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## Impact of ballast fouling on rail tracks

### Abstract

Ballast fouling is understood as major cause of track deterioration in many countries over the world. It decreases the drainage and load bearing capacity of the ballast layer. A series of large scale hydraulic conductivity tests were conducted with different proportions of fouling to access the drainage capacity of the track. A numerical analysis was conducted using SEEP/W to quantify the drainage capacity of ballast under different degrees of fouling. Subsequently, track drainage classification in relation to the degree of fouling, which is a very useful tool for practical engineers, is presented in this paper. The analysis showed that both the location and extent of fouling played an important role when assessing the overall drainage capacity of track. In order to establish the relationship between the extent of fouling and the associated strength-deformation properties, a series of large scale monotonic triaxial tests were carried out for different levels of fouling for three different confining pressures. Based on the laboratory findings, a novel empirical relationship between the peak deviator stress and VCI has been proposed to assist the practitioner in their preliminary track condition assessment. By considering drainage and strength aspects, a critical level of fouling to assist in track maintenance planning has been considered.

### Keywords

impact, tracks, rail, fouling, ballast

### Disciplines

Engineering | Science and Technology Studies

### Publication Details

Tennakoon, N., Indraratna, B. & Nimbalkar, S. (2014). Impact of ballast fouling on rail tracks. Second International Conference on Railway Technology: Research, Development and Maintenance (pp. 1-11). Scotland: Civil-Comp Press.

# Impact of Ballast Fouling on Rail Tracks

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## Abstract

Ballast fouling is understood as major cause of track deterioration in many countries over the world. It decreases the drainage and load bearing capacity of the ballast layer. A series of large scale hydraulic conductivity tests were conducted with different proportions of fouling to access the drainage capacity of the track. A numerical analysis was conducted using SEEP/W to quantify the drainage capacity of ballast under different degrees of fouling. Subsequently, track drainage classification in relation to the degree of fouling, which is very useful tool for practical engineers, is presented in this paper. The analysis showed that both the location and extent of fouling played an important role when assessing the overall drainage capacity of track. In order to establish the relationship between the extent of fouling and the associated strength-deformation properties, a series of large scale monotonic triaxial tests were carried out for different levels of fouling for three different confining pressures. Based on the laboratory findings, a novel empirical relationship between the peak deviator stress and VCI has been proposed to assist the practitioner in their preliminary track condition assessment. By considering drainage and strength aspects, a critical level of fouling to assist in track maintenance planning has been considered.

**Keywords:** ballast fouling, shear strength, permeability, numerical modeling.

## 1 Introduction

Railway ballast is a layer consisting of coarse angular aggregates between 10-60mm in size placed underneath the sleeper. Ballasted tracks are popular due to many advantages, including economy, higher load bearing capacity and good drainage. Figure 1 shows the typical cross section of a ballasted rail track.

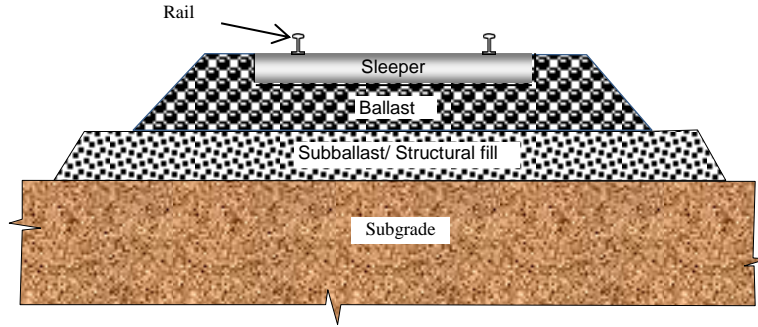


Figure 1: Typical ballasted railway track cross section.

To sustain proper functioning and longevity, it is crucial to maintain ballast to be relatively clean. However, during track operation, fine particles can accumulate within the ballast voids due to: (a) breakage of sharp angular projections (corners), (b) infiltration of fines from the surface, and (c) pumping of soft saturated subgrade under excessive cyclic loads. Fouling of ballast makes the granular mass effectively less angular and decreases its shear strength. Fouling also impedes drainage in the track. The routine replenishment of fouled ballast creates serious concerns for the Environmental Protection Authority (EPA), in addition to high disposal costs.

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 [1]. 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 [2]. 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, when trains operate in the absence of a properly graded filtration layer or geosynthetics underneath ballast layer [3,4].

