IMPROVING THE PERFORMANCE OF RAILWAY TRACK THROUGH GEOGRID REINFORCEMENT OF BALLAST

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Abstract: A wide ranging project was conducted to improve fundamental understanding of the mechanisms involved in effective reinforcement of railway ballast using geogrids, in order to reduce the accumulation of settlement under repeated loading. Application of this work to practice has the potential to significantly reduce the cost of railway track maintenance in the future by extending the periods between operations, such as tamping, to renew riding quality. Theoretical studies used the Discrete Element Method to model the geogrid, the ballast and the interactions between them and resulted in realistic results that compared well with measurements from some simple experiments. A wide range of geogrids was used in simulative track tests to identify the geogrid mechanical and geometric properties that gave best performance in terms of reducing the accumulation of settlement under repeated loading. Full scale tests followed in a newly designed Railway Test Facility, which confirmed the effectiveness of the selected geogrid and indicated that a three-fold extension in time between tamping operations may be realisable in practice. A test section was constructed on the West Coast Mainline and this allowed comparisons to be made of settlement rates for reinforced and unreinforced sections. Early results confirmed the effectiveness of the reinforcing technique using a geogrid that had been identified as offering optimum performance in the theoretical and experimental research.

Keywords: Cyclic load, Field performance, Full-scale test, Geogrid reinforcement, Railway, Settlement.

INTRODUCTION

This paper presents a summary of the findings from a major research project aimed at improving the understanding of how geogrids reinforce granular materials in railway trackbeds. The particular situation considered was that of reinforcing the ballast layer in a railway track with the objective of reducing the rate at which permanent settlement develops under repeated wheel loading. Such settlement tends to develop differentially along a section of track causing deterioration in the ride quality and safety of the train operations. The problem is tackled in current practice through monitoring the variation in settlement using a High Speed Track Recording Car, the results from which trigger the requirement for a maintenance operation to restore the ride quality. This is done routinely through lifting the rails to level and then tamping the ballast back into position to provide correct support. The idea behind the introduction of geogrid reinforcement is to significantly extend the periods between these maintenance operations.

In order to be effective, geogrid reinforcement must interact efficiently with the granular material in which it is installed and it must be placed at the correct location in the structure. The main reason for this is that the reinforcement mechanism is one of reducing the strains that would otherwise develop in the soil or granular material under the action of a combination of self weight and live load. While these principles apply equally for all applications of reinforced soil, the requirements for effective pavement or railway track reinforcement differ in that low strains are involved and repeated applications of live loads from moving wheels dominate as dead loads are low given that the reinforcement is required at a relatively shallow depth. The critical performance parameter for the geogrid is deformation, rather than ultimate strength, combined with the ability to interlock with the material in which it is installed. Consequently, the stiffness of the geogrid is a more important parameter than its ultimate strength but this alone will not be effective unless it can be mobilised via effective interlock (Chan et al, 1989).

In commencing this project, it was recognised that the use of geogrids in railway ballast presented a conceptually simpler problem with respect to effective interlock than its use in other soil materials because ballast aggregate is essentially single sized. Hence, it should be possible to optimise the geogrid aperture size to maximise interlock.

The research had several interlinking strands that are illustrated in Figure 1. This shows that the final objective was to develop sound concepts for the design of reinforced ballasted railway track and that to achieve this end, it was firstly necessary to improve understanding of geogrid/ballast interactions, both from suitable experiments and from the application of appropriate theoretical modelling. These activities proved successful and were followed by full scale laboratory testing in a major new Railway Test Facility (RTF) and by monitoring performance on a live railway in the field. Preliminary design recommendations were then evolved to assist users with the provision of reinforced track.

