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Contribution of a geotextile towards the improvement of sub-ballast filtration criteria under cyclic stress pulses

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ABSTRACT

Sub-ballast, which is laid between ballast and sub-grade, prevents the penetration of coarse ballast particles into the sub-grade and the upward migration of wet fine sub-grade materials into the upper ballast layer. In addition, sub-ballast allows dissipation of excessive pore water pressure that develops within a wet clayey subgrade due to the applied cyclic train load. The sub-ballast is generally designed based on the particle size distribution of the sub-grade materials using well known piping and permeability ratios. However, providing graded sub-ballast materials for fine subgrade soils to meet site specific filter design criteria may not always be cost effective. Therefore, alternative methods are to be investigated to solve the filtration problem. Since geotextile is used under the sub-ballast as an effective reinforcement layer, its effect on the improvement of filtration behaviour of sub-ballast materials is worth investigating.

Laboratory investigation was carried out using various opening sizes of geotextile at the sub-ballast-subgrade interface using the cyclic filtration apparatus developed at Monash University. Tests were conducted using a sinusoidal pressure variation having amplitudes of 70-140 kPa and frequency of 10Hz. The piping ratios for the sub-ballast materials were selected to a high value (generally greater than 15) for these tests. Filter performance were assessed based on measured interface pore water pressure, permeability, turbidity of effluent and settlement. This paper will include results of the laboratory investigations where a geotextile filter was included at the sub-ballast-subgrade interface. It was found that inclusion of geotextile significantly improved the performance of the filter when placed over subgrade materials not meeting conventional filter design criteria.

*Keywords: c*yclic stress pulse, filtration, non-woven geotextile, rail track, subgrade, sub-ballast

1 INTRODUCTION

Geotextiles are used to prevent fatigue and deformation of the wet soft subgrade to keep the railway track in fixed geometry. They act as a separator and/or filter when placed between ballast and subgrade of a rail track. Their main functions are to prevent mud pumping, settlement and contamination due to migration of fine particles in the ballast layer or vice-versa. Simulated laboratory investigations of railroad systems have indicated that the application of geotextiles can improve the performance of the system (Saxena and Hsu, 1986). Field tests have also been conducted and the use of geotextiles has been found to be effective in preventing mud pumping (Ayres, 1986; Imbert, 1986). Moreover, Tebay et al. (2002) suggested that the use of a single separator can be sufficient in low rainfall districts.

In this study, a comprehensive set of laboratory tests was undertaken to investigate the effect of a geotextile separator on filtration behaviour of the sub-ballast-subgrade system. Each specimen was tested using sinusoidal stress pulse with a minimum and maximum amplitudes of of 70 and 140 kPa (Haque et al., 2007) respectively. Non-woven geotextiles were selected since they were shown to perform better in relation to soil migration in comparison with other types of goetextiles (Narejo and Koerner, 1992; Rowe and Badv, 1996; Perkins and Brandon, 1998; Srikongsri and Fannin, 2009). Graded sub-ballast materials with a piping ratio (D_{15}/d_{85}; where, D_{15} represents the particle size of sub-ballast (also known as filter) at 15th percentile finer, and d_{85} is the particle size of the subgrade soil (also known as base soil) at 85th percentile finer) of 15, 20 and 30 with a constant uniformity coefficient (D_{60}/D_{10}; where, D_{60} and D_{10} represent the particle sizes of sub-ballast at 60th and 10th percentile finer) of 15 were investigated under sinusoidal cyclic stress pulses at frequency of 10 Hz. A sub-ballast filter with a piping ratio larger than 15 was utilized in this investigation since it had been reported in the literature that a filter with a piping ratio ≥ 15 was ineffective in preventing subgrade-sub-ballast deterioration due to severe erosion (Kamruzzaman et al., 2008). The filter performance was assessed by measuring permeability, turbidity and pore water pressure at a height of 20mm above the filter interface with the change in stress cycles. Average bulk vertical permeability, which is dominated by the low permeability base soil, was determined from the head drop across the test specimen using Darcy's law. These measurements were used to qualitatively assess the migration behaviour of the base soil, where an increase of permeability and turbidity values indicates an increase of particle migration or vice-versa. In addition, pore water pressure data near the interface were used to assess the filter performance (i.e. clogging) and base migration potential. Results of this investigation are analysed and the effectiveness of geotextile inclusion in subgrade-sub-ballast systems subjected to cyclic stress pulses is discussed.