## 2 Quantification of fouling

Several fouling indices are used for the quantification of fouling. Fouling material is defined as the fraction passing the 9.5 mm sieve [4]. The fouling index (FI) 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 [4]

$$FI = P_{0.075} + P_{4.75} \quad (1)$$

However, mass based index gave a false quantification of fouling when the fouling material (e.g. coal) had a low specific gravity. Therefore, the Percentage Void Contamination (PVC) was defined as the ratio of the bulk volume of fouling material to the volume of voids in clean ballast [2].

$$PVC = \frac{V_2}{V_1} \times 100 \quad (2)$$

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. By substituting relevant geotechnical parameters, a new Void Contaminant Index (VCI) parameter is proposed [5]:

$$VCI = \frac{(1+e_f)}{e_b} \times \frac{G_{sb}}{G_{sf}} \times \frac{M_f}{M_b} \times 100 \quad (3)$$

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 measure the amount of fouling.

Figure 2 shows the schematic diagrams of different stages of fouling.

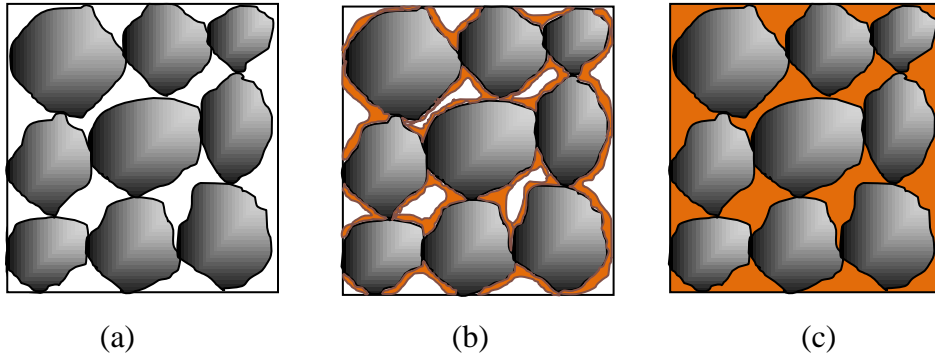


Figure 2: Schematic diagram of (a) clean, (b) partially fouled and (c) totally fouled ballast

### 3 Track drainage assessment

A series of constant head hydraulic conductivity tests [6] were conducted using large scale permeameter (Figure 3) with different levels of fouling to establish the relationship between the void contamination index and associated hydraulic conductivity.

This apparatus can accommodate ballast specimens up to 500 mm in diameter and 1000 mm in height. A filter membrane was placed below the layer of ballast while still maintaining a free drainage boundary. The test specimen was placed above the filter membrane and compacted in four equal layers to represent a typical field density. Commercial kaolin was used to simulate the clay fouling.

Figure 4 shows the variation of hydraulic conductivity of clay-fouled ballast with respect to the degree of fouling. It is clear that at low values of  $VCI$ , the overall hydraulic conductivity of ballast was relatively unaffected, then beyond certain degree of fouling (5% of  $VCI$  approximately), the hydraulic conductivity is

gradually decreasing until it reach closer to *VCI* of about 90%. Beyond this the overall permeability of fouled ballast was almost the same as kaolin clay.



Figure 3: Large scale permeability test apparatus

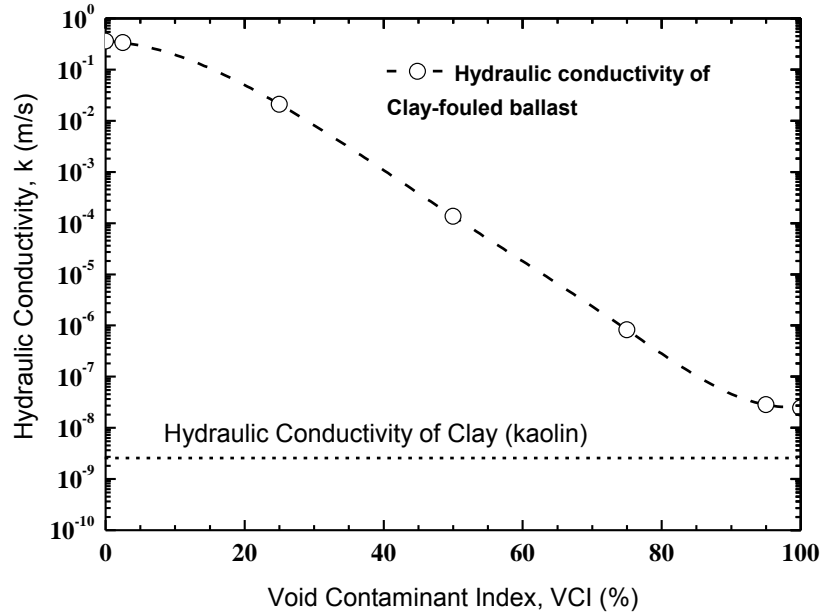


Figure 4: Variation of hydraulic conductivity with Void Contaminant Index for clay-fouled ballast (uniform distribution of fouling) (data sourced from Tennakoon et al. 2012)

