THE DEVELOPMENT OF A GEOCOMPOSITE TO PREVENT MUD PUMPING

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ABSTRACT

In 2010 GEOfabrics launched a new anti pumping geocomposite in the UK, which could be placed directly on the sub-grade or on a failed sub-ballast and prevent the development of mud pumping.

Subgrade erosion (mud pumping) is a serious problem in the UK. The upwards migration of fine soil from the subgrade into the ballast can significantly reduce the life of the ballast, typically from an expected 1000MGT sometime to less than 100MGT.

Although the percentage of track renewal sites affected by mud pumping annually is small, typically less than 10%, the renewal costs are proportionally much higher, as they require deep excavation and installation of additional granular layers. The implications of not treating the source of the problems are a potential risk to safety of the line; trackbed failure may occur sometimes a little as 1 year after reballasting.

While the use of an anti-pumping geocomposite does not offer significant savings on material costs, it has been found that the simplified logistics and reduction in construction time typically allow trackbed installation time to be reduced by up to 50%. Alternatively, the length of track that could be treated in a given track possession could be doubled.

This paper summarises the main causes of subgrade erosion. It gives a historical perspective on the identification and treatment of mud pumping problems in the UK. It then outlines the rigorous product development/test program undertaken by GEOfabrics over several years using a full scale track bed load test facility simulating the harshest conditions encountered under a main line railroad. The paper concludes with a case history summarizing performance on one of the first commercial installations.

INTRODUCTION

In the UK the traditionally solution to a severe mud pumping problem would be to place a layer of well graded sand, typically up to 200mm thick, directly on the subgrade before placing new ballast. This was expensive and time consuming, but it provided a permanent solution to the problem.

When geosynthetics were first introduced some 40 years ago it was initially hoped that these could replace the thick layer of sand, but none were found that could successfully prevent the passage of clay particles and at the same time survive in the abrasive environment encountered at the base of a ballast layer. The geotextiles available at the time did however act as a separator between sand and ballast, which allowed the thickness of sand to be considerably reduced. For over 20 years this remained the standard solution for a subgrade pumping problem.

BACKGROUND TO MUD PUMPING IN THE UK

Mud pumping has always been a problem in many areas of the UK, particularly on weakly cemented mudstones or overconsolidated clays. These soils have a high shear strength and as such do not need a deep trackbed to support track loading, yet if unprotected the upper surface degrades easily to a slurry when exposed directly to water.

New ballast has an open texture, which allows free water to come into contact with the exposed formation/subgrade surface. If the old formation is in good condition it will be stable and the new ballast will have a long life. However if the exposed surface contains fine grained particles, these can be readily eroded by the water accumulating in the voids, forming weak, highly mobile slurry. This slurry is then ‘pumped’ up into the overlying ballast by each passing axle load. Contamination of the clean ballast layer by the fine soil particles in the slurry very quickly reduces the load bearing properties of and leads to loss of track alignment in the affected area. Even a small amount of slurry can considerably reduce ballast life. Under extreme conditions the ballast will become unmaintainable within a very short time after installation. Figure 1 illustrates a severely contaminated ballast section as a result of this phenomenon. In this example 200g/sq m non-woven geotextile had been placed over a previously slurried formation in an attempt to hold back the fines, clearly without success. This photograph was taken just one year after installation and the track was already showing clear signs of distress. Figure 2 shows a typical example of severe track misalignment (vertical and horizontal) resulting from a mud pumping failure.

As modern mechanical methods of ballast renewal were introduced in the 1950s, there was growing evidence that deeper layers of ballast would reduce maintenance interval. At the same time there was pressure in some areas to lower track to increase clearances in tunnels and at overbridges. This led to the removal of much of the old well-established track substructure and replacing it with new ballast. In certain areas where the trackbed was very thin, it was removed completely in order to accommodate the required thickness of ballast, leaving the surface of the natural subgrade exposed. In addition to the above, it was also likely that the dynamic loading of the subgrade was exacerbated by the widespread introduction of concrete sleepers.