2 LABORATORY INVESTIGATIONS

2.1 Specimen preparation

In this investigation, locally available clayey silt was chosen as a typical base soil while crushed basalt rock of various sizes was used as filter to satisfy the piping ratios of 15, 20 and 30, and uniformity coefficient of 15 (Figure 1). The filter and the base materials were compacted in three layers at optimum moisture contents of 2 and 17%, respectively in a Perspex cylinder of 115 mm diameter and 300 mm height using a metallic tamper to achieve a density of 95% of standard compaction test. In this study, a 70mm thick filter and 50mm thick base were tested. More details on specimen preparation can be found in Haque et al. (2007).

Non-woven geotextiles were sourced based on retention criteria under natural dynamic condition as suggested by Heerten (1982) and the strength requirements from AREMA (2004), as listed in Table 1. The geotextile layer was placed on top of the compacted filter materials before the compaction of the base soil into the filter cell. This simulated the placement of geotextile between sub-ballast and subgrade in accordance with one of the suggestions made by Selig and Water (1994).

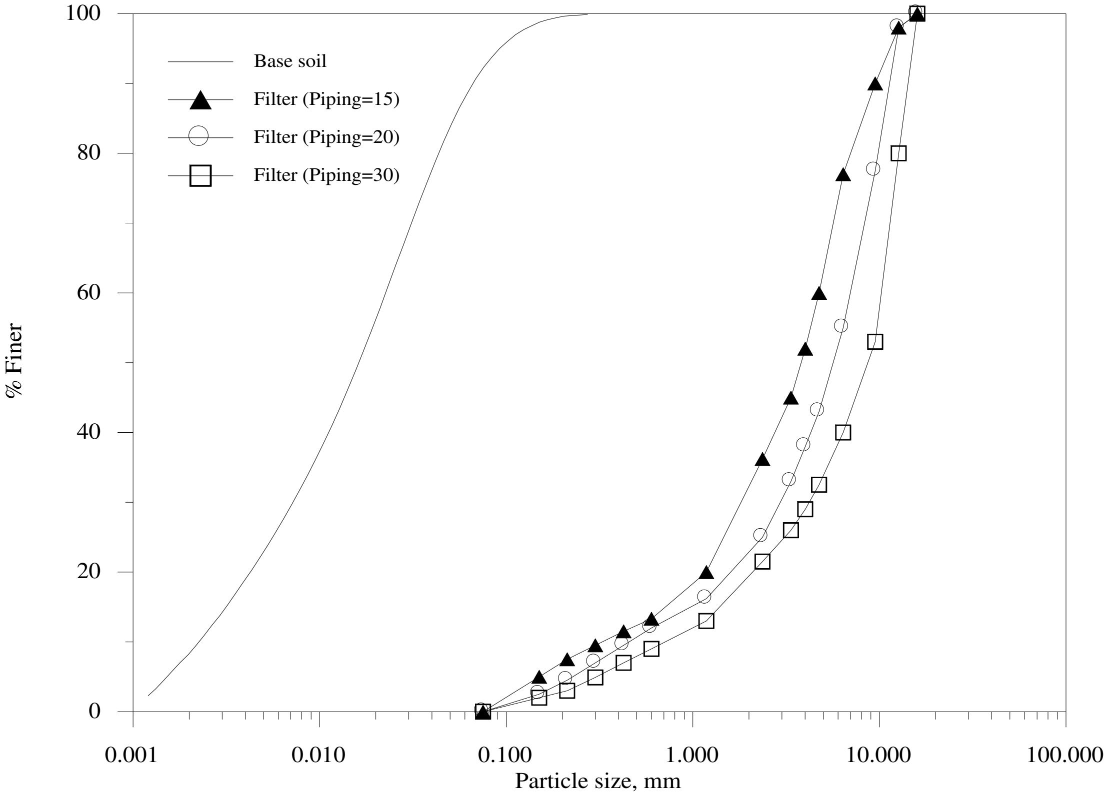

Figure 1. Particle size distribution of base soil and designed filter materials

2.2 Testing program

The cyclic filter test apparatus developed at Monash University (Haque et al., 2007) was modified by installing a pore water pressure transducer (approximately 20mm above the filter interface) to monitor the pore water pressure (u) at the filter interface with the number of load pulse cycles as discussed by the authors elsewhere (Ip et al., 2011). LabVIEW monitoring program was installed to capture the pore pressure variations and other control parameters such as cyclic pressure variations with real time. The cyclic filtration test procedure is described in details in Haque et al. (2007) and the guidelines for assessing the filter performance are given in Kamruzzaman et al. (2008).

