ACCELERATED TESTING OF GEOSYNTHETICS IN TRACKBED USING EUROPE'S LARGEST FULL SCALE RAIL RIG

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ABSTRACT

This paper describes the construction of a full scale trackbed load test facility which simulates the harshest conditions under which a geosynthetic layer is likely to be used. A background to the use of geosynthetics as separators between ballast and formation in the UK is given, together with a discussion of the scope for further development. The initial test schedule is described, which confirms that the loading conditions are representative of those experienced in typical main line traffic, followed by a summary of early tests on geotextiles in common use to assess their resistance to abrasion damage.

INTRODUCTION

The use of geosynthetic products in the UK as separators between ballast and formation has developed gradually since the introduction of the first geotextiles in the 1970's. After many years of experience the use of geosynthetics on the UK rail network has been standardised. This approach is necessarily conservative, since the cost of formation failure is high. While the incidence of failure is minimised, standardisation does not exploit the full potential of geosynthetics; neither does it encourage innovation. In the past various innovative products have been proposed, but difficulties have been experienced in taking them forward to the stage where there was sufficient confidence to undertake site trials. One of the main obstacles was the lack of suitable test facilities that would replicate the harsh environment encountered beneath a main line railway, which made it difficult to evaluate new products.

In 2001 a full scale trackbed test facility was constructed at Liversedge in order to undertake accelerated testing of geosynthetics under realistic loading conditions. The facility was supported by the DTI and a consortium that included leading rail maintenance contractors, industry suppliers and academics.

After the initial test programme was completed, confirming that conditions in the rig simulated those encountered under main line conditions, formation conditions in the rig have been adapted to simulate the harshest conditions under which a geotextile would ever be expected to survive. Tests have been completed on three commonly used geotextile separators to assess their resistance to abrasion damage.

Background to Use of Geosynthetics in UK Trackbed

The introduction of geosynthetics for use in trackbed coincided with increasing use of mechanical maintenance techniques during the second half of the 20th century. For the new techniques to be successful deep layers of clean ballast were required. Prior to this, the placing of new ballast layers beneath the sleepers was rare. Vertical track geometry faults were corrected by hand packing of ballast, which did not involve the disturbance of deep well consolidated lower ballast layers. The lower ballast would, in time, break down considerably, but would still retain its granular characteristics, enabling it to fulfil the required functions of drainage and load spreading.

The installation of deep ballast often necessitated the removal of well graded granular layers which had formed a good separation layer between ballast and subgrade. The removal of subgrade protection led to rapid subgrade erosion and consequent development of wet spots. The response to this was to install a complete new trackbed, incorporating a well graded aggregate beneath the ballast for formation protection, a process known as blanketing. The thickness of the blanket was normally between 200 and 300mm. Various sands and gravels were used for blanketing, some successful, others not so successful. Finally a grading envelope was found for “Blanketing Sand” (see RT/CE/S/033) which contained the correct proportions of fine and coarse material to ensure a stable blanket which could prevent the upwards migration of fines from the subgrade.

The ‘traditional’ sand blanket was highly successful at curing subgrade erosion problems. However it was not popular with track renewals engineers because it necessitated large volumes of excavation. Additional trains were required to transport the large amounts of spoil and import new materials. With increasing traffic on the rail network there was considerable pressure to reduce possession times and the movement of materials trains.