Since these laboratory results are one dimensional and to simulate two-dimensional flow in real track scenario, a numerical analysis should be conducted to assess the drainage condition. Therefore, in this study 2-D seepage analysis was conducted using the finite element (FEM) software, SEEP/W [7, 8]. Hydraulic conductivity values obtained from experimental results for different degree of fouling were used as input parameters in this analysis. Due to the symmetry only one half of the track is used as shown in Figure 5.

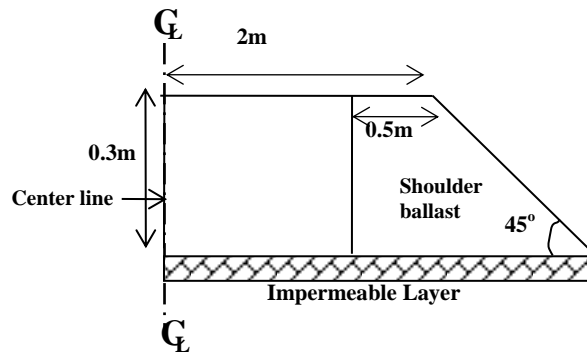


Figure 5: Vertical cross section of the typical ballast layer used in seepage analysis

In order to analyse the FEM results, it is important to classify the drainage conditions of the track. The classification as described by [5] was used in this study. The maximum rainfall intensity of 150 mm/h [9] which corresponds to flow rate (critical flow rate,  $Q_c$ ) of 0.0002 m<sup>3</sup>/s over the unit length of the track was considered in the FEM analysis. From the analysis, the maximum drainage capacity ( $Q$ ) of the ballast can be obtained for different degree of fouling. When  $Q$  is equal to or lower than  $Q_c$ , then the track drainage is classified as 'poor drainage'. The ratio ( $Q/Q_c$ ) as shown in Table 1 was used to classify the drainage conditions.

Drainage classification	Range
Free Drainage	$Q/Q_c > 100$
Good drainage	$10 < Q/Q_c < 100$
Acceptable drainage	$1 < Q/Q_c < 10$
Poor Drainage	$0.1 < Q/Q_c < 1$
very Poor	$0.001 < Q/Q_c < 0.1$
Impervious	$Q/Q_c < 0.001$

Table 1. Drainage capacity criteria [5]

Table 2 present the results obtained from the FEM analysis. The results show that for low degree of fouling (i.e. less than 25% VCI), the track is still maintaining the free drainage condition. It's apparent from Table 2, when the whole track is fouled more than 50% VCI, the drainage condition of the track is not adequate. These results are used later in conjunction with shear behaviour of clay fouled ballast to estimate the critical level of fouling.

VCI (%)	Q/Q <sub>c</sub>	Drainage classification
0	110	Free Drainage
25	7.5	Acceptable Drainage
50	0.045	Very Poor Drainage
100	8.67x10 <sup>-6</sup>	Impervious

Table 2: FEM predictions

## 4 Strength-deformation behaviour

A series of large scale monotonic triaxial tests were carried out to understand the effect of clay fouling on the stress-strain and degradation behaviour of ballast. Different levels of fouling ( $VCI = 0\%$  to  $80\%$ ) and confining pressures ( $\sigma'_3 = 10$  and  $30$  kPa) were used to simulate field conditions. A  $7$  mm thick cylindrical rubber membrane was used to prepare and confine the specimen. The *PSD* of clean ballast was used as per the recommended Australian Standards [10] where the maximum grain size falls between  $50$  and  $60$  mm. Commercial kaolin was used to simulate clay fouling. The amount of clay needed for a given value of *VCI* was calculated for each test specimen. Then a quarter of the clay was mixed with a quarter portion of ballast using the concrete mixer, and then placed inside the upright cylindrical membrane in preparation mould (Figure 6). The moisture content of clay ( $w = 52\%$ ) during mixing was slightly larger than the liquid limit. Special sample preparation methods were adopted for different levels of *VCI*. More details of these methods are given elsewhere [11].