Figure 1. Ballast Contaminated with Subgrade Fines

Figure 2. Misaligned Track Section Due to Subgrade Pumping

Early Trials of Geosynthetics

Polythene sheet was the first to be used, possibly as early as the 1960's, although no references can be found. It was however clear that polythene could not be used without some protection. By 1980, the standard practice in many areas of the UK was to protect the polythene by placing a layer of sand above and below. The intention of providing an impermeable layer beneath the ballast was to prevent rainwater from reaching the subgrade. However, it was subsequently concluded that the sand alone would be sufficient to protect the surface of the subgrade from erosion; thus rendering the polythene redundant.

With the introduction of geotextiles in the early 1970's, many engineers began to specify and experiment with these synthetic materials to replace graded granular filters in a wide range of civil engineering applications. Early applications were based on manufacturers' claims regarding performance rather than on scientific assessment. Although some claimed that these treatments had been effective shortly after installation, none were found to be sufficiently well documented to warrant critical review.

In 1983 various manufacturers were invited to submit proposals for treatment of a persistent mud-pumping problem in a deep cutting through the Blue Lias geology in the West Midlands. In its intact state Blue Lias varies between a stiff clay and a mudstone. Various geosynthetics and combinations were suggested, including both normal and heavy duty woven and non-woven geotextiles and geogrids. A short section combining a thin layer of sand (average 25mm thick) and a 200g/sq m non-woven geotextile and a geogrid used as a separator was also included. Trial pits excavated three years after installation showed that the only section to have prevented subgrade erosion was the sand/geotextile/geogrid combination (see Sharpe, 1988).

It was concluded that although geotextiles can function very effectively in separating and filtering dissimilar soil/rock materials, they are of limited usefulness in preventing the migration of very fine (clay) particles. This is due to the relatively large pore size of geotextiles, typically 40μ compared to clay particles, typically <2μ. This has been borne out by experience; geotextiles placed either adjacent to a clay subgrade or on a poor, previously slurried formation are almost completely ineffective. It was concluded by various researchers that geotextiles alone are not capable of replicating the separation and support provided by a degraded deep ballast layer or a graded sand blanket (Ayres, 1986; McMorrow, 1990).

It was also hoped that geogrids might address subgrade erosion by reducing shear strains at the base of the ballast, but early trials showed that they had no significant effect (Sharpe, 1988)

As a result of these trials it was concluded that the most cost effective treatment available was to place sand directly over the subgrade, then use a geotextile as a separator between sand and ballast, thus allowing the thickness of sand to be reduced considerably. At that time time it was considered impractical to lay 25mm of sand, so the standard solution became 100mm of sand in combination with geotextile.

The way in which sand works is considered to be as follows:

- the grading of the sand used is specified to include sufficient coarse particles to ensure its resistance to deformation.
- it forms an effective "filter" allowing water to pass freely while retaining fine soil particles(observations have shown that clay particles penetrate only a few mm into the sand layer; the remaining sand is unaffected)
- loose sand readily conforms to irregularities in the subgrade such that no voids exist which may encourage the development of slurry.
- while sand prevents the upwards migration of slurry into the ballast it does not necessarily stop the generation of slurry at the clay surface immediately or remove the slurry from the voids of the residual sub-ballast. Instead, the general upwards flow of water under traffic promotes desiccation (and associated long term strength gain) of the subgrade.

On the basis of the above experience the first successful anti-pumping geocomposite, Geosand, was launched in 2007 (see Li et al, 2007, Barker & Sharley, 2009). This consisted of an 18mm thick layer of sand, bound with latex, with a needle punched separator and fine geosynthetic mesh on its upper surface. The product was available either in tile form or in a short roll. While completely successful at controlling subgrade erosion, it was found to be difficult to handle as a result of its weight.

