figure 6 presents vertical alignment data in terms of the standard deviation of the rails as measured by the New Measurement Train. Clearly the renewal gave a dramatic improvement in all five sections. However, it is noticeable that the standard deviation of the reinforced sections was marginally better than elsewhere immediately after renewal despite having been worse immediately before it. Looking at the trend over the following two years, which includes a tamping operation a few weeks after the renewal, there is little difference in deterioration rate between the five sections. However, bearing in mind the poorer condition of the reinforced sections prior to renewal and the lower measured trackbed stiffness this is considered to be a very positive result.

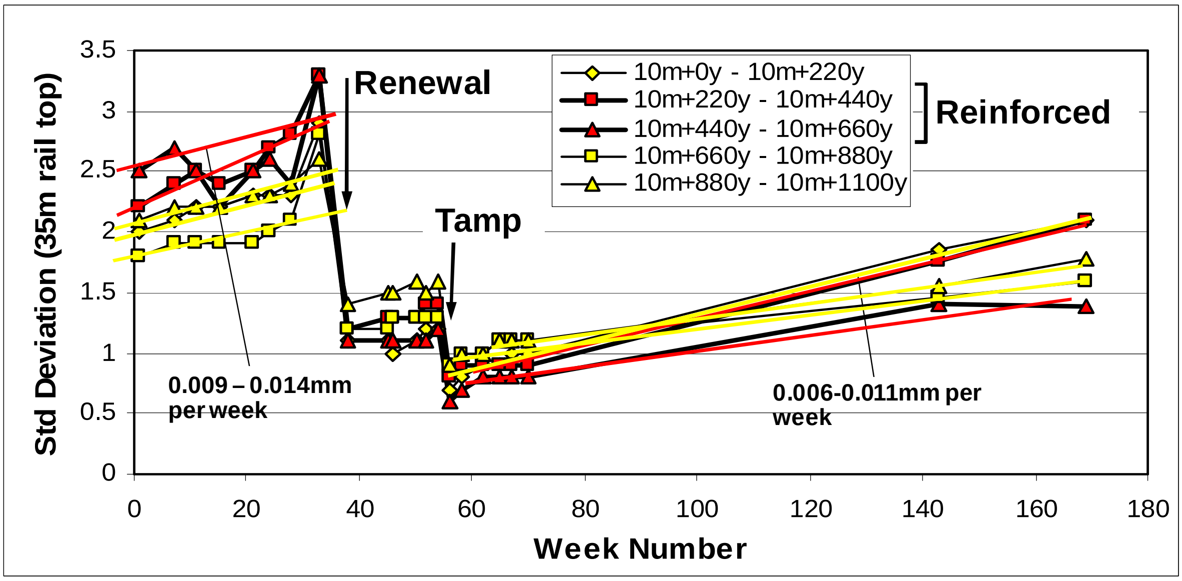

Figure 6. Vertical profile data, West Coast Main Line

PREDICTIVE MODELLING APPROACH

Sleeper settlement

The evidence of testing and site trials allows an approximate evaluation of the benefit of geogrid reinforcement to railway trackbed performance. However, the direct evidence is limited to the particular subgrade stiffness conditions encountered and the traffic details applying and it would be helpful to develop a means of extending this to other cases. While the detailed mechanism of geogrid reinforcement of a granular material is still subject to research, the following points are already apparent, both in the work described in this paper and elsewhere.

a) A geogrid in tension can act structurally by spreading load onto an underlying material. As it deforms out of its original plane it has to extend, assuming adequate anchorage either side of the deformed zone. When it extends it is subject to a tensile force and, by making appropriate assumptions regarding its deformed profile, the degree of load spreading can be calculated. In theory, its effectiveness is directly proportional to its stiffness.

b) Even without undergoing deformation, a geogrid can inhibit the build-up of permanent strain within an adjacent unbound material owing to the interlock that develops between that material and the ribs of the geogrid. According to the composite element tests carried out in this work, the effectiveness is dependent on both rib stiffness and the angularity of rib profile.

These two mechanisms are illustrated in Fig.7. However the key to understanding the effectiveness of geogrid reinforcement in railway ballast is believed to be Mechanism (b) since very little geogrid deformation took place in either the composite element test or the railway test facility. The approach taken here was as follows:

- Identify a suitable equation for accumulation of permanent strain in an unbound material, Thom (1988).
- Set up a suitably simplified model to calculate stresses beneath a loaded sleeper; for this the load spread angle approach was adopted, using an angle of 35°.
- Perform an incremental computation of sleeper settlement.

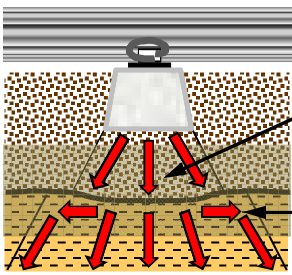

Figure 7. Mechanisms of reinforcement

The model was calibrated against the railway test facility results, as shown in Fig. 8.