THEORETICAL ANALYSIS

In order to model the behaviour of geogrid reinforced ballast, use was made of the Discrete Element Method (DEM) developed by Cundall and Strack (1979). This allowed the geogrid, then the ballast and, finally, a combination of the two, to be modelled as a series of spheres with their interactions specified by the contact mechanics. Reference was made at each stage to experimental data to ensure that the modelling reproduced the correct mechanical behaviour. As the computing time required for this modelling was very large, when it came to dealing with the interactions between the geogrid and the aggregate, a small boundary value problem was selected which could also be

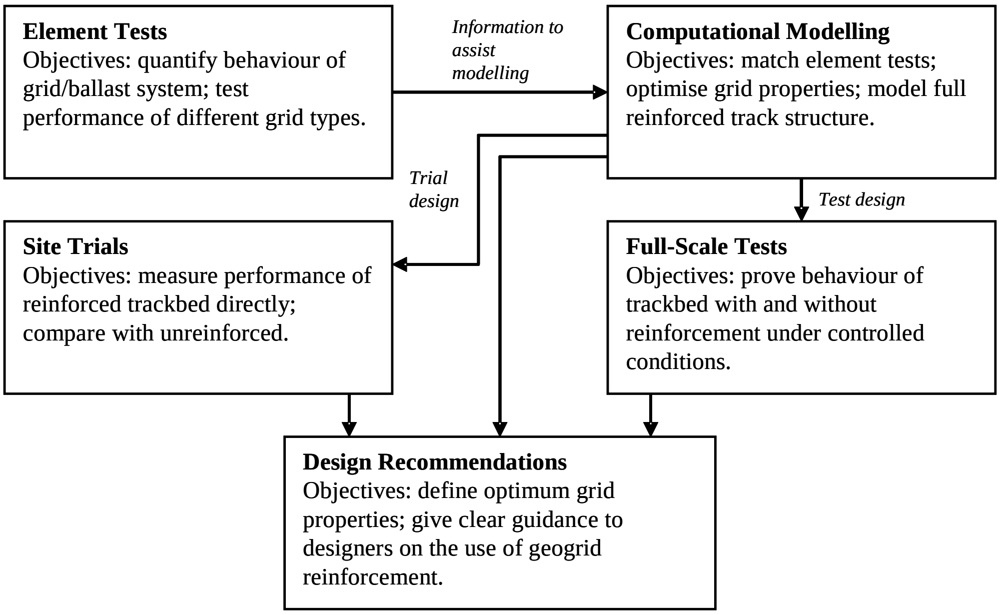

Figure 1. Various elements of the research

arranged as a simple experiment in the laboratory. The familiar pull-out test was used incorporating a piece of geogrid with four apertures. Tests were conducted with various normal loads applied to the ballast contained in a box incorporating the geogrid at mid-depth. The geogrid was pulled until the peak resistance force was exceeded. The input parameters were adjusted slightly to calibrate the theoretical predictions using the experimental data for one geogrid. Once this had been done, a variety of different parameters that influenced the pull-out force could be investigated. The most interesting aspect of these results concerned evaluation of the optimum ratio between aperture size of the geogrid and nominal aggregate particle size, defined as the Aspect Ratio, which gave the maximum pull-out force. This is illustrated by the results shown in Figure 2, which show that the largest force was predicted for an Aspect Ratio of 1.4. Full details of this work have been presented by McDowell et al (2006).