When heavy duty textiles first became available it was initially thought that they might replace the traditional sand blanket. However, it was soon realised that no geotextile available at the time had a pore size sufficiently small to prevent the upwards migration of clay or silt sized particles into the ballast, and that all geotextiles were susceptible to abrasion under dynamic loading conditions when placed between coarse granular materials. Figure 1 shows the condition of trackbed two years after treatment with a non-woven geotextile alone. It was concluded that no geotextile could replace a traditional sand blanket.
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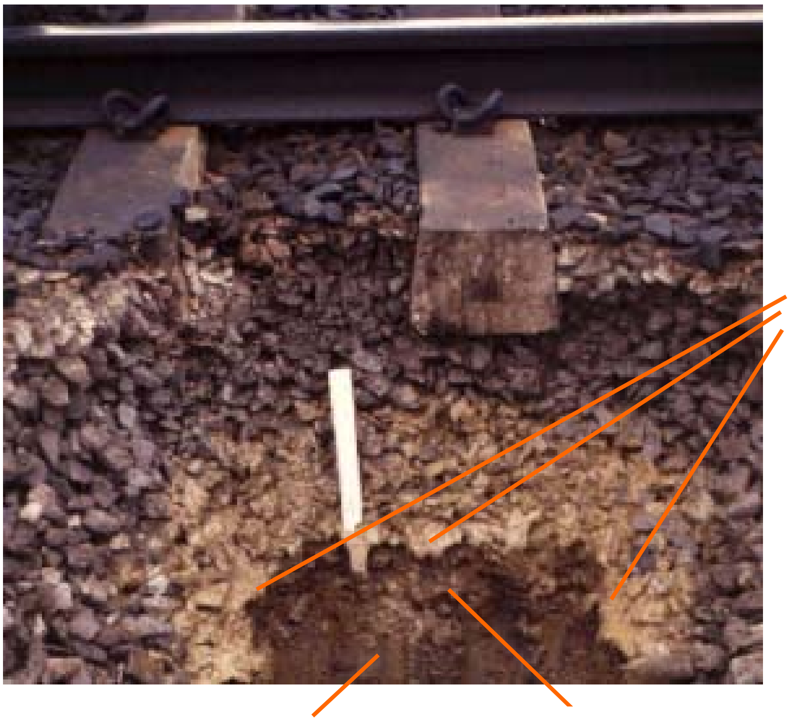


Figure 1
Failure of a non-woven geotextile after 2 years in a main line track.

Some geotextiles appeared to be working satisfactorily, but due to the lack of well monitored trials with adequate control sections, combined with poor reporting, there was no reliable information to define the circumstances under which geotextiles were successful. At one time there was a policy on some regions of always including a geotextile as a matter of course on a reballasting job because it was cheap and easy to install. If it was useful in only 10% of jobs it was worthwhile, but the occasional job that should have received a full sand blanket would be re-treated. Even if there was serious subgrade erosion it was considered that the geotextile bought time.

Research Undertaken by British Rail into Use of Geotextiles

During the 1980s considerable research was undertaken into the use of geotextiles and other types of geosynthetic layers.

When examined under a microscope, the pore size of non-woven geotextiles available at the time appeared to be similar for a given weight of product. This suggested that all commonly used non woven geotextiles should have similar performance regarding the reduction of upwards migration of fines. It was envisaged that the most significant factor would be the weight per unit area.

Testing was undertaken at British Rail's Central Soil Mechanics Laboratory using a "Pulsator" test to determine the separation ability of various commercially available products. The test involved placing a 200mm diameter sample of geotextile directly onto a hard intact sample of clay, covering with pea gravel and inundating before subjecting to repeated loading. Surcharge was added to raise vertical stress to the levels experienced at the base of the ballast layer. It was concluded that mechanically bonded materials generally performed better than thermally bonded materials, although this was attributed largely to the lower rigidity of ability of mechanically bonded products which enabled them to conform to the clay surface, which was thought to interfere with the process of slurry generation. (see McMorrow, 1990)

Subsequent testing at British Rail Research subjected four leading non-woven geotextiles to dynamic loading when sandwiched under water between 12mm chippings and railway ballast. The effects of abrasion were assessed by two methods, i.e. the loss of tensile strength and a visual assessment of the area of holes found in each geotextile after testing. Table 1 summarises the findings (see McMorrow et al. 1991)

Product Description	Mass per unit area g/m^2	Area of Holes after Testing mm^2	%age loss in strength
Heat bonded, heterogeneous filament	340	79.5	33
Needle punched, continuous filament	390	62.5	31
Needle punched with resin bonding	470	36.5	22
Needle punched, staple fibre on a split tape woven base	620	8.5	18

Table 1 – Results of Dynamic Loading Damage Tests, BR Research

The loss in strength did not differ greatly between products (range 18% to 33%). By far the best performer from a visual assessment was a needle punched staple fibre on a split tape woven base, although this was the heaviest of the geotextiles tested. It is interesting to note that the performance of the products in both tests improved according to their weight.

