Experimental analysis permeability characteristics of fouling railway ballast

Zhenyu Su[1,2], Hongmei Huang[3], Guoqing Jing [3]*

[1]Guangzhou metro group co., LTD, Guangzhou, 510000, China
[2]South China University of Technology
[3]Civil Engineering School, Beijing Jiaotong University, Beijing, 100044, China

Abstract
The railway ballast goes through deformation and degradation under train cyclic loading, then the fine particles accumulate within the particle voids resulting in reduction in drainage, track resiliency and stability, and the paper is aiming to investigate the permeability characteristics of different material and ratio of fouling. Therefore, a series of constant head permeability test of different fouling material and ratio on railway ballast were conducted, and the experimental results showed that the relationship of permeability capacity and fouling ratio of railway ballast is correlated. The fouling ratio increase leads to the permeability capacity decrease, and influences both the aggregates permeability and strength. The critical value of fouling ratio for track stability and maintenance could be determined by the permeability methods.
Keywords: BALLAST, FOULING, PERMEABILITY TEST

1. Introduction

Ballast is composed of coarse aggregates to provide stable loading-bearing and sufficient permeability for drainage [1]. As ballast degradation and fines accumulation due to cyclic loading, the track bed increasingly fouled by soil from subgrade, fines, and coal powder from outside environment [2]. The fouling fines decrease resistance and resiliency of ballast, furthermore, the presence of water can result in fines pumping which mainly due to fouling ratio increase reduce permeability of ballast and cyclic loading from passing traffic further cause this fines to be pumped up to the ballast surface initiating pumping failure [1,3].

In the past, most attention was paid to the mechanical behavior (stiffness resiliency and bearing capacity) of fouling ballast bed [4]. A series of direct shear tests or triaxial tests were conducted on fouled ballast at various levels of fouling ratio to study the mechanical behavior [5], and the results indicated that the highest peak shear stress decreased consistently with increase in fouling ratio, for a given value of normal stress and led to decrease of the track stiffness and bearing capacity [1]. Sufficient permeability for drainage is important as well as stable loading-bearing capacity for ballast, however, no detailed study into the drainage of railway ballast has been identified [1-2]. According to Indraratna et al., under saturated conditions water and fine particles mix to form slurry and will migrate to the ballast layer [6,7]. With the porosity get filled, the ballast loses its ability to drain the water and reduces track permeability which leads to increased pore water pressure and subsequent loss of shear strength and stiffness [6]. Some researchers presented that the drainage condition is poor if the overall hydraulic conductivity is less than 10^{-4}m/s while the average hydraulic conductivity of clean ballast is 0.3m/s [8]. The above research presented less research on fouling material, and the critical fouling ratio, furthermore, the test rig or equipment were small in dimension. Therefore, research on the drainage performance of ballast was required to establish a design criteria for the railway system.

This paper aims to study the relationship between permeability with the fouling ratio, and different fouling fines material. The study was carried out in the laboratory by conducting constant-head permeability test on four fouling levels. Results revealed that fouling ratios have a deep influence on the performance of ballast. Specimen with more fine particles showed poor permeability and shear strength. Therefore, there was a positive correlation between permeability and shear strength of fouled ballast.

2. Material and Experimental Methodology

2.1. Material

The ballast material tested was a 100% crushed granite aggregate with a specific gravity of 2.63 $*10^3$kg/m^3 which gradation meet Chinese railway standard and involved materials with particles ranging from 16 to 63 mm. The ballast specimen is generally the Grade 1, namely the broad gradation, where smaller size particles used, the void between the bigger sizes will be easily filled with these small particles exposing the structure for further drainage problem.

Fouling material has been defined as the material passing the 9.5 mm size sieve[2]. Sources of ballast fouling can be attributed to ballast particle degradation, infiltration of fine foreign particles from the track surface, sleeper wear, sub-ballast and subgrade infiltration[8]. In china, the clay pumping due to soft subgrade is frequently observed.

