Synthetic replacement for sand-blankets to prevent pumping failure

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ABSTRACT: This paper describes the development process undertaken to produce a lightweight, geosynthetic filter to replace a sand-blanket used within trackbed as a method of preventing and solving the subgrade erosion problem known as ‘pumping’. The issue of ‘pumping failure’ is examined, with an explanation of the cause and effect, as well as the various methods that have been tried as a means of tackling the problem.

The development program is then explained, including the design and construction of a full scale trackbed test facility that simulates real conditions in the harshest of environments. There is some discussion relating to the project deliverables and methodology used to test and prove the functionality of proposed materials. The materials selection process is discussed, with some explanation of the way in which each component within the geocomposite was selected and evaluated.

The movement from laboratory trials to full scale use is explained, with some evaluation of the field use and the scope for further development

1. INTRODUCTION

Geosynthetics have been employed to perform a number of functions in track construction and rehabilitation for almost half a century with varying degrees of success. When properly specified and installed, the use of geosynthetics has been proven to significantly enhance the performance of the trackbed in a number of ways, often reducing maintenance costs and increasing the lifetime of the design.

There are four principle functions (see fig.1) that geosynthetics fulfil when they are used within and beneath and around ballast and sub-ballast layers: separation, filtration, drainage and reinforcement/stabilisation (Pimentel, Bathurst, & Palmeira). The functions of separation and filtration are often considered as singular and for the purposes of this paper we will focus on this.

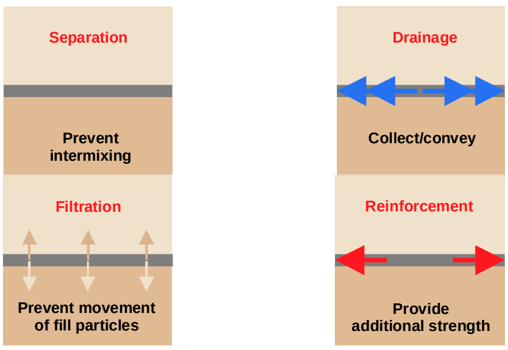

Figure 1: Principal Geosynthetic functions in rail

The introduction of geosynthetics for use below track precipitated as an indirect consequence of a transformation in maintenance techniques from a labour intensive technique to the employment of automated mechanical equipment and the requirement for the installation of deep ballast layers. Faults in track geometry were previously corrected by the manual removal of ballast which did not necessitate the disturbance of deep, well consolidated lower ballast layers. Over time, lower ballast layers would break down considerably, retaining granular characteristics and enabling natural filtration between the ballast and the clay subgrade. The use of automated equipment and this installation of deep ballast layers resulted in the removal of this well graded granular layer and a consequential lack of effective filtration.

The removal of this well graded subgrade precipated rapid subgrade errosion pumping failure (EPF), this being the migration of slurried clay into the overlaying ballast. This migration occurs when cyclic loading on ballast in conact with a clay subgrade which is abraded and when mixed with water is pumped upwards. This results in a failure in ballast performance and track modulus and consequencial reduction in bearing capacity. Figure 2 shows a severly failed subgrade.


Figure 2: Severe subgrade erosion


Figure 3: Sand formation layer

The way in which this issue was tackled in the UK was to apply a layer of compacted sand of a thickness of between 2-300mm. An assortment of sands and gravels were employed, with varying success, until ultimately a grading envelope was established with the correct particle size distribution necessary to prevent the upward migration of fines. (RT/CE/S/03, 1998).

The commercial availablity of geotextiles in the mid 1970's presented the promise of replacing the granular layer as an effective means of preventing errosion pumping failure. However, it quickly became evident that there was no geotextile that could effectively function as a slurry filter. Testing on a number of geotextiles by the British Rail Board (BRB) soil mechanics section found that slurried London clay could pass easily through available fabrics (Ayres, 1986).