Figure 6: First layer of fouled ballast placed inside the triaxial membrane

Figure 7 shows the variation of peak deviator stress with *VCI*. The peak deviator stress decreases significantly with the increase in *VCI*. The relationship that can represent the normalized shear strength of clay fouled ballast is useful in the preliminary assessment of track conditions in view of track maintenance. Therefore normalised shear strength is expressed in terms of *VCI* as below:



$$\frac{q_{peak,f}}{q_{peak,b}} = \frac{1}{1 + \beta\sqrt{(VCI)}} \quad (4)$$

where  $q_{peak,b}$  and  $q_{peak,f}$  are the peak deviator stresses for fresh and fouled ballast respectively,  $\beta$  is an empirical parameter dependent on  $\sigma'_3$ .

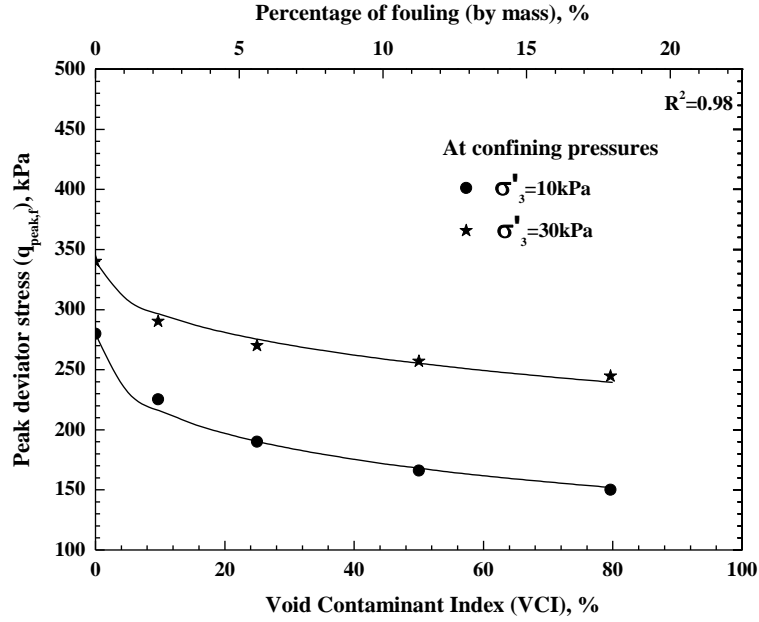


Figure 7: Variation of Peak deviator stress with VCI

## 5 Evaluation of critical level of fouling

This section presents a semi-empirical analysis of estimating the allowable train speed for varying levels of fouling, where axle loads of 25 and 30 tonnes are considered. The design wheel load is determined empirically as [12]:

$$P_d = \left[ 1 + \frac{0.0052 V}{D_w} \right] \times P_s \quad (5)$$

where,  $P_d$  is the design wheel load,  $P_s$  is the static wheel load (= axle load/2),  $D_w$  is the diameter of the wheel (m), and  $V$  is the velocity of the train (km/h). Assuming 50% of the design wheel load to be the rail seat load, the sleeper-ballast contact pressure ( $q_d$ ) is determined from [13]:

$$q_d = \left( \frac{q_r}{2aB} \right) F_2 \quad (6)$$

where,  $q_r$  is rail seat load,  $B$  is the width of the sleeper and  $a$  is the distance between rail head centre and edge of the sleeper.  $F_2$  is a factor depending on the type of sleeper.

In this study, Singleton (NSW) track data is used to determine the allowable train speed ( $V_a$ ), for which:  $D_w = 0.97$  m,  $B = 0.25$  m,  $a = 0.5$  m,  $F_2 = 1$ . Using the peak strength obtained from the Equation 4 and Eqs. 5 and 6,  $V_a$  can be determined and plotted against  $VCI$  as shown in Figure 8 for axle loads of 25-30 tonnes.

Figure 8(a) shows that at a 10 kPa confining pressure, the track can tolerate fouling up to 20%  $VCI$  for trains with 25 tonne axle load passing at an average speed of 70 km/h. However, if the confining pressure exceeds 30 kPa, the track is considered to be stable at all levels of fouling. In contrast, as described in section 3, the condition of 'poor drainage' can govern the track serviceability when  $VCI$  is more than 50%. Figure 8(b) shows that even if the confining pressure increases to 30 kPa, fouling cannot exceed 50%  $VCI$  for 30 tonne axle trains moving at an average speed of 70 km/h.