While geosynthetic layers could not normally replace a traditional sand blanket, it became clear that they could often either enhance the performance of existing trackbed layers, or reduce the required depth of construction sufficiently to warrant their use. For example, it had frequently been observed in effective sand blankets that the penetration of the sand by finer clay/silt sized particles was limited to a maximum of 20mm. The remaining depth of 180+mm was to ensure that the minimum thickness was achieved throughout and to provide for some sacrificial material on the upper surface in the absence of a separator (note, in some regions a thin layer of pea gravel was used a separator). In site trials undertaken in 1983 (Sharpe, 1989) it was demonstrated that the thickness of a sand blanket could be reduced to 25mm using a non woven geotextile as a separator between the sand and ballast. When cushioned by a sand layer the geotextile would survive indefinitely below the ballast without significant abrasion, and maintain the integrity of the sand layer. Thus the volumes of spoil and new materials could be reduced considerably and less time was required for construction.

Standarised Use of Geosynthetic Layers on Network Rail

While much attention was directed towards the use of geotextiles as permeable separators, other functions of geosynthetics were also studied. For example, it was found that inclusion of a plastic mesh in the ballast would reinforce the trackbed, effectively improving its load spreading ability. Impermeable membranes have also been extensively used as separators. The most appropriate type of geosynthetic product to use in a given location can only be determined by a thorough investigation of trackbed and drainage conditions. Network Rail have recently published a revised Code of Practice, RT/CE/C/039, Issue 2, which gives current best practice in trackbed investigation and design of remedial measures. Four classes of geosynthetic are included, as listed below :-

- Geotextile Separator – a non woven geotextile having a typical weight of about 300g/m^2. used to separate a sand layer from ballast (specified in RT/CE/S/010)

- Robust Geotextile Separator - either a heavy duty geotextile or permeable geocomposite which offers increased resistance to abrasion, used to separate a coarse granular layer from ballast (typically either a non woven geotextile having a weight of about 1000g/ m^2 or a 10mm aperture plastic mesh sandwiched between two layers of Geotextile Separator).

- Impermeable Geocomposite - a heavy duty impermeable membrane with provision for lateral dissipation of pore pressure from the underlying ground

- Geogrid Reinforcement - a plastic mesh with high tensile stiffness, used to reduce ballast movement over soft ground

Scope for Extending Use of Geosynthetics

There is still considerable scope to further reduce trackbed renewal costs by reducing the need for sand blankets. While there is currently no geosynthetic product available that can replace a sand blanket where a serious subgrade erosion problem has occurred, it is important to keep an open mind that such a product may be developed in the future. As a first step to considering what attributes the product would need it is useful to consider the way in which subgrade erosion is initiated, and how an effective sand blanket is thought to work..

Typically, a serious subgrade erosion problem would occur where an existing stone blanket layer is poorly graded, i.e. it contains voids which permit the upwards migration of fines. The voids in the stone layer would be too large to hold the fine particles at the exposed upper surface of the clay subgrade in place. The clay particles would become dislodged under the action of dynamic loading in the presence of water, and they would combine with the water to produce a slurry. Under the high pressure generated by traffic loading the slurry is forced upwards, which causes a suction force to develop in the voids after the load has passed. The suction will cause slurry to flow back into the voids, but at a slower rate than it was forced out. Under these conditions there will be a tendency for water to be drawn out of the slurry, resulting in the slurry becoming thinner closer to the clay surface.. Thus, in the presence of a suitable water supply, the process of subgrade erosion is self perpetuating.

The presence of clay slurry in a granular layer reduces its modulus of elasticity considerably, such that it behaves as a soft subgrade. So even if the slurry has not risen into the ballast it can still cause poor track quality.

When a sand blanket is laid, the sand flows into the surface voids and fills in any depressions in the excavated surface on which it is placed. This prevents upwards movement of slurry. Slurry generation might continue at the clay surface after the sand has been placed, but there is no process for perpetuating it. Water can move upwards through the sand, but the clay particles are retained, so the slurry will dry out in time. In this way a sand blanket increases the stiffness of the granular layer.