The installation of a sand blanket having the correct proportions of fines was proven to either treat an existing slurry problem or prevent one from developing. It achieves this by filling in all of the depressions in the surface of the exchavated formation, i.e. it conforms to the shape of the ground (see fig.3). This was recognised as being fundamentally important because it had been identified that the development of a slurry can be trigered in small voids which become filled with water, causing localised softening and the subsequent formation of slurry, which is then pumped out under pressure of the passing of a train.

Although a compacted sand layer established itself as a very effective as a means of preventing slurry migration, it was not, conversely, popular with renewals engineers. The use of a sand blanket necessatated the need for large volumes of excavation which required additional trains to remove spoil and deliver new materials. The process is very time consuming and consequentially very expensive. It was therefore desirable to find an effective replacement.

2. The Use of Geosynthetics in UK Rail

Research into the use of geotextiles showed a clear benefit in their use in enhancing the performance of existing trackbed layers, or significantly reducing the required depth of construction. Geotextiles were shown to be effective as filter/separators when used between non-cohesive soils where the filer function was simply to allow the passage of water and to separate fines. The benefit to the use of geotextiles when used in combination with a sand filter also became evident; the penetration of the sand blanket by the clay particles was seen to be limited to approximately 20mm. The remaining depth of 180mm was to ensure that the maximum thickness was achieved throughout and to provide for some sacrificial material on the upper surface in the absence of a separator. Reports from the performance of site trials undertaken in the 1980's (Sharpe,1988) show that the sand blanket could be reduced to as little as 25mm with the inclusion of a geotextile seperator.

Although they could not indefinitely prevent it, geotextiles were considered to delay the onset of slurry in some circumstances, and the belief was that they could be used as a matter of course to delay the need to install a complete sand blanket.

McMorrow (1990) reports on a series of tests undertaken on geotextiles in a pulsator apparatus. Tests on an assortment of nonwovens were conducted to examine the ability of a geotextile to prevent the migration of slurry into ballast. The tests involved a 200mm diameter geotextile specimen being placed onto a hard clay subgrade in a sealed container and then overlaid by lightly compacted gravel, water was added simulate poor drainage and a pulsating load was applied.

The testing showed that mechanically bonded staple fibre nonwovens performed better in preventing the migration of slurry into the ballast layer. It was concluded that the stiffer heat bonded nonwovens were not able to effectively conform to the underlying formation as a result of their inherent rigidity, and thus acted as an abrasive thereby attributing to the formation of the slurry. The report concluded that preference should be given to more flexible filters when choosing between geotextiles where other attributes are equal (e.g. Abrasion resistance, filtering ability).

McMorrow makes a clear distinction between separation and filtration in this application. The word 'separation' is used to describe the process whereby a clay subgrade is prevented from pumping into the ballast layer. It is stated that this separation could depend on the ability of the geotextile to provide good drainage, to spread the applied load. It could also depend on whether a geotextile can filter out sufficient large particles from the parent material. Filtration is the name given to the second process, however separation is considered to be the global result. The tests did not identify a geotextile that was able to fulfil this 'separator' function by effectively filtering the underlying clay formation.

Following on from this it should be noted that British Rail also used impermeable membranes as a method of preventing the migration of slurry. This process, known as waterproofing, is no longer used as it is seen as ineffective for a number of reasons. Impermeable membranes do not allow for the desiccation of any underlying slurry, and thus there is a consequential reduction in trackbed quality. The presence of slurry, can reduce track modulus even if it has not risen through the ballast. Subsequently, the use of impermeable membranes is not permitted for use below ballast in UK rail.

Selection of geosynthetics within Network rail is now standardised, whereby following a site investigation an appropriate product is selected based on a table of accepted mediums. Four main classes can be identified:

- A Standard geotextile separator,
- A robust geotextile separator,
- Geogrid reinforcement,
- A geogrid/geotextile composite.