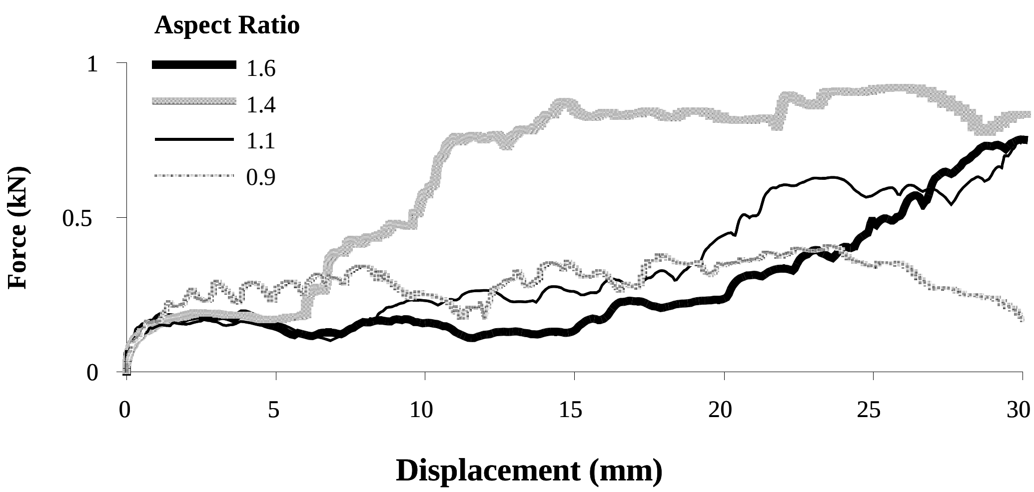

Figure 2. Influence of Aspect Ratio (aperture size:aggregate size) on pull-out force

EXPERIMENTS TO STUDY KEY PARAMETERS

The experimental arrangement shown in Figure 3 was designed so that geogrids could be installed in full-sized ballast and subjected to a loading regime simulative of that to be expected in railway track. The idea was to evolve an experiment that was relatively realistic and fast to conduct so that a range of important variables could be investigated in a reasonable time scale. It was also considered important to validate the theory using a more realistic test than the simple pull-out configuration, prior to commencing work on full-scale railway track experiments, which would be more time consuming and expensive. The apparatus shown in Figure 3, together with the test specification, became known as the Composite Element Test (CET). Full details have been presented elsewhere by Brown et al (2007). The term CET arose because the design philosophy used for this research was to treat the reinforced ballast as a composite material and to determine its response to load as such.

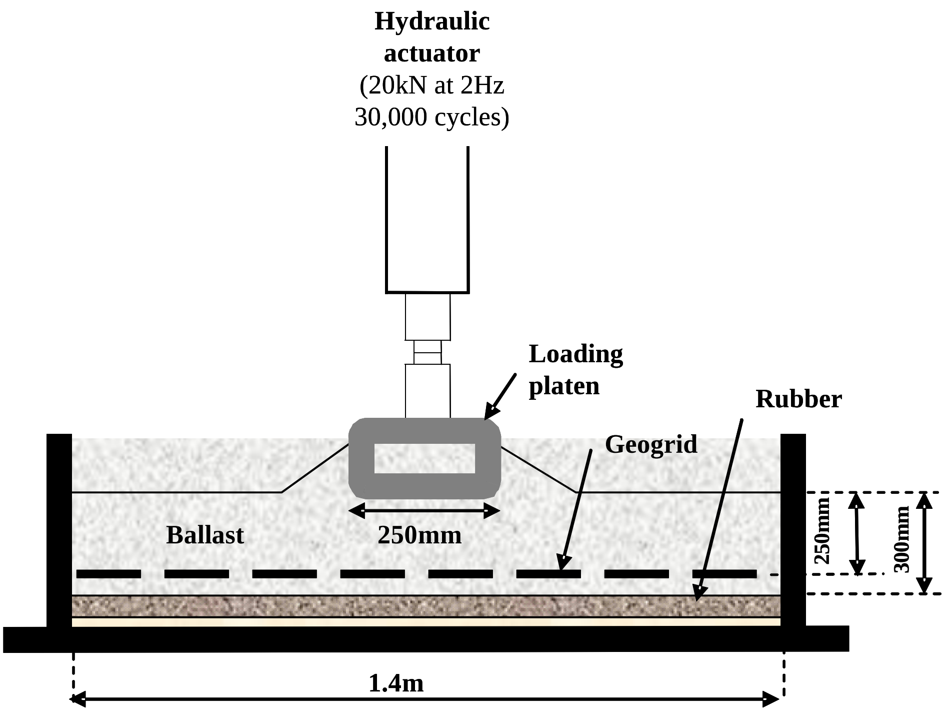

Figure 3. The Composite Element Test (Specimen width = 0.7m)

