A New Generation ~~O~~of Geogrid ~~F~~for Railway Ballast Stabilisation ~~T~~to Reduce Trackbed Maintenance Costs

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ABSTRACT

Over the past twenty five years, high stiffness polymer geogrids have been proven to reduce the rate of settlement of railway ballast. Geogrids which performed well had features that enhance the mechanical interlock and restraint of the ballast particles. Full scale research, both in the laboratory and the field, have indicated that mechanical stabilisation of railway ballast can provide a beneficial effect on the maintenance cycle of the ballast tamping operation. Research was carried out at the University of Nottingham in a small scale 'composite element test' and then verified in both a full scale test in the railway simulating 'railway test facility' and in the field. From this work, a simple cost model has been produced to evaluate the benefit of mechanical stabilisation of ballast. Further research has been conducted at the University of Nottingham to investigate new varieties of geogrid that are being developed to seek increased improvements in ballast stabilisation.

1. INTRODUCTION

The use of geogrids has normally been limited to sites that have poor subgrade stiffness characteristics and would therefore clearly benefit from improved trackbed support. For those railway foundations that normally include a sub-ballast support layer, weak subgrade problems are best addressed at this low level in the trackbed. There is growing evidence that geogrids can provide benefits by direct stabilisation of the ballast layer in its function of sleeper support.

2. BRIEF HISTORY OF THE USE OF GEOGRIDS

Understanding the way in which a geogrid works, as well as its varied uses and benefits in the trackbed, has been a gradual process. Figure 1 illustrates the form of geogrid currently used in trackbed stabilisation by Network Rail in the UK.

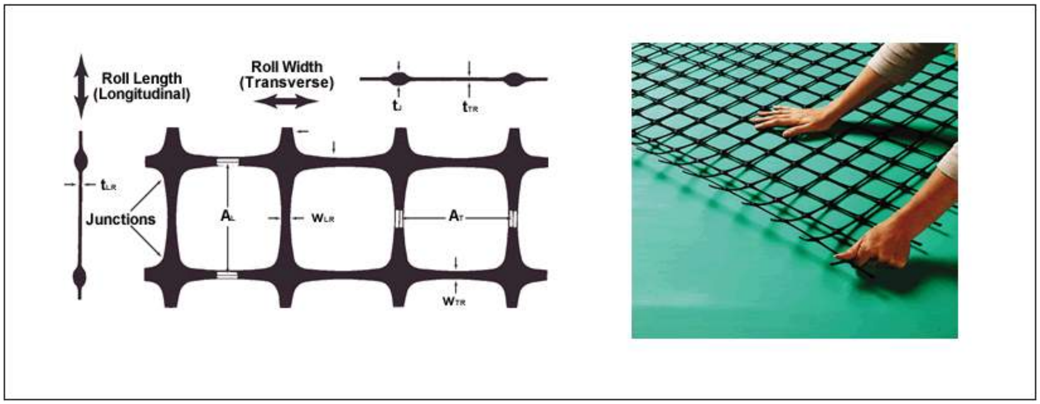

Figure 1: A typical form of geogrid for use in railway ballast.

One of the earliest reference projects in the literature, Walls (1987), indicated that a geogrid provided a structural benefit to the ballast layer of the permanent way on a problematic site, (a weak and wet subgrade), in Alabama, USA. The effect of a geogrid and geotextile composite, placed at the base of a ballast layer, was to lengthen the maintenance cycle and to allow the line speed to be increased within three months of the installation; the 8 km/h speed restriction was increased to 56 km/h. After nearly four years of service, only routine maintenance was required. This is probably the earliest example of geosynthetics being combined as a ballast separator, filter and reinforcement. Having now been in service for over twenty years, much could be learned from returning to site to examine the condition of the geosynthetics and obtain the maintenance record from the owner. Unfortunately, as is often the case, no record, memory or awareness exists on the whereabouts of the site.