A standard geotextile is used either in combination with a new sand blanket or where there is an existing good quality formation with a small percentage of coarse particles, i.e. less than 10% by weight <14mm. (see fig 4)

A robust separator is used in an existing formation where there is a larger percentage of coarse particles, i.e. greater than 10% by weight >14mm. It should be noted that the current practice for a robust separator is to use a 10mm aperture plastic mesh sandwiched between two standard separators (see fig 5). I believe that this product category was originally intended to act as a drainage medium rather than a robust separator and that this is not the most effective construction for the application; the development of a robust separator should be investigated further with a more specific objective in mind, this could provide potential material savings.

A geogrid/geogrid textile composite is used to prevent the movement of ballast over soft ground (see fig 6).

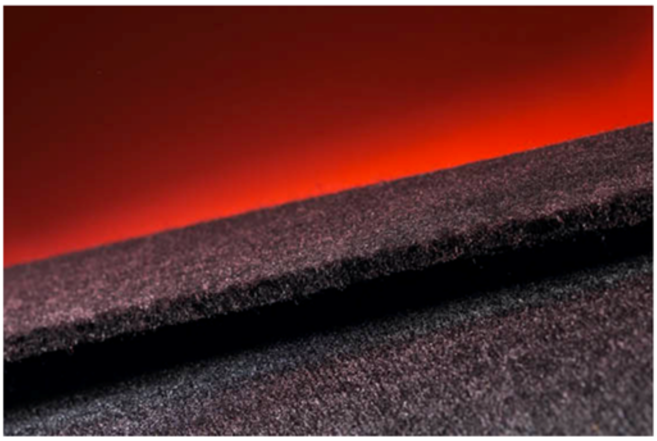

Figure 4: Standard geotextile separator

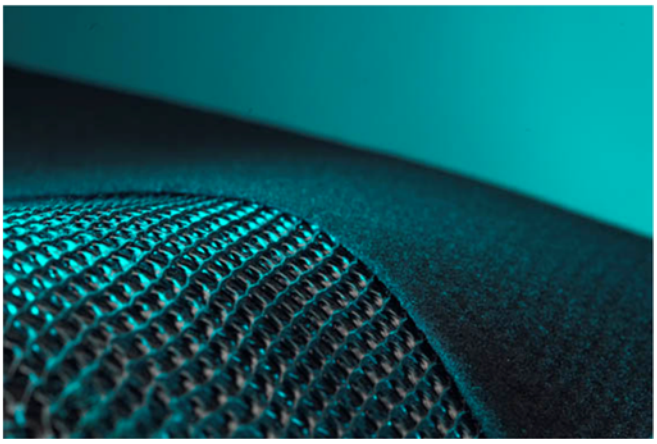

Figure 5: Robust separator

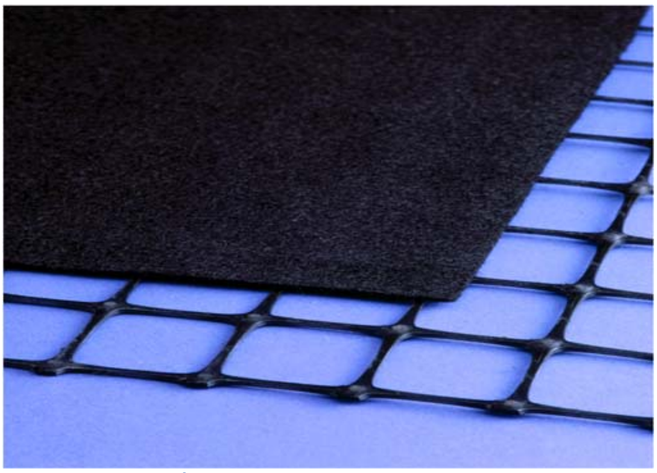

Figure 6: Geogrid / Geogrid Composite

For many years, the standard practice in the UK was to install a sand blanket where there appeared to be a subgrade erosion problem taking place, sometime even as a precautionary measure. The standard practice became a combination of geotextile separator with a 100mm sand blanket layer.