Two series of tests were carried out to investigate the filtration behaviour of the sub-ballast-geotextile-subgrade system. In both series, a sinusoidal stress pulse with minimum and maximum amplitudes of 70 and 140 kPa was applied at a frequency of 10 Hz. Series 1 tests consisted of the use of two non-woven geotextiles (i.e., GT1 with O_{90}=0.08 mm; GT2 with O_{90}=0.10 mm), associated with sub-ballast having a piping ratio of 15, to study the effectiveness of the geotextiles on the overall filtration behaviour. In Series 2, GT1 was used to evaluate the performance of sub-ballast-subgrade combinations with piping ratios of 15, 20 and 30 simulating large particle sizes as expected in the recycling process of fouled ballast as filter materials.

Table 1 Geotextile properties* and selection criteria

Geotextile	GT1	GT2	AREMA (2004)	Heerten (1982)
Raw material	Polypropylene (PP)	Polypropylene (PP) & Polyester (PES)	-	-
Mass per unit area (g/m^2)	800	800	-	-
Elongation-longitudinal (%)	60	80	20	-
Puncture strength (N)	8000	3600	355	-
Characteristic opening size, O_{90} (mm)	0.08	0.1	-	≤ 0.1mm
Permeability (m/s)	2.2×10^{-2}	4.5×10^{-2}	-	-
Thickness (mm)	6	5.4	-	-
O_{90}/d_{50}	4.57	5.71	-	< 10
O_{90}/d_{90}	1.18	1.47	-	< 1

(*) Provided by the supplier

3 RESULTS AND DISCUSSION

3.1 Series 1 tests

In this series of tests, two types of non-woven geotextiles (GT1 and GT2) were tested, keeping the subgrade-sub-ballast gradation fixed at a piping ratio of 15 and uniformity coefficient of 15. The opening sizes of the geotextiles (O_{90}) were 0.08 mm for GT1 and 0.10 mm for GT2. During the experiments, turbidity, permeability and pore water pressure (u) were measured with cycles and the results are plotted in Figures 2, 3 and 4. . The turbidity of GT1 system (Figure 2) initially increased up to about 90 NTU and gradually decreased to below 50 NTU at around 400 thousand cycles. Pore water pressure was observed to increase by 10 kPa within the same period (Figure 4). After 400 thousand cycles, the system started to stabilise. The turbidity and pore water pressure gradually dropped to 20 NTU and 15 kPa respectively at 1,400 thousand cycles. The permeability measurement values (Figure 3) were observed to drop to 2×10^{-9} m/s at about 200 thousand cycles and to stabilise at around the same level up to 1,400 thousand cycles.