EVALUATION OF ANTI-SUBGRADE PUMPING TECHNIQUES AND MATERIALS

Experience and research related to subgrade pumping problems led researchers to develop a list of criteria required for any proposed solution. It was understood that a geosynthetic must provide the same benefits as a sand blanket while being economical and easy to install. It was also understood that the development process could not rely on full-scale field testing. Such full-scale testing is time consuming, expensive and subject to significant random variation. In order to develop, test, evaluate, refine and retest such a product, it was concluded that laboratory or bench scale testing device would be required during the initial stages of development.

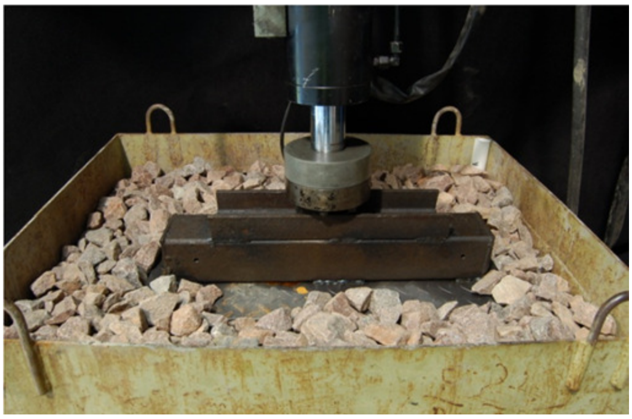

Figure 3. Half-Scale Test Rig

Small scale laboratory test rigs such as that shown in Figure 3 is particularly useful for rapid assess to use in development efforts. This rig models the performance of a sleeper, ballast and clay subgrade combination at realistic loads. While this rig is useful for preliminary evaluation of the potential of new “concept” geocomposites to address subgrade pumping, it does not include the effects of shear stress reversal between sleepers which occurs under a moving load. In order to fully demonstrate the properties of a new product and reduce the need for site trials it is important to undertake testing at full scale in a rig that can simulate a moving load.

In 2001 a new full scale test rig was installed, as shown in Figure 4. It consists of a half-track panel (i.e. single rail supported on seven half-length but otherwise full dimension sleepers) seated on a box measuring 4.5m by 1.5m by 1.0m deep which contains the track bed.

The new rig was:

- large enough to construct a full scale trackbed and subgrade
- capable of operating in an indoor, controlled environment;
- capable of replicating real traffic loading simulations and progression;
- capable of accurate, real-time monitoring/recording of track position and modulus; and
- able to model various rainfall and water table conditions effectively.

Figure 4. Full Scale Test Rig

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 are located above the ballast, giving the ability to simulate rainfall. Load is applied by three computer controlled hydraulic actuators to apply real rail loading profiles up to ten times per second. Introducing a time delay between the profiles simulates a rolling load. This simulated a maximum axle load of 20Tonnes passing at a maximum frequency of 3Hz.

An extensive program was first undertaken to assess whether the behavior of trackbed in situ could be reproduced in the new test facility (see Sharpe & Caddick [2004]). The first stage was to confirm that the rig could simulate slurry development on an inadequately protected subgrade. A conventional sand blanket was then installed over the slurried subgrade to check that the performance in the lab matched the observed behaviour in situ. The new rig was then used to assess the damage caused to geosynthetic layers by abrasion.

Test Criteria for Evaluation of Anti Pumping Characteristics of a Geocomposite

In order to assess the ability of a trial geocomposite to resist the transmission of clay slurry it was necessary to develop conditions in the base of the test rig that simulated a failed sub-ballast layer. This was done as follows:

- the subgrade was a remoulded firm/stiff Oxford Clay (typically 80% clay sized particles - <2μ). This is considered to be one of the most erosion susceptible soils.
- a 275mm thick layer of open graded ballast was placed directly over the unprotected subgrade. Water was added to the box such that the water level was maintained 50mm above the clay surface. Experience has shown that 200,000 cycles of maximum load would be required in order to generate sufficient slurry.
- Once slurry had formed, 200mm of ballast was excavated to reveal a slurried sub-ballast, ready for the trial geosynthetic to be installed (see Figure 5). This condition represents the harshest environment under which any geosynthetic could be expected to experience in a track situation.