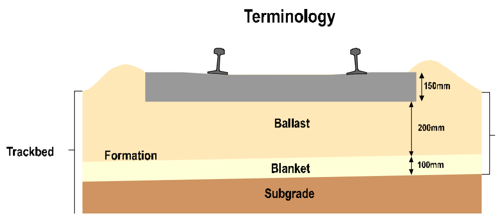

Figure 7: Current trackbed layout

The long term aim, however, always remained to find a geosynthetic that could completely replace all of the functions of the sand blanket. From the research that had previously been undertaken, it was clear that any geosynthetic alternative would need to fulfil the following criteria:

- It must not permit the upward migration of clay fines
- It must conform to the excavated formation thereby preventing subgrade erosion.
- It must be durable to the dynamic environment encountered below ballast for the full duration of the required design life.
- It must allow for the desiccation of existing slurry – i.e. it cannot be an impermeable barrier.

3. The need for accelerated – full scale testing

GEOfabrics Limited, a UK manufacturer of geotextiles and geocomposites recognised that if a solution was to be developed, a full size test facility would be required that was capable of generating subgrade erosion and then allowing potential solutions to be examined. The company had previously purchased a small test rig from Scientifics in Derby, however, it was felt that to be confident of the success of any results, a much larger facility would be required that was able to replicate conditions much closer to a real trackbed. The smaller facility would not however, become redundant, it would act as a method for a quick assessment of ideas before the larger facility would be utilised.

The project deliverables for the large rig were:

- It must have a sleeper to ballast ratio to that of live track.
- It must have the ability to replay real traffic loading simulations and progress them along the line.
- It must be able to monitor track modulus and position accurately.
- It must be able to add water and maintain a water table within the test bed.
- It must be truly representative of live track.

Based on these deliverables, designs were drawn up and construction was undertaken over the summer of 2001.

The completed facility comprised a 4.5m x 1.5 tank deep enough to accommodate 200mm subgrade, 300mm ballast, 7 half width sleepers and a length of rail. The tank is watertight, with drainage points available at set levels facilitating the ability to examine the effect of poor drainage and a high water table. Spray head nozzles were located above the ballast, giving the ability to simulate rainfall under controlled parameters.

Figure 8: Large rail rig

Load on the rail is applied via the use of three computer controlled hydraulic actuators, which have the ability to replay complex loading profiles. The loading profiles that were used within the test were based on curves derived from a research study in the United States which examined theoretical maximum line speeds on a perfectly straight track. The loading curves that were generated had three parts to their profile; the first part is the preceding increase in load as the wheel leaves the previous sleeper, but prior to it reaching the sleeper being monitored. The main hump occurs when the wheel passes over the sleeper and the last occurs when the wheel leaves and passes onto the following sleeper. This loading profile is then progressed along the line by introducing a time delay between the profiles. This time delay determines the simulated train speed and the frequency of the wave allows accelerated testing to be conducted (see fig.8). Deviations and combination of the profile shown in figure 8 are available to represent differing axel loadings when desired.

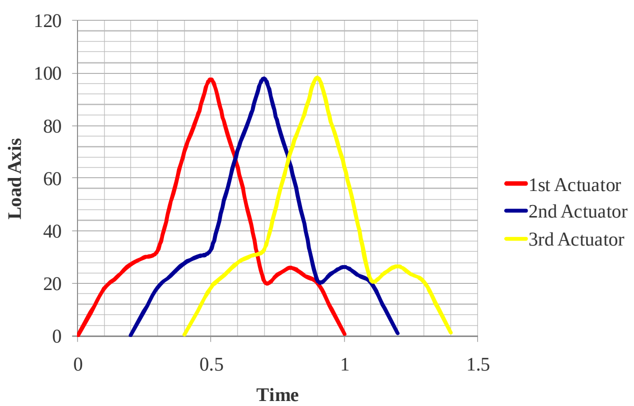

Figure 9: Loading profile

Following completion of the facility, a number of work programs were undertaken to investigate the potential use of various geosynthetics in trackbed and their ability to function over time (Sharpe & Caddick, 2001), however the development of a full replacement for a sand blanket always remained a of paramount importance and over the preceding years a number of prototypes were evaluated to varying success.