Similar to GT1 system, the permeability of GT2 system was found to stabilise at around 2×10^{-9} m/s after 200 thousand cycles. Turbidity also followed a similar trend with an increase up to 40 NTU at around 300 thousand cycles, followed by a gradual reduction to 20 NTU at 1,400 thousand cycles. Pore water pressure reduced moderately from 10 to 3 kPa at 1,600 thousand cycles. Although GT2 has a larger opening size, the initial turbidity value is lower, possibly due to the compaction of base soil over the geotextile, which may allow some fine to migrate into the filter before the application of the cyclic stress pulses (Rowe and Badv, 1996). Nonetheless, more base particles were captured by GT1, which has smaller opening size, as evidenced by the weight of geotextile before and after testing (Table 2).

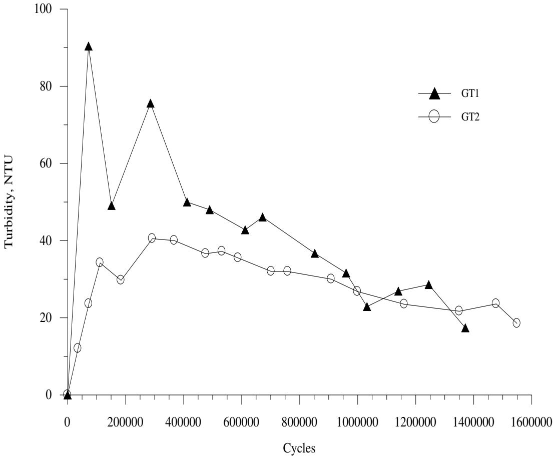

Figure 2. Effect of geotextile pore sizes on turbidity for piping ratio of 15

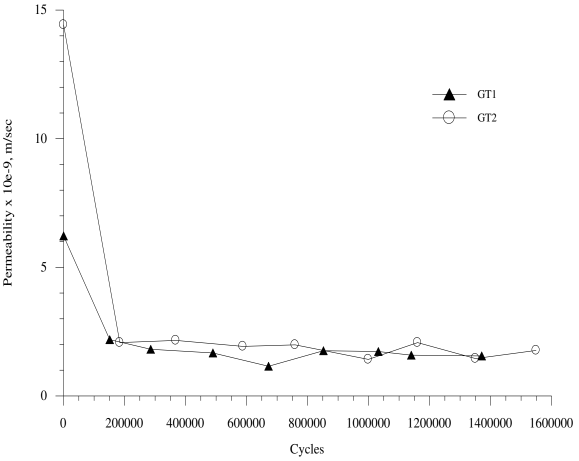

Figure 3. Effect of geotextile pore sizes on permeability for piping ratio of 15.

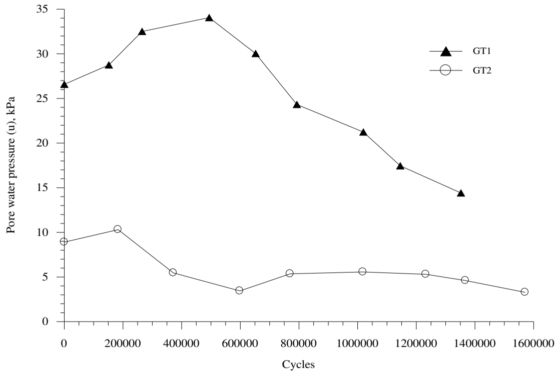

Figure 4. Effect of geotextile pore sizes on interface pore water pressure for piping ratio of 15.