Practical examples of monitored geogrid inclusions in railway ballast are few and far between: see Hall, (2007). Sharpe (1988) demonstrated that the all-important horizontal strains experienced by a geogrid placed at the base of the ballast layer were well below 1%, indicating that the stiffness of the material in tension was all-important. This was confirmed later by Hamed (1987) who demonstrated that the rate of sleeper settlement was influenced favourably by increasing the tensile stiffness of the geogrid inclusion. More recently Sharpe (2006) has reported controlled trials of geogrid reinforced trackbed at Coppull Moor on the West Coast Main Line, UK. By comparing the performance of a quarter of a mile of reinforced trackbed with that of a similar length of unreinforced trackbed these trials demonstrated conclusively that inclusion of a stiff monolithic geogrid significantly reduces maintenance requirements.

3. RESEARCH ON GEOGRIDS

Landmark research by Bathurst (1986) showed that a geogrid in ballast on weak foundations can reduce the rate of settlement by a factor of about 4 to 5 times. Matharu (1994) showed that the inclusion of a geogrid in ballast, on a weak foundation, can enhance the performance to that expected of a firm foundation.

In reviewing published information, the beneficial effect from the geogrid inclusion comes from the interlocking of ballast stone into the grid apertures. The setting up of a confinement mechanism counter-acts the lateral migration of ballast particles under dynamic traffic loading. In other words geogrids effectively provide ballast with a means to support a tensile stress at its base level. The net effect is to control sleeper settlement, thus preserving the vertical and horizontal alignment of the rails. The form and nature of the geogrid ribs, junctions and apertures must be such that they are capable of counter-acting the lateral strains in the ballast, (Figure 2).

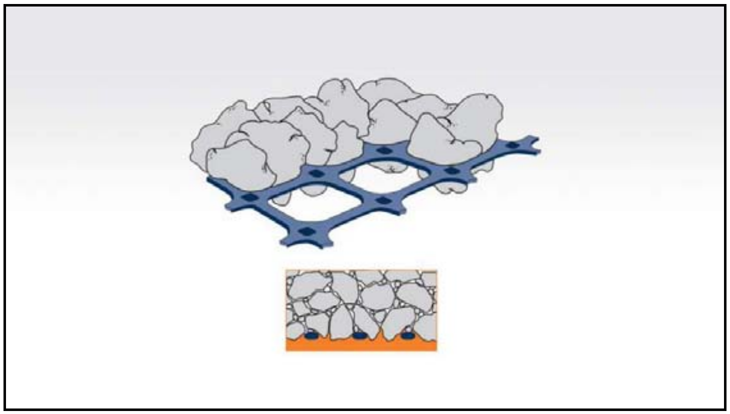

Figure 2: Interlock and the penetration of ballast particles into the apertures leads to a lateral confinement of the aggregate particles as provided by the stiffness of the planar geogrid structure.

The mechanical stabilisation effect has been the subject of recent and comprehensive research by Brown et al (2006). Included in that program of work was a round of testing in a composite element test (CET), apparatus, (Figure 3).

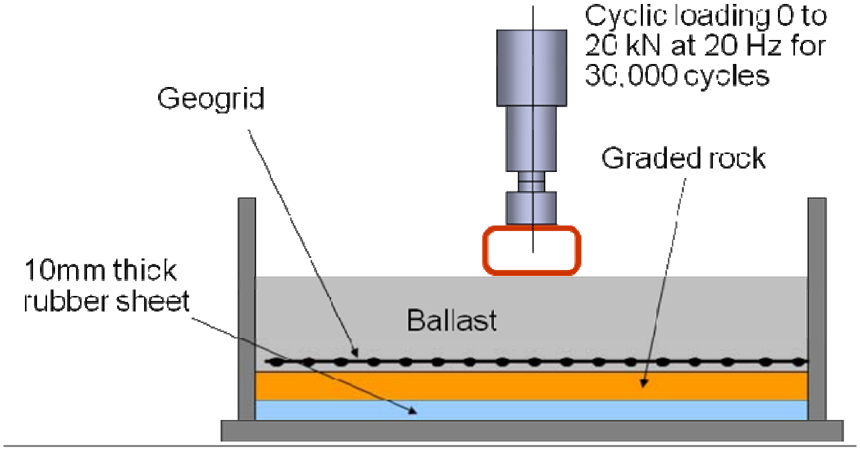

Figure 3: Composite Element Test, (CET), apparatus

The major findings on the performance of the stiff monolithic form of geogrid were reported as:

- geogrid reinforcement of ballast can reduce the rate of settlement,
- the aggregate size of railway ballast and the aperture size offered by the geogrid should be matched for optimum performance,
- the stiffness of the geogrid and its cross-sectional shape of the ribs are considered to be parameters having a bearing on the efficiency of the reinforcement mechanism,
- in deconstructing the laboratory test beds, the observation was made that serious abrasion effects on the geogrid were not apparent after 1 million load cycles.

Concentrating on the first and second of these conclusions, that is the reduction in the rate of settlement and the matching of ballast particle size and geogrid aperture size, this has an interest to the permanent way owner. The level of maintenance required to preserve the vertical and horizontal alignment of the rails has an obvious financial implication on his safety responsibility and his ride comfort aims.

As part of the test procedure the ‘sleeper’ was raised to its original level using pneumatic hammers in a simulation of the manual methods of tamping ballast under sleepers. The frequency of performing this procedure was recorded for an unreinforced and a reinforced case, (Figure 4), where settlement v load cycles in presented.

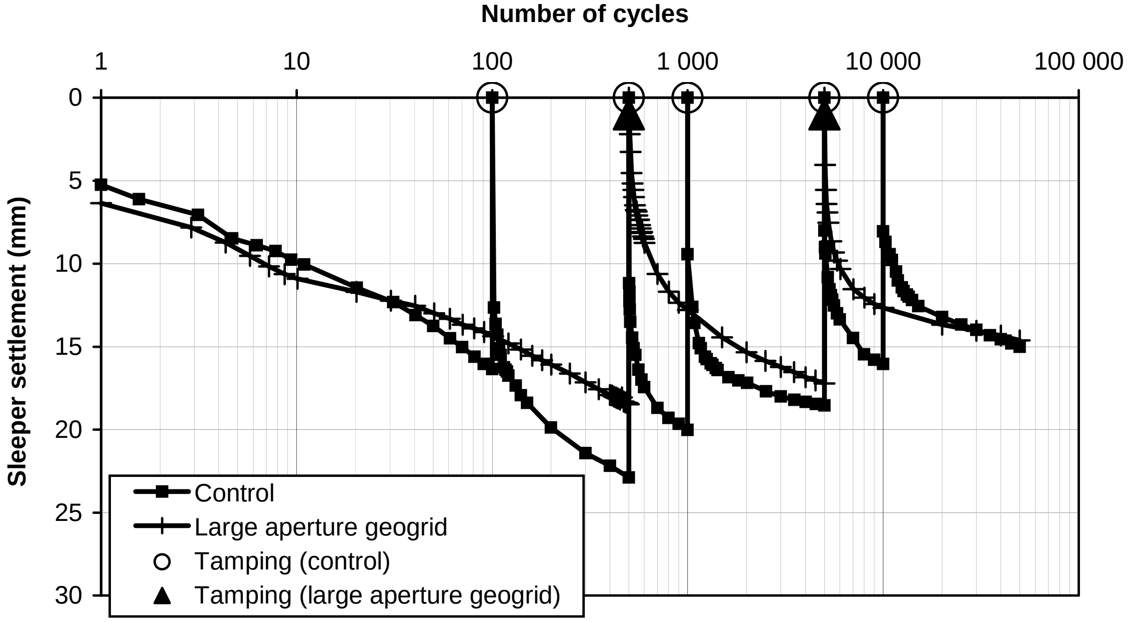

Figure 4: Sleeper settlements and tamping frequency

It can be seen that after some 40,000 load cycles that the sleeper is at a similar level of settlement, say 14mm. However to reach this condition, the unreinforced control was tamped five times and the geogrid reinforced ballast was tamped twice. Further testing not only on this, the composite element apparatus, but also the full scale railway track facility, have supported the view that a factor to represent the reduction in the frequency of tamping can be at least 2.5 for a railway ballast-optimised stiff and monolithic geogrid.