4. DEVELOPING A GEOSYNTHETIC FILTER TO REPLACE SAND

The continued use of the facility and the proceeding failures allowed us to develop a number of deliverables required of a geosynthetic solution:

- A geosynthetic must act as a filter – it was known that to simply insert a barrier would not allow for the dissipation of pore pressures.
- It must conform to the excavated formation – this is important to prevent localised softening in voids.
- It must be durable to installation and continued use below ballast for the full design life.
- It must be economical and easy to install.

A standard assessment of potential materials was developed, the small ‘derby’ rig was utilised as a means of quickly assessing a theory. Although the small rig was not truly representative of live track, it could give a good indication of potential success or failure, and due to its relatively quick set-up was a useful tool (see fig. 10). The smaller rig could not produce complex wave forms and had a relatively poor recording facility. The load applied on the small rig was at a frequency of 3.2Hz on a sine wave on the following settings: 80% - 4000KG/10% 500KG.

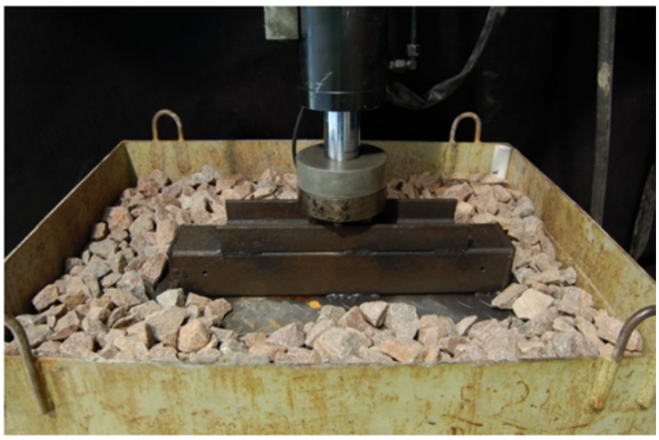

Figure 10: The small 'derby' rig

Although it was known that the inclusion of a sand blanket of the correct grading would prevent the formation of slurry, it would normally be used to cure an existing problem. It was on this basis that the standard test methodology was developed.

We would therefore need to firstly develop slurry conditions.

The development of the erosion pumping failure was undertaken using stiff oxford clay overlaid by 75mm of a 'poorly' graded ballast, to represent an eroded formation.

Sieve size (mm)	% passing
37.5	100
28	70
20	50
14	32
10	20
5	10
1.18	5
300 micron	2

Table 1: Grading of lower ballast

The lower ballast level was overlaid with 200mm of clean, new ballast. The load on the small rig was applied using a steel plate, welded on to give a width equal to that of a full size sleeper. Water was then added and slurry would normally form in approximately 200K cycles. Once slurry had formed, the formation was excavated to the point where a geosynthetic replacement could be installed (see fig 11).

Figure 11: Excavated/failed formation in 'derby' rig

5. THE USE OF MICROPOROUS FILTRATION MEDIA

Based on the above product deliverables, the use of specialised filtration media was investigated. It was well known that standard geosynthetics would not function effectively. Their relatively large pore size values, when compared with that of cohesive soil such as clay would not prohibit any filtration.

Following a number of tests in the small rig, one material stood out from the rest as having significant potential. The filter consisted of an orientated microporous polymeric film with a series of microcells and interconnecting pores. Such films have been used in a number of applications such as high end sports fabrics where restricting the flow of liquid but retaining breathability is important. They are characterised by their relative strength, and their ability to transmit vapour.