In order to fulfil all of the functions of a sand blanket a geosynthetic product would need to have the following properties:

- Conform to the excavated surface, thereby preventing upwards migration of fines
- Resist abrasion under harsh dynamic environment encountered in main line trackbed
- Allow desiccation of existing slurry

It is estimated that there are about 30 miles of sand blanket laid each year on UK railways. Much of this is laid to cure serious subgrade erosion, for which there is no currently available geosynthetic option. There are however many sand blankets which are placed in order to remedy minor subgrade erosion problems or suspected subgrade erosion problems, for which there may be scope for increased exploitation of currently available geosynthetics. Figure 2 shows typical examples of minor subgrade erosion problems. In these cases the existing blanket is serving a useful function by distributing the loads adequately, but there appears to be some subgrade erosion taking place. Current practice in these circumstances would be to install sand as a precaution, but it is likely that the use of a robust separator would enhance the properties of the blanket which would enable it to resist further erosion. In order to function under these conditions a separator must offer considerable resistance to abrasion under dynamic loading in a harsh railway environment. Until now there has been no test which replicates these conditions. Thus it has not been possible to assess the likely performance of new geotextiles before they are subjected to full site trials.

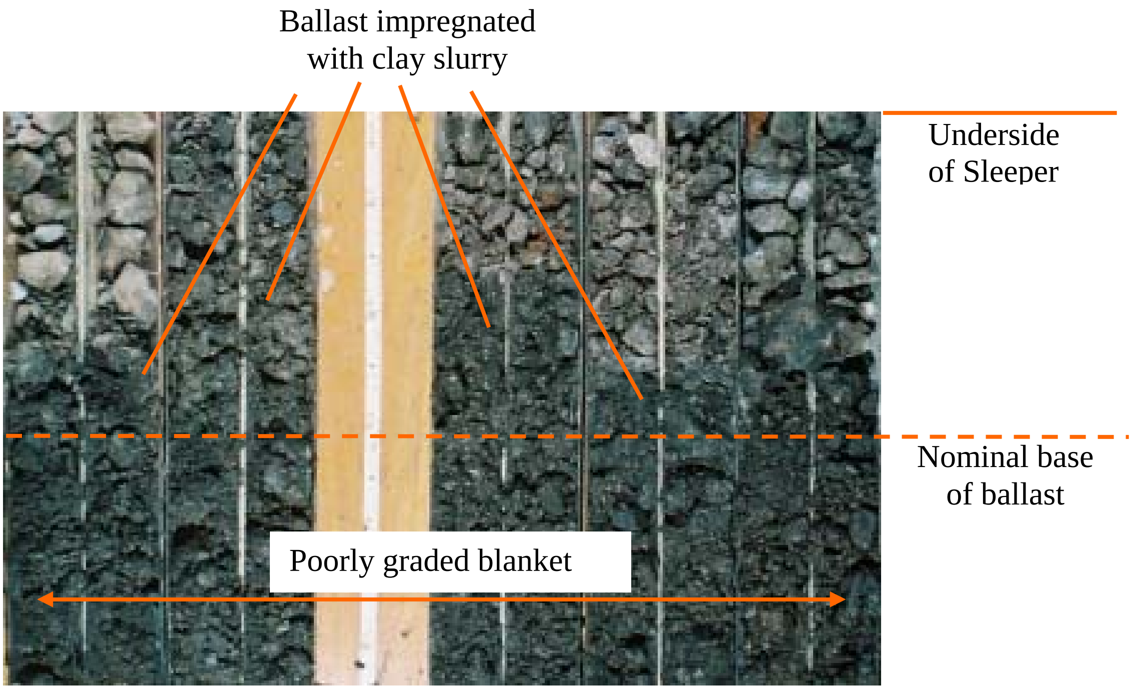


Figure 2 Boreholes taken through trackbed with poor quality blanket.