4. COST MODEL

By assembling typical cost data for the installation of the materials components of a reballasting operation and some mechanised tamping rates per linear metre of single track, (Table 1), a simple cost model can be created. For the purposes of comparison, the following data provides the result, (Figure 5).

Table 1: Cost data

Activity	Cost per linear track metre (£/m)
Ballast renewal	50
Ballast tamping	25
Geogrid installation	15

The data was provided by a trackbed owner and are typical, and 2007-current, contract unit rates for the three main operations. The interest rate that is common in ‘whole life’ cost models has been set to zero in this example.

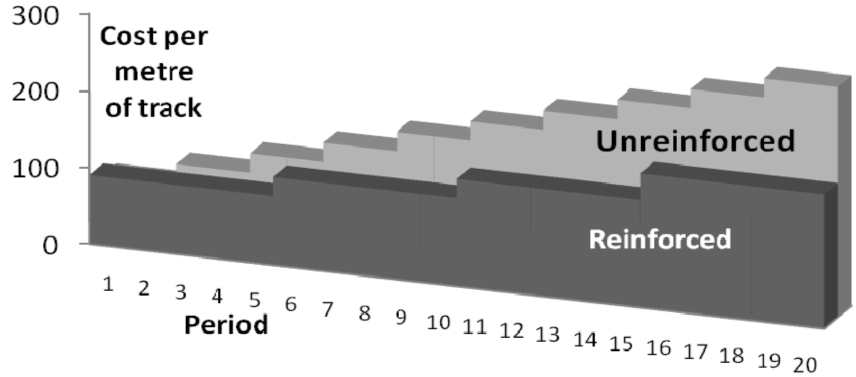

Figure 5: Cumulative maintenance costs through the maintenance cycles

It can be seen that, typically, over an arbitrary period of 20 maintenance time units, i.e. tamping, that the cumulative cost of the tamping component of track maintenance can be very nearly halved by the use of geogrids of the type that provides maintenance cycle increase factor of 2.5. The payback period is 2.5 maintenance period time units. These results vary only marginally if the cost input data is varied. The indications of a short payback period and significant reductions in long term costs are still evident. The more sensitive parameter is the maintenance frequency improvement factor, (2.5 in this case).

5. INITIAL EXAMINATION OF A NEW GEOGRID STRUCTURE

With the development of a geogrid with a three directional rib orientations and, hence triangular apertures, (Figure 6), much of the research carried out on biaxial geogrids needs to be repeated for rolling wheel loads, static and dynamic plate loading. In the case of railway ballast stabilisation, this meant a return to the University of Nottingham and the CET apparatus, (Figure 3).

Figure 6: A geogrid with three equilateral rib directions

The established test procedure, Brown, (2006), was observed but the subgrade reaction was ‘softened’ by the exclusion of the graded rock sub-ballast and the introduction of a thicker layer of compressible rubber pad. This change was introduced to make the settlements more sensitive and to accentuate small differences in performance.

There were two aims in the product development test program:

i. to investigate the influence of aperture shape and size,
ii. to identify a candidate geogrid, having triangular apertures, which compares favourably with the performance of a biaxial geogrid with its square apertures and which was described as having optimal properties within the range of biaxial geogrids that were tested in previous CET work. (Brown, 2006).

The candidate geogrid identified in these initial composite element tests as displaying the best performance is then to be adopted for further study in full scale railway test facilities.

Three geogrids with triangular apertures were tested, (TX 75, TX 80 and TX 90) and one biaxial geogrid, (BX 65). The aperture sizes and shape and its relationship with a 50mm diameter circle, representing a common ballast particle size, is shown in Figure 7. In all other respects, (e.g. weight) the products were broadly similar: aperture size and shape were the principal differences.