In a rail application it was paramount that the film filter could not be susceptible to any type of damage under ballast loading. It was therefore necessary to protect the filter using a high strength nonwoven; part of the development would include engineering a nonwoven that could effectively protect the filter for the full design life.

Following a number of successful tests on the Derby rig, and once the required level of protection for the filter had been established, it was decided that a large scale test would be performed. Testing was undertaken with and without irrigation once the composite had been laid to ensure that water would pass though the material. The prototype material consisted of two thick needle-punched nonwoven geotextiles which sandwiched the microporous filter.

The test methodology on the large rig was largely the same; it involved creating a failed formation and then laying the geosynthetic composite on failed formation (see fig.12, 13 & 14)

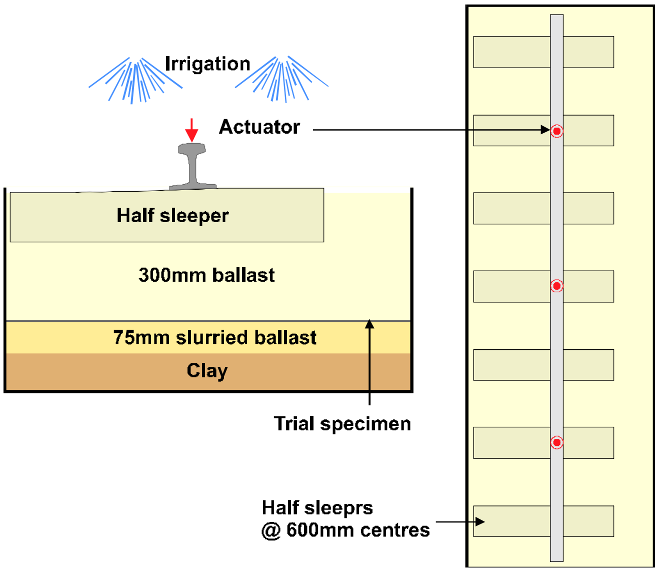

Figure 12: Test set-up on large rig

Figure 13: Failed formation on large rig

Figure 14: Installing prototype composite and ballast

The initial testing on the large rig subjected the composite to 3.7 million cycles prior to any excavation; this simulates approximately 70 million gross tonnes of heavy traffic. The water above the specimen was drained upon completion and the ballast was removed to allow inspection of the upper surface of the composite. There was no sign of slurry above the composite, the water that had collected in the deformations beneath the sleepers was dirty, it was believed that some finer clay particles had migrated through the composite, but the surface felt gritty, indicating that much of the material was a result of ballast attrition (See fig. 14).

Figure 15: The upper side of the composite after 70MGT loading

The composite was then rolled back to reveal the underside. The underlying ballast was full of wet slurry. The slurry adhering to the underside of the composite was stiffer (more viscous) than the slurry in the ballast voids, indicating a lower moisture content. This process had been observed beneath sand blankets in the past. The action of cyclical loading had squeezed the water out of the slurry leading to desiccation.

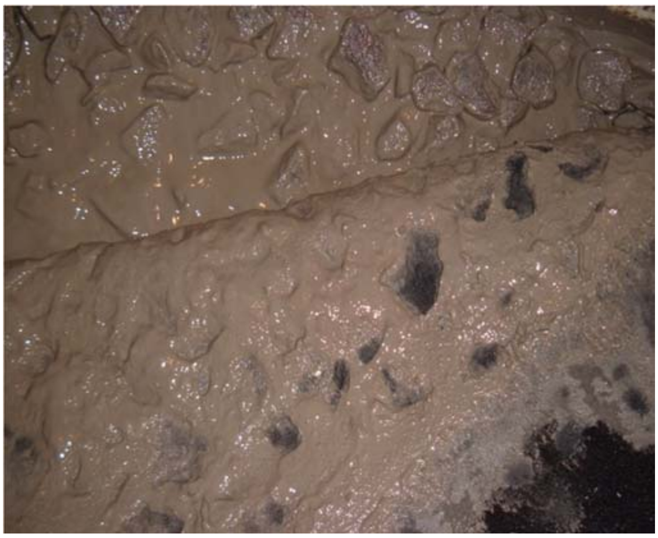

Figure 16: Underside of composite following test

A section of the composite was removed, the slurry was washed away so that it would be inspected for damage. There were indentations caused by the ballast, but there were no holes.

