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Effect of Plastic Fines on Drainage Capacity of Ballasted Rail Track

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ABSTRACT: Ballasted tracks are very common in many countries including Sri Lanka due to its low capital cost, high resiliency and high drainage capacity. However, progressive contamination of ballast by plastic fines due to soft subgrade pumping leads to decrease its drainage capacity. In order to study the effect of plastics fines on the drainage capacity of the track, a numerical analysis was conducted using SEEP/W to quantify the drainage capacity of ballast under different levels of contamination. Actual track geometry was simulated and the experimentally derived permeability values were used as input parameters. In this study, the drainage classification chart is proposed based on the maximum permissible rate of rain fall. The track drainage values obtained from this numerical model were then analysed in order to determine the drainage category based on the classification chart.

1 INTRODUCTION

Railway ballast consists of coarse angular aggregates between 10-60 mm in size placed underneath the sleeper. The source of ballast (parent rock) varies from one country to the other, depending on the quality and availability of the parent rock, and the economy. Common ballast materials include Rheolite, dolomite, gneiss, granite, basalt, limestone, and blast furnace slag (Lackenby 2006).

Fig. 1 illustrates the typical cross section of a ballasted rail track. The track structure is subdivided into superstructure and substructure. The track superstructure consists of rail and sleepers while substructure comprises of ballast, subballast (or structural fill) and subgrade. The ballast is one of the most important substructure elements which is contributes to stability and drainage, if maintained properly.

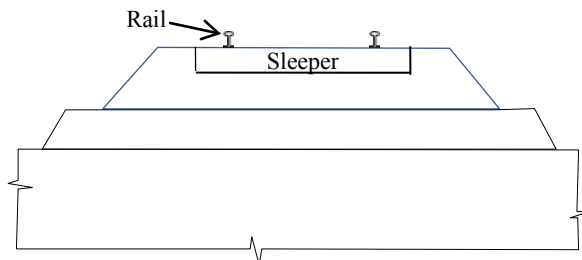


Fig. 1 Typical ballasted railway track cross section.

It is very important to maintain ballast to be relatively clean for serviceability and longevity of track. However, during track operation, fine particles can accumulate within the ballast voids due to: (i) breakage of sharp angular projections (corners), (ii) infiltration of fines from the surface, and (iii) pumping of soft saturated subgrade under excessive cyclic loads (Indraratna et al., 2013). As fouling material occupies the free voids of ballast, it leads to the impediment of drainage capacity of the track.

The majority (around 76%) of ballast fouling originates from the fracture and abrasion of ballast particles, followed by 13% of infiltration from subballast, 7% infiltration from surface, 3% from subgrade intrusion, and 1% from sleeper wear (Selig et al., 1992). In Australia, the intrusion of coal fines and ballast breakage are the major sources of ballast fouling contributing about 70-95% and 5-30%, respectively (Feldman and Nissen, 2002). In low-lying coastal areas where the subgrade is usually saturated, the finer silt and clay particles get pumped up into the ballast layer as 'slurry' under train loading (

Fig. 2), when trains operate in the absence of a properly graded filtration layer or geosynthetics underneath ballast layer (Indraratna et al., 2002 and Selig and Water, 1994).



Fig. 2 Ballast fouling due to clay pumping (Photograph were taken during track maintenance at Ashfield, NSW).

1.1 Assessment of fouling

There are several fouling indices are available for the assessment of ballast fouling. Selig and Water (1994) introduced a fouling index (FI) which is defined as a summation of the percentage (by weight) of fouled ballast passing the 4.75 mm (No. 4) sieve and 0.075 mm (No. 200) sieve.

Feldman and Nissen (2002) introduced Percentage Void Contamination (PVC) to overcome some of limitations associated with FI. The PVC is defined as the ratio of the bulk volume of fouling material to the volume of voids in clean ballast. As the mass based index gave a false quantification of fouling when the fouling material (e.g. coal) had a low specific gravity, this fouling index became more popular in QLD, Australia since the common source of fouling is coal spillage from the coal wagons which transports coal from the coal mines.