Extensive CET testing produced useful results concerning the influence of several parameters on the development of permanent accumulated settlement in the ballast under repeated loading. They were as follows:

- Aperture size of geogrid
- Resilient stiffness of geogrid
- Cross-sectional profile of geogrid ribs
- Effect of a geotextile bonded to the geogrid
- Position of the geogrid in the ballast
- Effect of subgrade stiffness

Figure 4 shows some typical data from the CET tests. Most of the tests involved a soft subgrade of 30MPa stiffness with a few tests carried out at 90MPa. The effect of reinforcement was significantly greater for the soft subgrade and the results presented here are all for that condition. The code used to identify the different geogrids involves two numbers (e.g. 20-65) that refer to the standard tensile strength in kN/m and the nominal aperture size in mm. It is clear from Figure 4 that reinforcement can be very effective at reducing the rate of settlement accumulation if the correct aperture size is used. In Figure 5, data from a large number of tests is brought together and shows that the optimum aperture size for the geogrid was about 70mm for the nominally 50mm particle size of the granite aggregate that was used throughout this research. Interestingly, the UK specification prior to this research was for a 38mm aperture, which was too small to be effective. With reference to the theoretical analysis, described above, the Aspect Ratio of 1.4 determined as giving the best performance, implies an aperture size of 70mm for 50mm nominal size of the ballast particles that were used. This agrees exactly with the CET results.