The composite was functioning effectively in preventing the migration of clay into the upper ballast, yet without acting as a barrier. It was evident that we had a geosynthetic filter that could be used effectively with a cohesive soil. The filter facilitates the passage of liquid under pressure, but the pores are such that the passages of fines are prohibited. Without pressure, water cannot pass though the filter, therefore any underlying clay formation will, over time, dry out and have an improved modulus (see fig. 17). Testing was continued to 10 million cycles (approx. 190MGT of traffic) without any sign of degradation to the material or passage of slurry. Following the 10 million cycles, the clay showed a further reduction in moisture content.

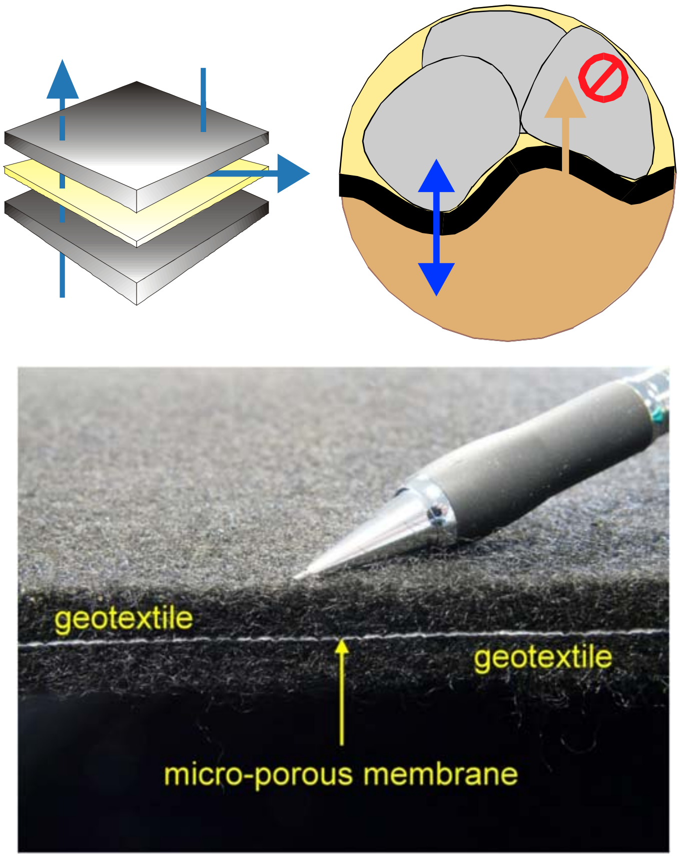

Figure 17: Geocomposite filter

6. CONCLUSION

A composite has been developed that can effectively used as a formation treatment to prevent erosion pumping failure.

The material has met and exceeded its original deliverables:

- It has been demonstrated to function effectively following 190MGT of trafficking.
- By allowing pore pressures to dissipate under loading, it encourages any existing slurry to become stiffer – improving the quality of the formation.
- It's flexibility would allow it to be used in conjunction with a geogrid without affecting the grids ability to interlock.
- Site use has confirmed that the composite is much easier and more cost effective than a traditional sand blanket. In some instances the number of required positions to complete works halved.

The composite received Network rail product acceptance in March 2010 and has since been used on a number of sites across the UK. Use by Network rail over a 12 month period is estimated to translate a £1.5 million when compared to the previous use of a traditional sand blanket.

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