$$PVC = \frac{V_2}{V_1} \times 100 \quad (1)$$

where V_1 is the volume of voids in the ballast and V_2 is the total volume of re-compacted fouling material passing through a 9.5 mm sieve. Since the volume V_2 is usually measured after compacting them with standard proctor technique, that does not represent the real volume of fouling that may exist in the field. To overcome this issue, Tennakoon et al. (2012) modified above fouling index by replacing the term V_2 by the real volume of fouling. By substituting relevant geotechnical parameters, they proposed a new fouling index called Void Contaminant Index (VCI):

$$VCI = \frac{(1 + e_f)}{e_b} \times \frac{G_{sb}}{G_{sf}} \times \frac{M_f}{M_b} \times 100 \quad (2)$$

where e_b is the void ratio of clean ballast, e_f is the void ratio of fouling material, G_{sb} is the specific gravity of the ballast material, G_{sf} is the specific gravity of the fouling material, M_b is the dry mass of clean ballast, and M_f is the dry mass of the fouling material. There is a significant variation in the void ratio (e_f), specific gravity (G_{sf}), and gradation characteristics of fouling material, and the VCI can take all these variations into account. In this study, VCI is used to quantify the amount of fouling.

2 LABORATORY INVESTIGATION

A series of constant head permeability tests (Tennakoon et al, 2012) were conducted using large scale permeameter (Fig. 3) designed and built in University of Wollongong, NSW with different levels of fouling to establish the relationship between the void contaminant index (VCI) and associated permeability.



Fig. 3 Large scale permeability test apparatus.

The size of this apparatus is 0.5 m in diameter and 1 m in height. A filter membrane was placed above a coarse granular layer (prepared from coarser ballast aggregates) while still maintaining a free drainage boundary to prevent fouling material flowing out. The thickness of ballast layer in Australian rail track varies between 300 mm and 500 mm. In view of this, 500 mm thick ballast layer was used to determine the permeability of fouled ballast. The test specimen was placed above the filter membrane and compacted in four equal layers to represent a typical field density of 1600 kg/m³. Commercial kaolin (plastic and liquid limits are 26.4 % and 52.1 % respectively) was used to simulate the clay fouling. Predetermined amount of fouling

corresponding to different degree of fouling was mixed with ballast and compacted to gain similar density of ballast, so that the voids of the ballast (V_1) were kept constant throughout the test series.

Fig. 4 shows the variation of permeability of clay-fouled ballast with different degree of fouling. It is evident that at low degree of fouling (i.e. $VCI < 5\%$), the overall permeability of ballast was relatively unaffected. This is because at low level of fouling, plastic fines (clay) only creating thin films of coating around ballast particles without reducing the voids of ballast significantly. Then beyond this level of fouling, the permeability is gradually decreasing until it reach closer to VCI of about 90 % as the considerable amount of ballast voids are now occupied by the plastic fines. Beyond this the permeability of fouled ballast was almost the same as plastic fines.

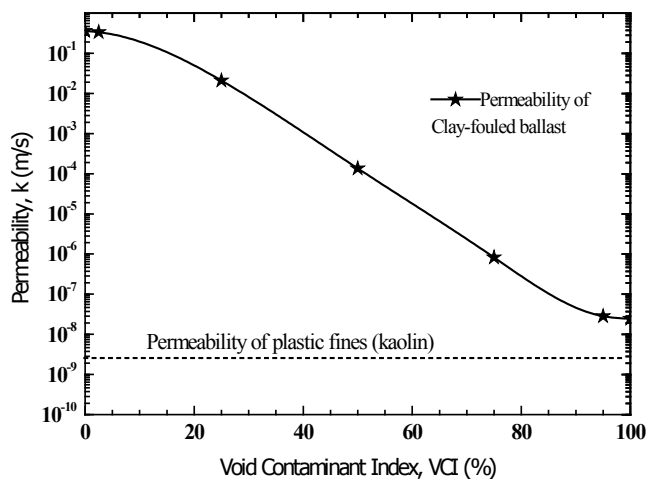


Fig. 4 Variation of permeability with Void Contaminant Index for clay-fouled ballast (data sourced from Tennakoon et al. 2012).

3 NUMERICAL MODELING

A numerical analysis has been conducted to estimate the drainage capacity of the track. In this analysis, two-dimensional (2-D) flow in real track scenario was simulated using the finite element (FEM) software, SEEP/W (Geostudio, 2007). In this analysis permeability values obtained from experimental results for different degree of fouling were used as input parameters. Due to the symmetry only one half of the track is used as shown in Fig. 5.