Table 2. Mass of geotextile in Series 1 before and after tests

Geotextile	Before test (g)	After test (g)	Amount of captured particles (g)
GT1	7.39	14.22	6.73
GT2	9.20	13.77	4.57

3.2 Series 2 tests

In this series of tests, a fixed non-woven geotextile (GT1) was placed at the subgrade-sub-ballast interface with piping ratios of 15, 20 and 30, and a uniformity coefficient of 15. The turbidity variations with stress cycles for piping ratios of 15, 20 and 30 are plotted in Figure 5. The piping ratios of 15 and 20 showed initial increases of turbidity up to around 80 NTU at 400 thousand cycles, followed by a moderate decrease to 20 NTU at 1,400 thousand cycles for a piping ratio of 15, and a gradual reduction to 50 NTU at 1,800 thousand cycles for a piping ratio of 20. However for the piping ratio of 30, the trend was very different from the piping ratios of 15 and 20. In the first 200 thousand cycles, the turbidity remained at a very low level, less than 10 NTU, due to the presence of very low amount of fines in the filter which influences initial turbidity values. It then increased to 35 NTU as a result of migration of fine base soil, and stabilised at an average value of 20 NTU at around 1,200 thousand cycles.

The permeability measurements are given in Figure 6, which shows that the values for all three samples were almost identical, stabilising at around 2 x 10^{-9} m/s after 200 thousand cycles, because of the minor losses of base soils observed in all the tests. Despite this, the capture capacity varied, as shown in Table 3. When a geotextile is associated with a coarser filter material, less fine particles are captured. The reason can be identified from Figure 7, which shows photographs of the geotextiles after the tests. More thinning areas can be observed at piping ratios of 20 and 30 due to the coarse filter materials and the application of cyclic loading. The thicknesses of these thinning areas were reduced to around 2 mm for both cases (initial thicknesses of the geotextiles were GT1=6 mm and GT2=5.4 mm). However, these areas of thinning did not show significant effects on turbidity and permeability because the geotextile is sufficiently thick to provide high puncture resistance. It is evident from the laboratory tests that these geotextiles are subjected to possible damage under cyclic load conditions particularly over larger graded materials as represented by piping ratios greater than 15. Thus, higher piping ratios should be avoided for all filter design.

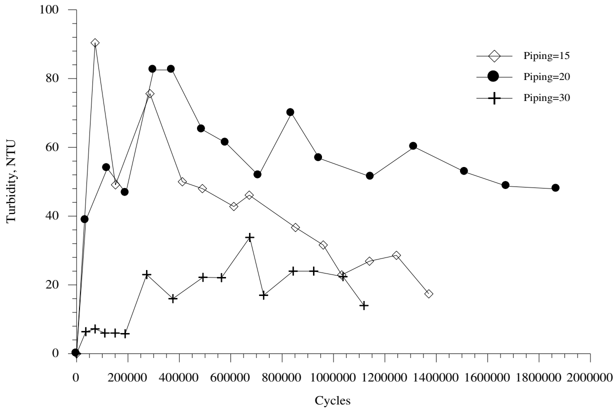

Figure 5. Effect of coarser filter materials on turbidity for GT1 geotextile.

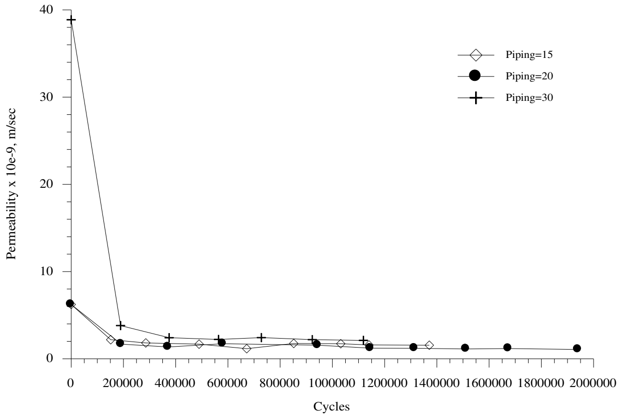

Figure 6. Effect of coarser filter materials on permeability for GT1 geotextile.