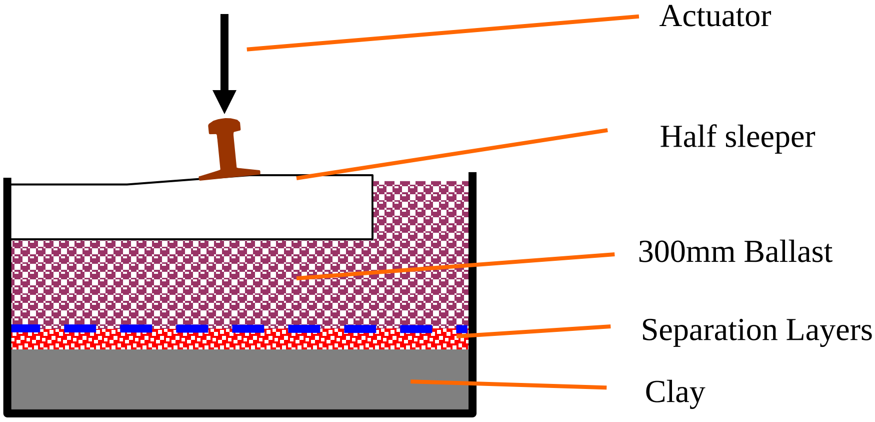
Development of Full Scale Rig

After a considerable time was spent researching the market to find out what new products might be required, GEOfabrics invested in a large 6m wide laminating facility which enables virtually any combination of geosynthetics to be laminated together to form a multi-layer multi-function geocomposite. It found itself in the position of having new ideas and being able to produce prototype products, but unable to generate interest within the industry. This was largely due to the difficulties of demonstrating the effectiveness of experimental products under live loading, and the timescale involved in conducting full scale trials. To remedy this situation, the decision was taken to construct a full scale trackbed test facility.

The test rig is illustrated in Figure 3. It consists of a half track panel (i.e. single rail supported on seven half length sleepers) seated on a box measuring 4.5m by 1.5m by 1.0m which contained the trackbed, as shown in Figure 4. The load was applied by three computer controlled hydraulic actuators which could replay real rail traffic loadings of up to ten tonnes, ten times per second. The box was watertight and could therefore be used to examine the effects of poor drainage and high water table. Spray head nozzles were located above the ballast, giving the ability to simulate rainfall.