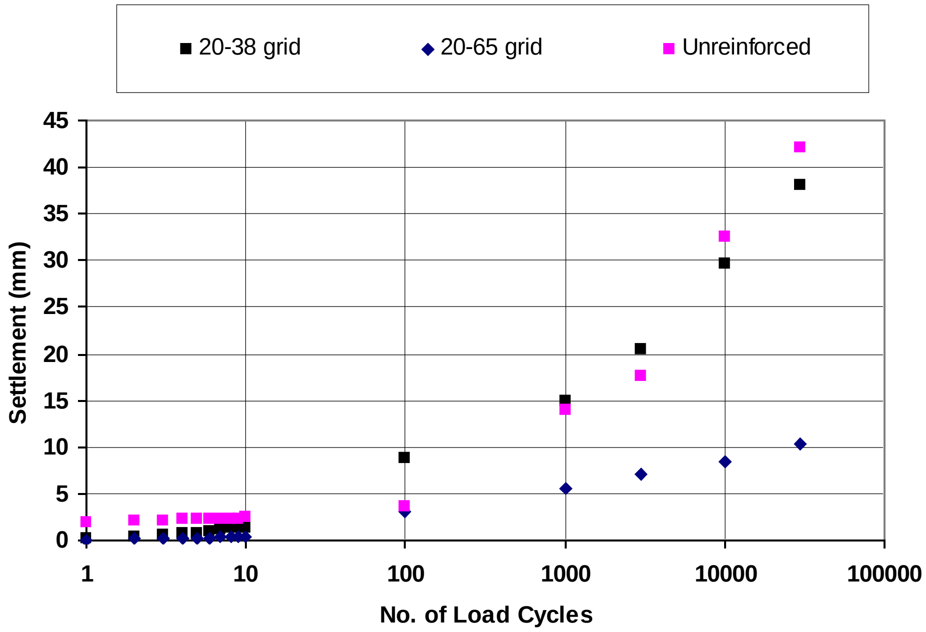

Figure 4. Effect of geogrid aperture size on accumulated settlement

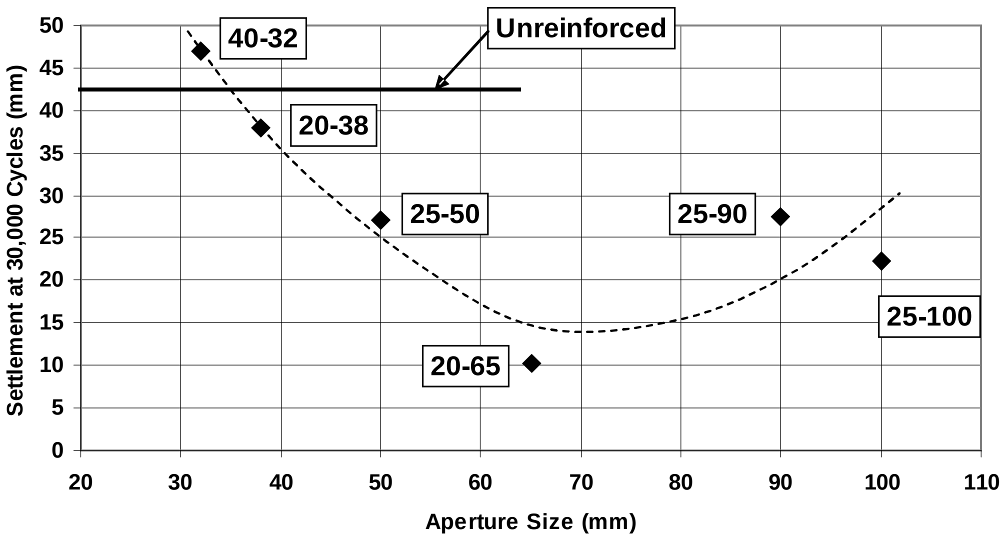

Figure 5. Optimisation of geogrid aperture size

Figure 6 shows the influence of geogrid stiffness, regarded as of more importance than ultimate strength for pavement and railway applications involving small strains. It shows that a 45-65 polymeric geogrid is more effective than the 35-65 material, although cyclic tensile tests (Brown et al, 2007) revealed that its resilient stiffness was only marginally greater (1.3MN/m compared with 1.2MN/m). Comparison with a much stiffer steel grid (60MN/m) shows that this provides advantages in the early stages of the test but the polymeric geogrid performs better as strain levels increase. These two observations together with a study of the cross-sectional shapes of each geogrid led to the conclusion that it is a combination of stiffness and rib shape that provides most effective reinforcement for a given aperture size (Brown et al, 2007). The steel grid had round section ribs while the polymeric grids were rectangular with sharp corners

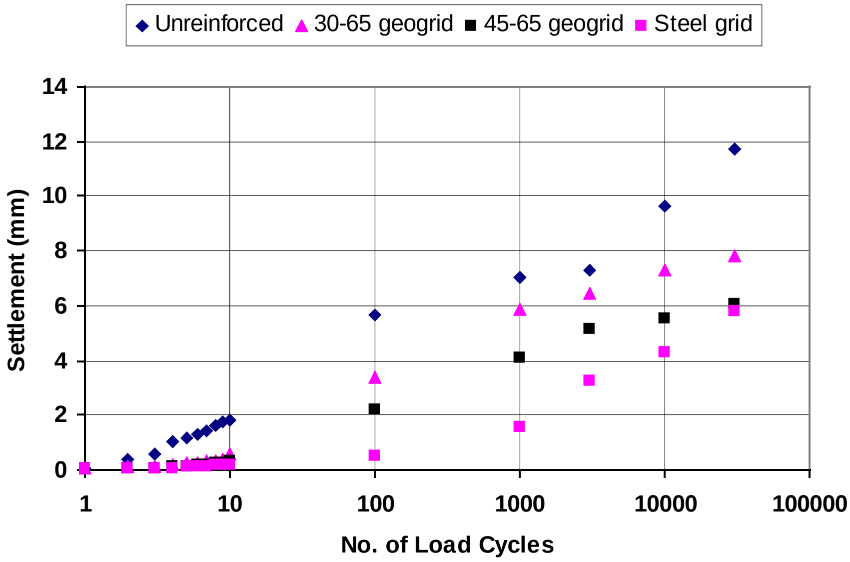

Figure 6. Relative performance of 65mm aperture grids of different stiffness and rib profile.