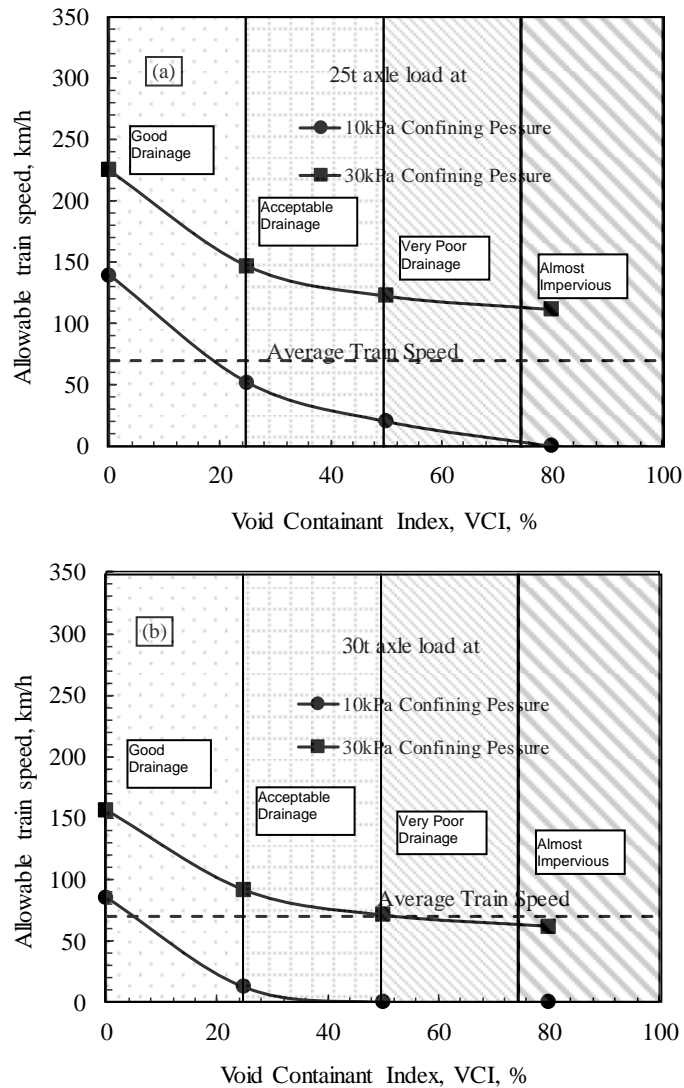


Figure 8: Allowable train speeds for (a) 25 t and (b) 30 t axle loads at different confining pressures

Therefore considering drainage and strength aspects, 20% *VCI* can be considered critical for axle loads below 25 tonne with 10 kPa of confining pressure. If the axle load is 30 tonne, the confining pressure should increase to at least 30 kPa where fouling level is not anticipated to exceed 50% *VCI*. The results presented in Figure 8 can be used as guidelines for track maintenance activities due to fouling.

## 4 Conclusion

Rail ballast becomes contaminated or fouled due to the infiltration of subgrade fines such as clay. The strength and drainage aspects of ballasted rail tracks under various

levels of fouling are discussed through large scale laboratory tests. In this study the detrimental effects of fouling on shear strength and drainage characteristics were assessed using Void Contaminant Index (VCI). Initially, even a small increase in the VCI lead to a significant decrease in the hydraulic conductivity of the fouled ballast, but beyond a certain limit of VCI the hydraulic conductivity converged to that of the fouling materials itself. A series of isotropically consolidated drained monotonic triaxial tests using a large scale cylindrical triaxial apparatus were conducted on clay fouled ballast. Based on the laboratory test findings, a novel empirical relationship between the peak deviator stress and *VCI* is proposed with the aim of assisting the practitioner in the preliminary track assessment. A non-linear shear strength envelope is introduced in a non-dimensional form, where the relevant shear strength coefficients could be conveniently evaluated based on the proposed empirical equations. The relationship between allowable train speed based on the levels of fouling is useful for rail practitioners in view of track maintenance.

## 5 Acknowledgement

The authors are grateful to the CRC for Rail Innovation (established and supported under the Australian Government's Cooperative Research Centres program) for the funding of this research. Project No. R3.106 Project Title 'Integrated Ballast-Formation-Track Design and Analysis including the Implications of Ballast Fouling and High Impact Loads'. They would also like to thank the Industry partners including Sydney Trains (Previously, RailCorp), ARTC and Aurizon (Previously, QR National) for their keen collaboration in this study. The assistance provided by senior technical officers, Mr. Alan Grant, Mr. Ian Bridge, and Mr. Cameron Neilson is also appreciated. A significant part of the contents of this paper are described in a number of scholarly journals including *Géotechnique*, and *ASTM Geotechnical Testing Journal*, as cited in the text and listed below.

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