Figure 6 show the test set-up for assessing the performance of trial geocomposites. The first material to be trialed under these harsh conditions was a conventional 400g/m^2 non-woven heat bonded geotextile, in order to replicate known performance of a conventional geotextile. The water level was maintained at 50mm above the level of the geotextile. 1 million cycles of the maximum load were then applied. As expected the slurry continued to rise in the ballast, appearing not to be slowed by the geotextile. Figure 7 shows the results as the end was removed from the rig.

On the basis of the above test it was concluded that the success criterion for adequate performance of an anti-pumping geocomposite would initially be a visual assessment of whether slurry was retained.

Figure 5. Failed Formation (pre-test)

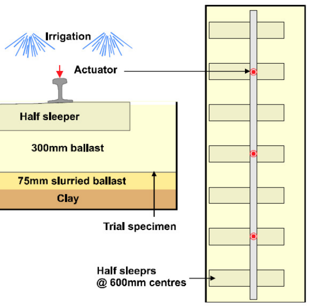

Figure 6. Test Setup Schematic

GEOSYNTHETIC MICROPOROUS FILTER AS AN ANTI-PUMPING SOLUTION

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. It was determined that the development effort and large scale testing regime would be centered on this type of filter media.

This type of filter has been used in a number of applications where restricting the flow of liquid but retaining breathability is important. They are characterized by their relative strength, and the ability to transmit vapor. However, the relatively thin depth profile of this type of film was obviously not capable of surviving the installation and operation stresses of a heavy rail environment intact. It was therefore necessary to protect the filter using a relatively thick, high-strength nonwoven geotextile. Product development included selection of a suitable non-woven geotextile that could effectively protect the filter through installation and the full design life of the product. Following a number of successful tests on the small rig, and once the required level of protection for the filter had been established, it was decided that a program using the large scale test would be performed.

The prototype material consisted of two thick needle-punched non-woven geotextiles which sandwiched the microporous filter. The test methodology on the large rig was nearly the same as the early phase.

Figure 7. Failed Geotextile Separator After 1 Million Load Cycles

Initial testing on the large rig subjected the composite to 3.7 million cycles prior to any excavation; this simulates approximately 70 million gross tons of heavy traffic. During the test water level was maintained at 50mm above the geotextile surface. 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 but the water that had collected in the deformations beneath the sleepers was dirty. Initially, it was believed that some finer clay particles had migrated through the composite. However, further investigation showed that the surface felt gritty, indicating that much of the material above the prototype was the result of ballast attrition, not fines migration (See Figure 8).

Figure 8. Top of Geocomposite After 70 Million Gross Tons of 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 as illustrated in Figure 9.

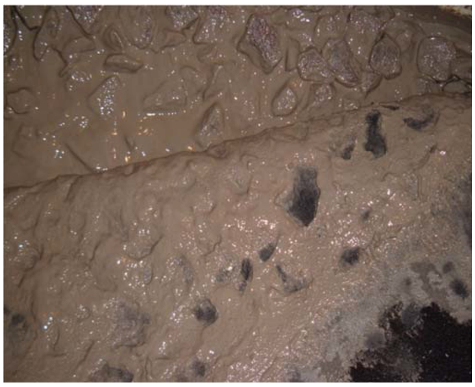

Figure 9. Underside of Geocomposite after 70 Million Gross Tons of Loading

A section of the composite was removed and 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. Importantly, the integrity of the microporous filter was maintained. It was assumed that the geotextile provided sufficient protection by stretching to dissipate point load stress without failure. The composite proved to be functioning effectively in preventing the migration of clay into the upper ballast, yet without acting as a barrier. On the basis of this test it was concluded that the geocomposite performed successfully as a 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.

This work clearly demonstrated that the prototype microporous geocomposite filter is an effective formation treatment to prevent erosion pumping failure. In summary, through the equivalent of 70 million gross tons of full-scale traffic, the product:

- prevented subgrade fines and slurry from migrating up into the ballast;
- facilitated desiccation of the existing subgrade slurry by allowing pore pressures to dissipate under loading improving the quality of the formation;
- proved sufficiently robust to installation and operational damage; and
- is flexible enough to conform to even uneven subgrade formations such that no slurry inducing voids exist.