Other CET tests indicated that weak geogrid junctions offer poor reinforcement and that bonding of geotextiles to geogrids can interfere with the ability of the aggregate to effectively interlock with the grid. A few tests were undertaken with the geogrid at mid-depth in the ballast and with two layers of geogrid, one at the bottom and the other at mid-depth. Neither arrangement offered any improvement in performance over the single layer near the bottom of the ballast, which is the most practical position for site installation.

FULL-SCALE EXPERIMENTS

A new full-scale laboratory test facility was designed and built as part of this project. The Railway Test Facility (RTF), shown in Figure 7, has been described in detail by Brown et al (2007). It allows a short section of full-scale railway track to be constructed in a test pit and subjected to cyclic loading through three hydraulic actuators programmed to act in sequence to simulate moving wheels. Peak loads of up to 94kN can be applied at 3Hz directly to the sleepers through transverse beams. The instrumentation included displacement transducers, to monitor both the resilient and permanent deformation of the sleepers, and earth pressure cells to determine subgrade stresses. The track construction consisted of a soft silt subgrade 0.9m thick having an effective resilient stiffness of 15MPa. The loading tests involved 1 million cycles of load, which is thought to be equivalent to 50 Million Gross Tonnes (MGT) or about 2 years of typical main line traffic.

The 30-65 geogrid was selected for the RTF reinforced section, since this was a material available commercially, although its performance in the CET tests was not quite as good as the 45-65 grid (Figure 6) that was produced specially for the research. The object was to demonstrate, under more realistic conditions than in the CET, that effective reinforcement could be achieved prior to installing test sections on a main line railway. Figure 8 shows that was indeed the case with a significant reduction in settlement for the reinforced ballast. In terms of assessing the significance of these results in relation to savings in track maintenance, the extension in life at a typical level of settlement should be considered. In Figure 8 it can be seen that the reinforced section took about three times as many load cycles to reach a settlement of 6mm compared with the unreinforced case. This represents a potentially very significant increase in the time between maintenance operations and a consequent reduction in costs.

The other significant finding from the RTF and the CET tests was that the presence of the geogrid did not reduce the resilient deflections under cyclic loading. In the RTF, this was also apparent from comparing the vertical stresses measured in the subgrade for the two cases, which gave similar values, implying that the overlying ballast layer was of similar stiffness with and without the geogrid. The significance of geogrid reinforcement is that it reduces the larger permanent strains that accumulate under repeated loading when it effectively interlocks with the surrounding aggregate.