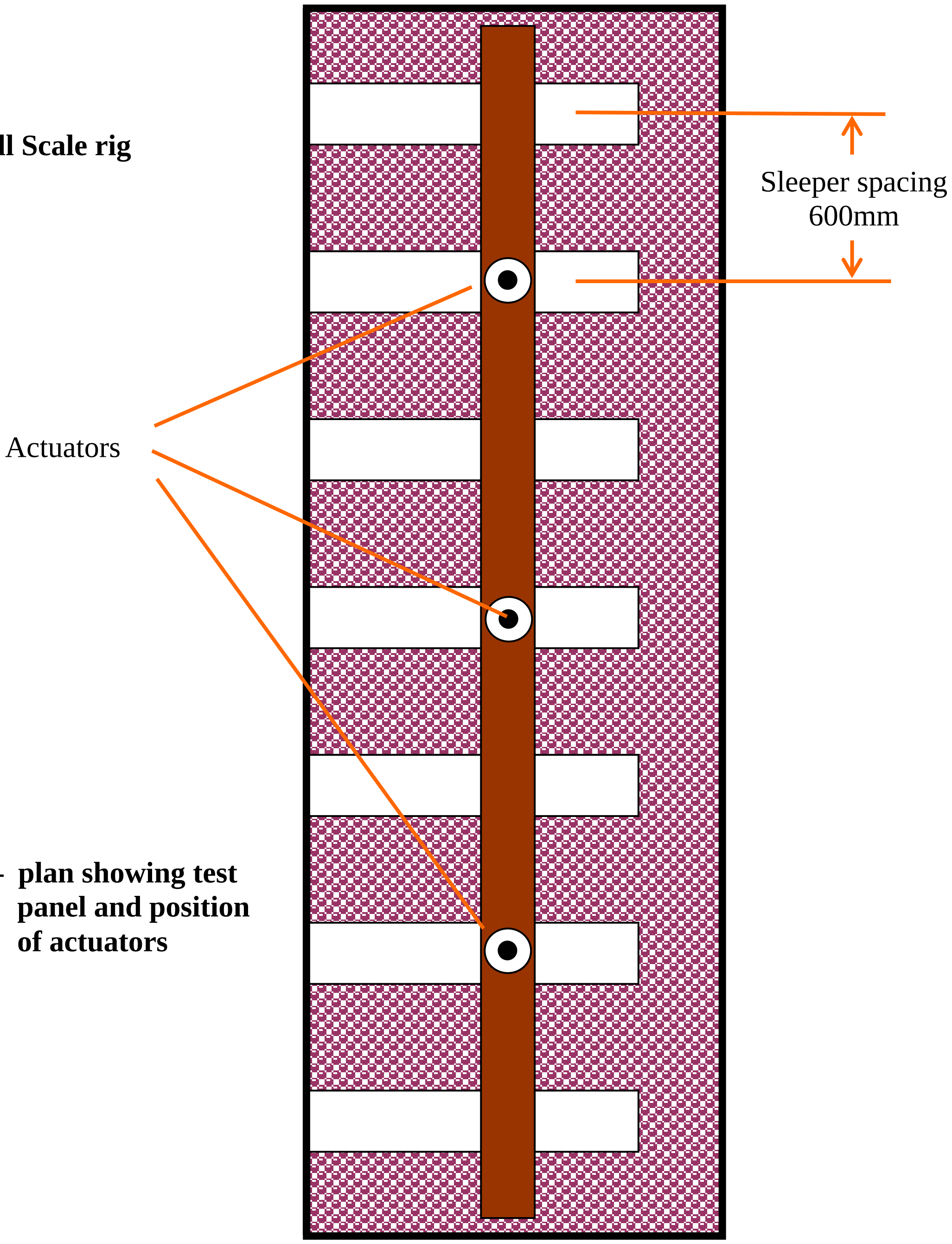
Figure 3 – The Full Scale Rig

The trackbed was founded on a subgrade of 300 mm of reworked London Clay which, in its intact condition, initially had a shear strength above 100kN/m^2. This is a typical poor subgrade which has been responsible for countless subgrade erosion problems on tracks of South East England throughout the history of the railways. The test bed was prepared to replicate as close as possible a natural London Clay subgrade whose surface had been weathered by over a century of rail traffic, i.e. the upper horizons of clay had softened to a “firm clay” consistency. This was done by placing the clay in lumps and compacting using a Kango hammer, then softening by adding water and forking the top surface to a depth of 50mm, until a soft clay consistency was achieved. In the early tests consolidation occurred, which brought the shear strength of the clay surface to between 25kN/m^2 and 50kN/m^2. This remained sensibly constant for the remainder of the test period.



a – section through box showing a typical test set-up

Figure 4 – The Full Scale rig



b – plan showing test panel and position of actuators

Summary of Initial Test Programme

The initial test programme consisted of placing various separation layers between the ballast and clay to assess their efficiency in preventing subgrade erosion. A standard test was devised. The traffic applied represented continuous running of high speed trains. A total of 1million load cycles were applied, giving the equivalent of a years traffic on a typical section of main line track. With poor drainage and inadequate subgrade protection this amount of loading is usually sufficient to generate a severe subgrade erosion problem.

In addition to visual inspection, the effectiveness of each separator was assessed by measuring the sleeper settlements during the tests. Settlement is the key determining factor from the point of view of deterioration of track geometry. Large settlement results in rough track which causes poor vehicle ride and requires additional track maintenance.

The first stage in the programme was to demonstrate the performance of known trackbed constructions, in order to demonstrate that the box tests could adequately simulate real track performance. The initial test was undertaken with no separator in order to provide a control. 300mm of rail ballast to RT/CE/S/006 was placed directly on the clay surface.

Figure 5 shows the results of placing a single layer of non-woven geotextile between the clay and ballast. This has been shown in the past to offer little resistance to subgrade erosion, especially under wet conditions. This behaviour was simulated well by the testing; clay slurry had formed rapidly during the test and had risen to a height of 100mm above the geotextile during the course of the test.