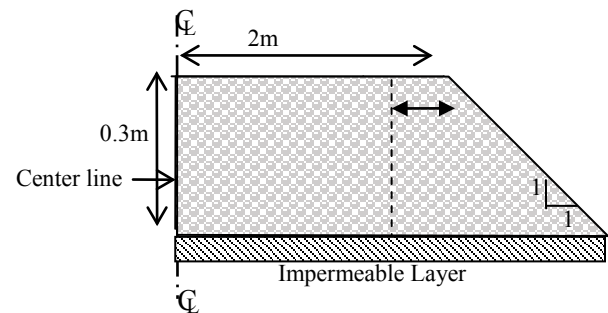


Fig. 5 Vertical cross section of the typical ballast layer used in seepage analysis.

Different degrees of fouling were assigned to different layers (i.e. 3 horizontal layers of load bearing and 1 layer of shoulder ballast) of the track to study the effect of plastic fines (clay) corresponding to their location in the track. Fig. 6 shows a typical output of numerical analysis using SEEP-W software.

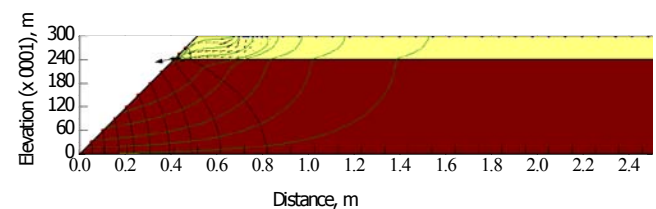


Fig. 6 Typical output of numerical Seepage analysis (top layer has fresh ballast while bottom layers are fully fouled).

In order to analyse the FEM results, it is important to classify the drainage conditions of the track. The drainage classification as described earlier by Tennakoon et al, (2012) was adopted in this study. The maximum rainfall intensity of 150 mm/h (Pilgrim, 1997) which corresponds to a flow rate (critical flow rate, Q_c) of 0.0002 m³/s over the unit length of the track was considered in this FEM analysis. The drainage capacity (Q) of the contaminated ballast could be obtained for different degrees of contamination. When Q is equal to or lower than Q_c (i.e. track becomes saturated under a given rainfall), then the track condition can be classified as ‘poor drainage’.

Table 1 presents the results obtained from the FEM analysis when shoulder ballast was not considered and whole track is divided into two horizontal layer (100 mm thick top and 200 mm thick bottom layer). The results show that when top layer is relatively clean (i.e. $VCI < 25\%$), the track is still maintaining the good drainage condition. If the

top layer is highly fouled ($VCI > 50\%$), the track becomes poor drainage even though the bottom layer is clean. If the whole track is fouled more than 50 % VCI , the drainage condition of the track is not adequate.

Table 1. Results of Numerical Seepage model without incorporating shoulder ballast.

VCI (%)		Q/Q _c	Drainage classification
Top 100 mm thick layer	Bottom 200 mm thick layer		
0	0	110	free drainage
50	0	1.2	acceptable drainage
75	0	0.1864	poor drainage
100	0	0.00054	impervious
0	100	20	good drainage
25	25	7.5	acceptable drainage
25	50	1.4	acceptable drainage
50	50	0.045	very poor drainage
100	100	8.67×10^{-06}	impervious

Table 2 shows the FEM results when the shoulder ballast layer was considered as shown in Fig. 5. It is interesting to see when the shoulder ballast is fouled more than 50% of VCI the track become poor drainage. On the other hand, when the shoulder ballast is clean, other section of the track should not be exceeded 50% of VCI to maintain acceptable drainage condition of the track.

Table 2. Results of Numerical Seepage model incorporating shoulder ballast.

VCI (%)		Q/Q _c	Drainage classification
Load bearing ballast	Shoulder ballast		
50	0	0.165	poor drainage
25	25	7.5	acceptable drainage
0	50	0.11	poor drainage
25	50	0.076	very poor drainage
100	25	0.000	impervious

4 CONCLUSIONS

Based on the permeability test results, the drainage capacity of the track was determined using 2-D FEM analysis applied to actual track geometry. It is shown that both the location and the extent of ballast

fouling play an important role when assessing the overall track drainage capacity. It is shown that when the shoulder ballast is fouled to more than 50% VCI , then the cleaning or replacement of the track shoulder is important to maintain an acceptable track drainage capacity. At the same time if top ballast layer is highly fouled ($> 75\%$ of VCI), the track is under the poor drainage condition.

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