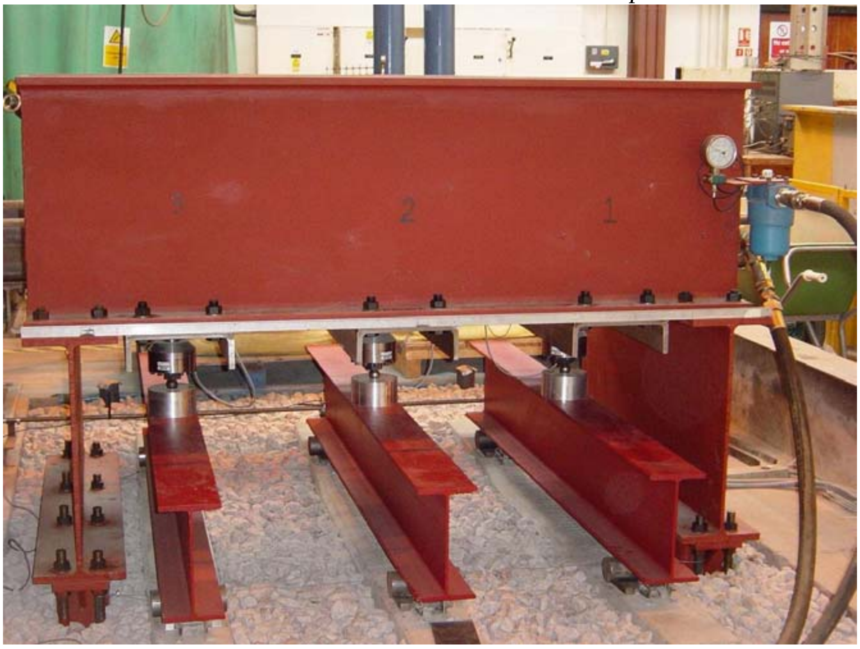

Figure 7. The Railway Test Facility

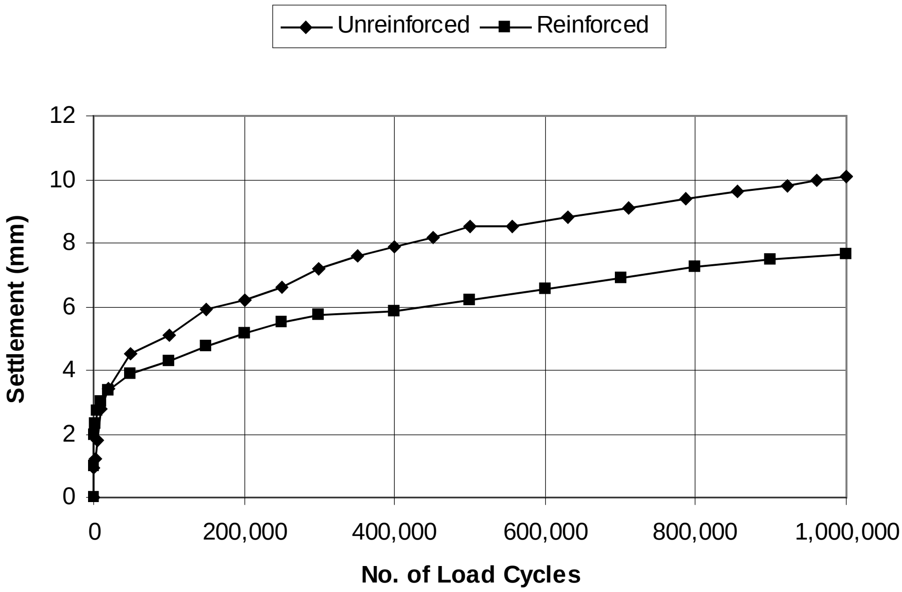

Figure 8. Comparison of performance for reinforced and unreinforced sections

FIELD TRIALS

Sharpe et al (2006) have described a full-scale site trial that was conducted on the West Coast Main Line at Coppull Moor, in which reinforced and unreinforced sections were constructed as part of a track renewal programme allowing direct comparison of performance to be monitored. Although the data available to date only covers a two year period, monitoring is continuing, but the results have generally been consistent with those obtained in the laboratory tests. Figure 9 shows details of the site which was selected, most of which was on embankment with a deep wet ash foundation. A realistic length of reinforced ballast was placed using a commercial product that was equivalent to the 30-65 geogrid that performed well in the laboratory. An adjacent control section was also monitored. The lower part of Figure 9 shows the resilient deflections recorded from testing with a modified Falling Weight Deflectometer before and after renewal. The D_0 values give an overall idea of the track stiffness, while the D_{1000} values relate to the stiffness of the subgrade. Over the section that was renewed with reinforced ballast the subgrade was slightly softer (higher D_{1000} values).

Performance of the track was measured using a conventional High Speed Track Recording Car, which determines the standard deviations of the rail level. The data available to date is shown in Table 1. From this it will be seen that greater improvements to the rate of settlement were observed for the reinforced section. The improved average rate of deterioration in standard deviation of settlement for the reinforced section (0.45 compared with 1.25mm/yr) is reported to equate to an extension in the time between tamping operations of a factor of three, in line with the laboratory RTF experiments.