Figure 5 – generation of clay slurry when using a geotextile alone

Tests were undertaken after covering the surface of the clay with a layer of blanketing sand to RT/CE/S/033. This is the traditional way to cure a severe subgrade erosion problem. Figure 6 shows intermixing at the sand/ballast interface after testing with no geotextile present. This is typical of sand blankets on sites with poor drainage. Figure 7 shows a section through a sand blanket with a non-woven geotextile separator after testing. The sand formed a good interface with the clay, with no upwards migration of fines. Rolling back the geotextile confirmed that no fines had risen through the sand.

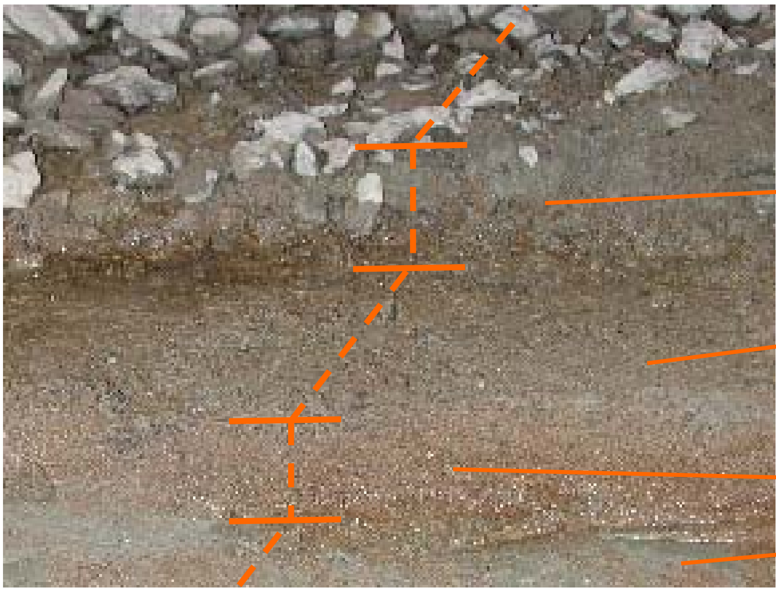


Figure 6 – layers removed to show intermixing at sand/ballast interface when sand used without geotextile separator

Figure 7 – Section through geotextile/sand blanket, showing its effectiveness as a separator

<u>Discussion of Results of Initial Test Programme</u>

Table 2 gives the results of the initial test programme. Settlements before 2000 load cycles were not reported because this would largely eliminate bedding in errors. All of the products tested are in common use in railway trackbed except product D, which was produced for experimental purposes.

The results confirmed that the Network Rail current use of geosynthetics is correct. Where there is a serious subgrade erosion problem there is no commercially available product which can fulfil the function of a sand blanket. In the tests without sand the settlements were generally large. Settlement with no geosynthetic was 40mm and this was reduced to between 21.3mm to 33mm with the products in common use. It must be stressed that none of these products are currently recommended for use without sand where there is a serious subgrade erosion problem. Product D gave encouraging results with a settlement of only 7.1. Further testing will be required to confirm the performance of this specialist composite.

Table 2 – Results of Initial Test Programme

Geotextile Type	Settlement - mm after 10^6 load cycles.	
	No sand	+ 50mm sand
No Geotextile	40	19.5
A - Needle punched staple fibre geotextile	33	-
B - Heat bonded continuous filament geotextile	24.6	7.6
C -Double cuspated impermeable core wrapped in needle punched non woven continuous filament geotextile	27.3	7.9
D – HDPE impermeable membrane monodirectional extruded drainage core wrapped in needle punched non woven staple fibre geotextile	7.1	-
E - Diamond mesh core wrapped in heat bonded non woven geotextile	21.3	10.5
F - Diamond mesh core wrapped in needle punched staple fibre geotextile	-	8.1

Addition of a 50mm thick sand layer reduced the settlement to 19.5mm. No clay had risen through the sand but there was considerable intermixing between the sand and ballast. The inclusion of a geotextile separator above the sand reduced the ballast settlement even further, to an average of below 10mm. The spread of results was small, 7.6mm to 10.5mm, indicating that from a settlement point of view there was little to choose between the different product types.