SUCCESSFUL COMMERCIAL USE OF THE ANTI-PUMPING GEOCOMPOSITE MICROPOROUS FILTER

Following nearly 10 years of development, refinement and testing, a commercial ready geosynthetic anti-pumping solution, Tracktex™, was introduced in the UK in 2010. Figure 10 illustrates the product functions schematically as well as the current appearance.

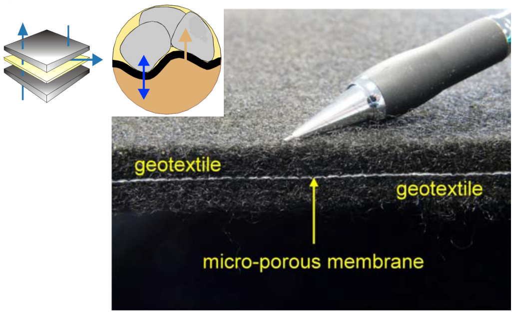

Figure 10. Geocomposite Microporous Filter

The composite received UK Network Rail product acceptance in March 2010 and has since been used on many sites across the UK with over 3,000 rolls supplied to date. The product is light weight, easily handled and installed by unskilled labor, reduces possession time and cuts excavation requirements.

Case History – Bradley Junction – Norther England

In 2009 Network Rail decided that the Up Line through Bradley Junction was life expired and would not be able to carry the proposed increase in annual tonnage from 6 million to 11 million. An investigation undertaken in 2010 (Scott Wilson, 2010) described the track bed as variable, with very dirty waterlogged ballast and evidence of upwards migration of clay formation which had caused track geometry to deteriorate rapidly (Figure 11). The report originally recommended approximately 210 meters of sand blanket to protect the existing formation. The specification for the sand blanket was 100mm sand with a geotextile separator to prevent intermixing with the ballast.

Figure 11. Slurried formation at Bradley Junction, prior to laying Geocomposite Microporous Filter

However, this proved to be a suitable application for the newly developed geocomposite microporous filter which was designated to be installed over areas of previous formation failure instead of the traditional sand blanket/geotextile treatment. In September 2011, Network Rail performed the installation which also included a geogrid placed above the geocomposite filter to reinforce the ballast as compensation for the reduced construction depth over what would have been required if a conventional solution had been applied. The work was undertaken in three consecutive weekends. The decision to use geocomposite microporous filter over the part of the site with formation failure enabled the excavation depth to be maintained constant throughout. Figures 12 and 13 illustrate the installation process and current conditions of the track.

Figure 12. Geocomposite Microporous Filter Installation

Figure 13. Bradly Junction Installation as of Today

The cost of use the geocomposite product was effectively offset and savings realized by the reduced amounts of sand required and a corresponding reduction in excavation. Reduction in installation time also required less possession time required, thus increasing the availability of the railway.

At the time of writing of this paper, the subject area is still performing well and has not shown any signs of continued pumping failure. In recent evaluation of the project (URS, 2013), a series of test pits were excavated to determine the effectiveness of the rehabilitation. As shown in Figure 14, a test pit in the same location at the area shown in Figure 11 (pre-rehabilitation), there is no evidence of subgrade pumping or ballast contamination above the geocomposite microporous filter. The success on this early installation has lead Network Rail to specify geocomposite microporous filter for use in all situations where they would have used a sand blanket/geotextile combination in the past with the exception of high-speed lines. Evaluation for use on lines including high speed corridors is currently underway.

Figure 14. Test Pit at Bradley Junction - After Reconstruction with Geocomposite Microporous Filter

CONCLUSION

This paper has summarized the historical development and commercial use of a geocomposite microporous filter developed to prevent and repair subgrade pumping failure in track bed. The product has shown significant benefit and effectiveness in full commercial installations under both passenger and cargo applications. It is now available free issue to rail engineers for introductory/trial applications and commercially to rail operators worldwide.

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