Table 3 Mass of geotextile in Series 2 before and after test

Geotextile	Piping ratio	Before test (g)	After test (g)	Amount of captured particles (g)
GT1	15	7.39	14.22	6.73
	20	9.20	13.77	4.57

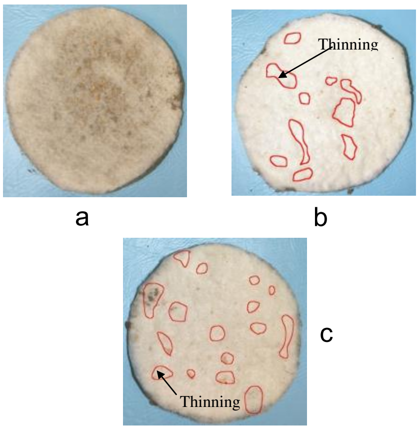

Figure 7. Geotextiles (GT1) after end of cyclic filtration tests with granular filters of piping (a) 15 (b) 20 (c) 30

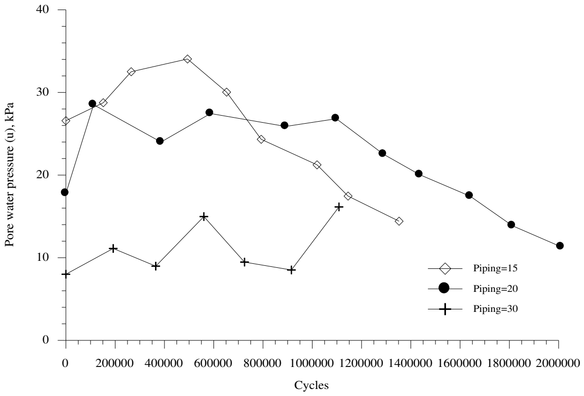

Figure 8. Effect of coarser filter materials on interface pore water pressure for GT1 geotextile.

The measurements of pore water pressures are shown in Figure 8, which shows a peak value of 35 kPa at 500 thousand cycles, followed by a reduction to 15 kPa at around 1,500 thousand cycles for a piping ratio of 15. A similar trend was also observed for a piping ratio of 20. However, after the increment to about 27 kPa at around 100 thousand cycles, the pressure remained at around the same level up to 1,000 thousand cycles, followed by a drop to about 10 kPa at 2,000 thousand cycles. For the piping ratio of 30, the pore water pressures were gradually increased to above 15 kPa at around

120 thousand cycles, but the trend appeared to increase. It is expected that the trend would be similar to piping ratios of 15 and 20, in which pore water pressure increased to a maximum value under cyclic load condition, and then decreased with increasing load cycles (Perkins and Brandon, 1998).

The findings of this study will encourage recycling of fouled ballast with geotextile inclusion as a potential alternative for conventional graded filter materials (i.e. sub-ballast) in track reconstruction works.

4 CONCLUSIONS

A study on the contribution of geotextiles towards the improvement of sub-ballast filtration criteria under cyclic stress pulses was carried out. Two non-woven geotextiles with O_{90} of 0.08 mm for GT1 and 0.10 mm for GT2 were tested. These geotextiles were included in a subgrade-sub-ballast system with a piping ratio of 15, which is considered to be ineffective for the protection of fine base soil by itself (Kamruzzaman et al., 2008). In addition, geotextile over coarse sub-ballast materials as represented by piping ratios of 20 and 30 were investigated to study the effect of coarser particles on the geotextile filtration behaviour. These studies prove that the introduction of a geotextile layer in subgrade-sub-ballast systems with piping ratios larger than 15 can significantly improve the filter performance. Based on the study, the following conclusions can be made:

- Inclusion of geotextile separator at sub-ballast-subgrade interface of a rail track was found to improve the filtration behaviour of sub-ballast materials with piping ratios larger than 15. However, higher piping ratios (i.e. >20) should be avoided since thinning was observed on the geotextiles due to the presence of coarse particles in the filter layer.

- The retention criteria, $O_{90}/d_{50} < 10$, $O_{90}/d_{90} < 1$ and $O_{90} \leq 0.10$ mm, as proposed by Heerten (1982) could be considered as a conservative design criterion for subgrade-goetextile-sub-ballast systems, based on the investigated range of geotextiles.

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