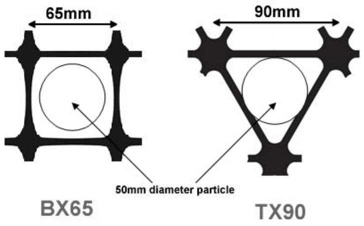

Figure 7: Aperture shape with respect to a ballast particle representation

The form of the settlement v load cycles curves followed the form is commonly obtained, (Figure 8). TX 75 was eliminated part way through the test programme as it did not indicate a performance having the prospect of providing a performance greater than the biaxial reference BX 65. This is an indication that aperture size for triangular apertures has an optimum relationship with the median particle size in much the same way as do biaxial geogrids with their rectangular apertures.

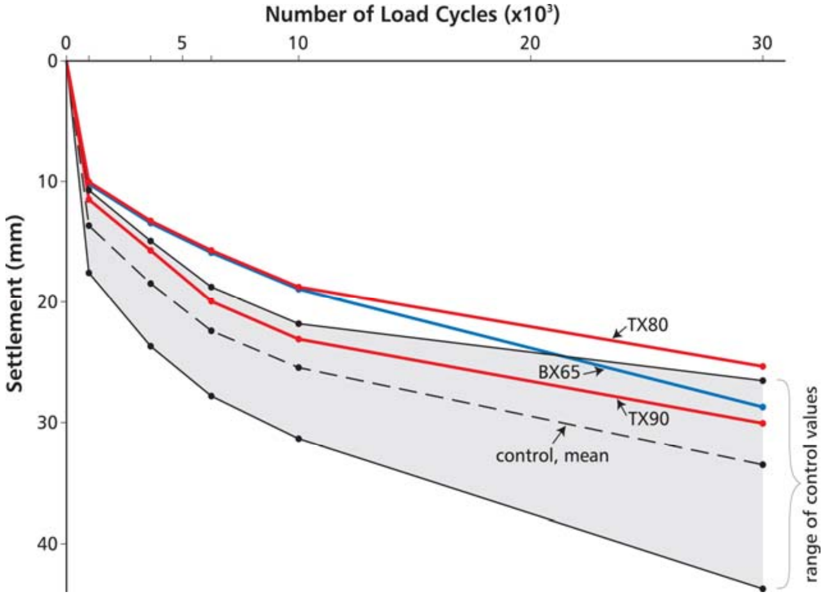

Figure 8: Settlement v Number of Load Cycles TX 80, TX 09 and BX compared with Control

The following is a summary of the measured settlement, after 30,000 load cycles, from four control tests on unstabilised ballast and five individual tests on geogrid-stabilised ballast.

Table 2: Final settlement values

	Control	BX 65	TX 80	TX 90
Settlement after 30,000 cycles, (mm)	43.5	28.9	28.3	29.2
	33.1		22.0	30.5
	26.5			
	30.2			
(mean)	33.3	28.9	25.2	29.9

Observations:

i. The settlement values in the control tests were more variable than in the previous CET work, (Brown 2006). A mean value is therefore indicated in Figure 8.
ii. All three geogrid types showed a stabilisation effect.
iii. The flatness of the settlement v deflection curves after a large number of load cycles indicated that a useful increases in life, (i.e. the ballast tamping maintenance cycle), is available from geogrids with triangular apertures – even though the final settlement values differ by only a few millimetres in these CET tests.
iv. TX 80 triangular geogrid provided a better performance over the biaxial BX 65.
v. From this work, TX 80 holds out the prospect of providing a maintenance period improvement factor of 2.5 or perhaps slightly better.
vi. TX 80 was selected as the candidate geogrid for further testing in a more realistic railway trackbed context.

6. SUMMARY

In the interim, the cost model that was developed for a biaxial geogrid can be applied to geogrids of the same type and having triangular apertures with a side dimension of 80mm.

Geogrids with appropriate stiffness and geometrical properties can mechanically stabilise railway ballast and provide a significant financial benefit to the owner. The financial impact of a 2.5 times increase of the tamping cycle period of a renewed track can reduce cumulative tamping maintenance cost by around 50%. The geogrids under current development can maintain this benefit, and initial indications are that the 2.5 factor that was indicated in these CET tests can, at least, be preserved.

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