The Abrasion Resistance Assessment Test

The initial test programme confirmed that the rig simulated subgrade erosion occurring on an unprotected clay surface, and that the current method of treatment used by Network Rail provides the most effective cure. However it was recognised that these conditions did not represent the harshest conditions under which a geosynthetic would be expected to survive. A test was therefore devised to assess the performance of a geosynthetic under similar conditions to those encountered at the base of the ballast above a failed coarse blanket layer when subjected to heavy traffic.

The formation should consist of the existing compacted clay layer (surface level) overlaid by a poorly graded coarse blanket, 75mm deep. The grading was chosen to represent a coarse crushed stone blanket, as follows

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Sieve Size mm	%age passing
37.5	100
28	70
20	50
14	32
10	20
5	10
1.18	5
300µ	2

Such blankets are frequently found to have failed and resulted in subgrade erosion. Ideally it would be desirable to place a geosynthetic layer above this type of blanket to enhance its filtering/separation abilities, but the geosynthetic would need to be able to resist abrasion under these conditions. The chosen grading therefore includes sufficient coarse particles to ensure that abrasion will take place, while providing some fines that would assist in forming a graded filter against the base of the geotextile.

At the time of writing only the first test had been completed. The objective of this test was to demonstrate that subgrade erosion would develop under this type of blanket and to observe the abrasion resistance of three different non-woven geotextiles under these conditions. Products A and B (see Table 2) were tested together with a third, a needle punched, continuous filament heat treated geotextile referred to as Product G. All of the geotextiles tested had a weight of approximately 400g/m^2. A test sample 1.5m long was used in each case, each effectively covering a third of the blanket in the box.

The blanket was saturated with water with the water level maintained at a height of 25mm above the base of the ballast. A dipstick was placed at one corner of the box to observe the rate at which slurry was generated. After 100,000 load cycles the slurry was observed to have reached the top of the sub-ballast layer. The test was continued to 2 million load cycles, thus simulating two years traffic.

On completion of the test excess water was permitted to drain from the box. The track panel and ballast were then removed, taking care not to cause additional damage to the geotextiles. The slurry had risen approximately 50mm into the ballast above the geotextiles, as shown in Figure 8. From an initial visual inspection there was no obvious difference in the ability of tested geotextiles to hold back the slurry. However, after washing the fines from the geotextiles it became clear that considerable damage had been caused, particularly to Product B.

Figure 8 – Uncovering geosynthetics after completion of attrition test.

Assessment was made by measuring the area of the holes in each geotextile. A piece of graph paper, area 124,800mm^2 was placed under each geotextiles in the worst area of damage, which appeared to be in the position beneath the end of a sleeper. Holes were marked by tracing with a soft leaded pencil onto the paper behind. Measurements were made of the area bonded by each pencil mark in turn and the total area calculated in each case. Table 3 gives the results of the tests.

Geotextile	No of Holes	Area of Holes mm^2	%age of test area
Product A	6	8	0.01
Product B	67	1133	0.91
Product G	10	104	0.08

Table 3 – Measurement of Area of Holes in Geotextiles after Testing

It is clear from the above that geotextile type is very important from the point of view of abrasion resistance

CONCLUSIONS

It has been demonstrated that the full scale rig can provide a repeatable test that allows trackbed loading condition under severe operating conditions to be assessed.

The initial set of tests on exisiting geosynthetics used in trackbed has shown that they reduce subgrade erosion to varying degrees. At present a sand/separator combination remains the best solution. However some very encouraging results were found from a specialised geocomposite which, if successful, could obviate the need for expensive sand solutions. Further testing is required to verify this result.

Conditions beneath a trackbed are more aggressive than first thought. After a relatively short time some geosynthetics can be very badly damaged through abrasion. The test rig has been a useful tool to show the limiting conditions for each geosynthetic type and agrees with and extends work of McMorrow on his small scale rig.

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