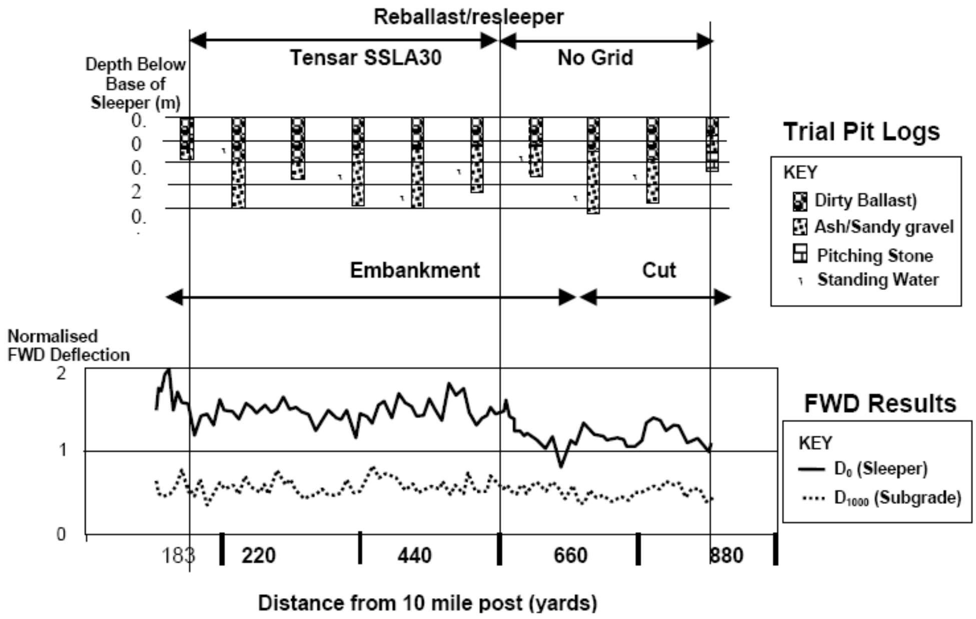

Figure 9. Test site on West Coast Main Line at Coppull Moor (after Sharpe et al, 2006)

Table 1. Performance data for Coppull Moor field trial (after Sharpe et al, 2006)

Rate of increase in standard deviation of settlement (mm/yr)	**Reinforced**		**Unreinforced**	
	220-440yds	440-660yds	660-880yds	880-1100yds
Before renewal	1.4	2.2	1.0	1.2
One year after renewal	0.4	0.7	0.6	0.7
Reduction	1.0	1.5	0.4	0.5

DEVELOPMENT OF A DESIGN METHOD

Initial work was carried out on the development of an analytically-based design method using the information gained during the experiments for validation and calibration. A simplified approach was used and guidance provided for one of the commercial collaborators in the project, so this information is not yet in the public domain.

CONCLUSIONS

This wide ranging project involving various experimental and theoretical investigations has led to the following conclusions:

- Geogrid reinforcement of 50mm nominal sized railway ballast can be effectively achieved by use of a geogrid with an aperture size of 65mm. The Aspect Ratio of about 1.4 could probably be applied to other aggregate sizes.
- Geogrid reinforcement of railway ballast is more effective when the geogrid has high resilient stiffness and an appropriate rib cross-sectional shape to ensure good interlock with the aggregate particles.
- Location of the geogrid towards the bottom of a 300mm thick ballast layer is effective and represents a convenient location for field operations.
- Use of a polymeric geogrid with a resilient stiffness in the order of 1.2MN/m will not increase the effective stiffness of the ballast layer.

Acknowledgements: This research was principally funded through a Royal Society Senior Mercer Award for Innovation and partly by an Engineering and Physical Sciences Research Council grant. The Authors acknowledge this support and also that of the following companies that provided assistance and advice during the project: Tensar International, Scott Wilson, Carillion Rail, Network Rail and PS Rail. The Authors also wish to recognise the skilled equipment development work carried out by their colleague Barry Brodrick.

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