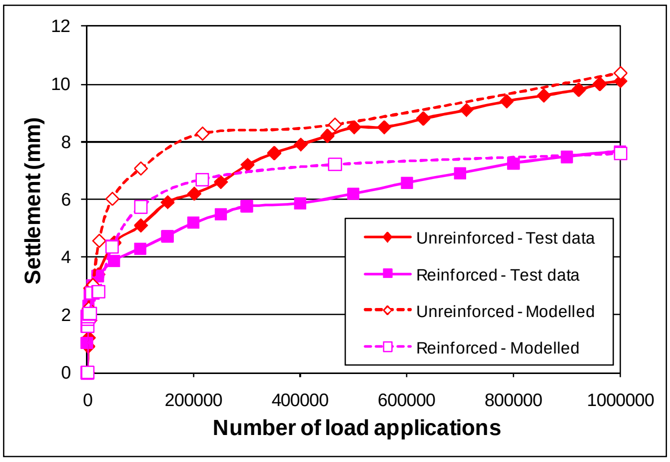

Figure 8. Comparison of measured and modelled settlement

Differential Settlement

To translate a sleeper settlement to a differential settlement it is necessary to take account of train dynamics. In this work (Thom and Oakley, 2006), this has been achieved by considering the passage of individual axles along a track, each of which is assumed to be loaded vertically by a mass on a spring. An initial track profile is assumed, appropriate to the level of standard deviation present, and the dynamic load is then calculated as the train passes over each sleeper. This is a function of the speed of the train, the suspension system stiffness and the unevenness of the track. The load taken through the sleeper is calculated assuming the rails act as beams on a Winkler foundation. Bearing in mind the various uncertainties inherent this is believed to be a suitably realistic methodology.

The next step is to calculate the settlement of each individual sleeper due to the predicted dynamic load over a certain number of load applications. At this stage and for reasons of computational simplicity a significant approximation has been introduced, namely that sleeper settlement can be expressed as a function of load taken to a certain power. The most appropriate value for that power is however not a straightforward choice. Based on the calculation approach for individual sleeper settlement introduced above a power up to 8 could be justified – depending on trackbed details; however other researchers (see Dahlberg, 2001) have adopted powers of 5 or less based on empirical evidence. The issue is therefore acknowledged to be as yet unresolved and the following outputs, which have used a power of 8, should therefore be seen as indicative only.

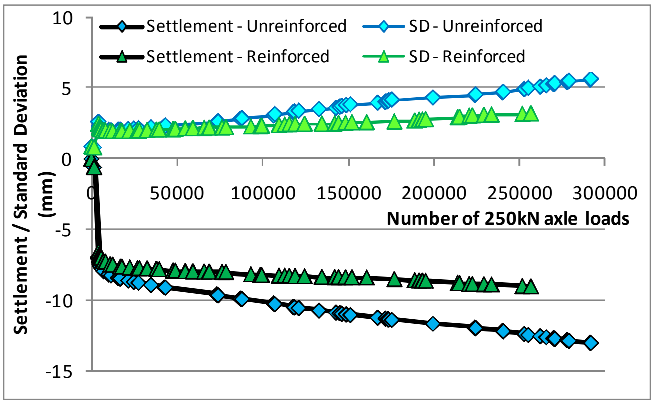

Figure 9. Predicted settlement and standard deviation

Output

Figure 9 illustrates the potential of this type of prediction. The trackbed simulated is intended to be representative of UK main line under the action of a 250kN goods wagon axle. The parameters controlling reinforcement effect are assumed to be those deduced from railway test facility tests incorporating Tensar SSLA30 geogrid. Admittedly this is a single prediction and confidence in the entire trackbed model (with or without reinforcement) is yet to be established.

However, it is worth noting that the improvement predicted is equivalent to a factor of a little over two for traffic at a given level of standard deviation.

CONCLUSION

The evidence summarised in this paper leads to the conclusion that the benefit of geogrid reinforcement at the bottom of the ballast layer is real. Indications are that it may reduce the need for trackbed maintenance by means of tamping by a factor of about two, although the site trial described here gives only indirect support since the subgrade condition was worse where geogrid reinforcement was used. Furthermore, geogrid stiffness and, particularly, rib profile have been identified as key parameters affecting the performance of the reinforced structure as a whole.

REFERENCES

Brown, S.F., Brodrick, B.V., Thom, N.H. and McDowell, G.R. 2007a. The Nottingham railway test facility. Proceedings ICE – Transport, 160(TR2), 59-65.

Brown, S.F., Kwan, J. and Thom, N.H. 2007b. Identifying the key parameters that influence geogrid reinforcement of railway ballast. Geotextiles and Geomembranes, 25(6), 326-335.

Dahlberg, T. Some railroad settlement models – a critical review. 2001. Proceedings IMechE, 215(F), 289-300.

McDowell, G.R., Harireche, O., Konietsky, H., Brown, S.F. and Thom, N.H. 2006. Discrete element modelling of geogrid-reinforced aggregates, Proceedings ICE – Geotechnical Engineering, 159(GE1), 35-48.

Sharpe, P., Brough, M. and Dixon, J. 2006. Geogrid trials at Coppull Moor on the West Coast Main Line. Ghatoara and Burrows (Eds), Railway Foundations – Railfound06, University of Birmingham, 367-375.

Thom, N.H. 1988. Design of road foundations. PhD Thesis, University of Nottingham.

Thom, N.H. and Oakley, J. Predicting differential settlement in a railway trackbed. Ghatoara and Burrows (Eds), Railway Foundations – Railfound06, University of Birmingham, 190-200.