As fouling materials deeply influences performance of ballast, such as coal, fines, and soil etc., so the two kinds of sand were chosen as fouling materials in this study. The sands were divided into fine sand and coarse sand whose size were less 2mm and between 2mm with 5mm according to particle size which were shown in Figure 1(a) and (b), separately. Robert L. et found the lower-density coal will occupy more of the void space than an equivalent mass of clay or crushed ballast and will occupy approximately 100% of the ballast void space for a 40% fouling ratio [6]. What's more, we can see from the Figure 2 that the void space between larger aggregates was filled with fouling materials when the fouling percent was 40% by volume, therefore, four fouling percents (10%, 20%, 30% and 40%) were chosen to study the permeability of ballast. The specific gravities of fine sand and coarse sand were determined to be 1.47 and 1.67, respectively. They were carefully sieved by conducting sieve analysis test. Gradation curves for these materials are shown in Figure 3. Each of these fouling materials was added to the clean ballast in defined amounts. When ballast was mixed with fine sand and coarse sand, it denoted in this paper as fine sand-fouled and coarse sand-fouled ballast respectively.

The sample was then compacted by tapping the mixture to represent a typical field density [2]. The mixed sample were compacted by 3 layers, with wood hammer, and then satured with water for 24 hours before the tests.

Figure 1 (a). fine sand

Figure 1 (b). coarse sand

Figure 2 (a). fine sand with ballast (40% fouling)

Figure 2 (b). coarse sand with ballast (40% fouling)

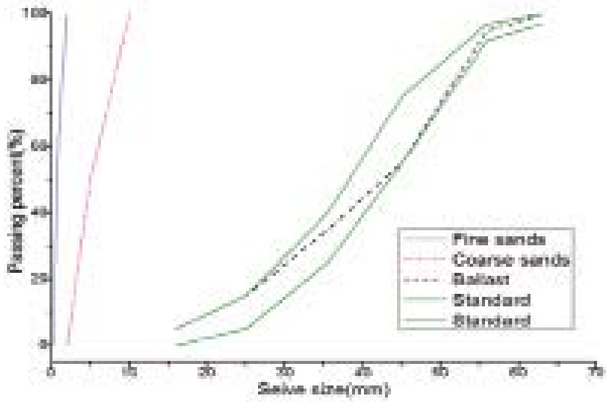

Figure 3. particle size distribution

2.2. Constant-head permeability test

Tests were conducted for each fouling material to determine the permeability at different fouling levels. Constant-head permeability tests were carried out in a test box designed for that purpose to determine the permeability of the sample. The box that made of transparent glass to allow visual observation was designed with 100cm long, 70cm wide and 70cm high. The dimensions of the sample were 68cm long, 50.5cm wide and 19cm high [9]. Two outflow pipes were installed at the upward of the box to assure constant head and a 15 cm pipes and valves were installed at the bottom of the box to fill the box with water and drain water out during the test. A filter was placed below the layer of ballast to prevent the fines from being washed away and maintain a free drainage [10]. A schematic diagram of the test is shown in Figure 4(a) and Figure 4(b) shows an actual test sample. The samples which were prepared at 10%, 20%, 30% and 40% fouling ratio by volume, was mixed and added to the box in layers and spread out uniformly around the box which was shown in Figure 2(a) and (b), separately [11].

A hose was connected to the box and water was introduced into the sample. A constant head condition was established as water entered the box, passed downward through the sample, exited through the up outflow pipe and the flow rate is stable. Water was collected from the downward pipes for a measured time period (30s) and the time and water were recorded.

A series of large scale constant head permeability tests for different fouling materials have been conducted and Parsons B K. found that linear Darcy's law was valid for fresh ballast at low hydraulic gradients (less than 4) [12]. Therefore, Darcy's law considering laminar flow was used in this study. Note that cell as well as the filter above which the packed ballast was put should be washed and each sample should be immersed into the water for more than one day to completely fill the micro porosity of ballast before test and maintain a steady state laminar flow to ensure the applicability of Darcy's law in the permeability experiment [13, 14]. To get accurate results, each fouling percent should do two different constant head tests.

Permeability, k, determined by Darcy` Law is given by:

$$K = \frac{QL}{hAt} \quad (1)$$

Where h is the height of water, A is the cross-sectional area of the specimen, L is the height of the specimen, Q is the water collected for the measured time period and t is the measured time.

$$Q = \frac{M}{\rho} \quad (2)$$

Where M is the weight of the water collected and ρ is the density of water.

3. Results and discussions

Four constant head permeability tests were conducted for each fouling material and the fouling ratios were 10%, 20%, 30% and 40% by volume, separately. The hydraulic conductivities was calculated using equation (1-2), and the results are presented in the below Figures.

Figure 5(a) and 5(b) clearly show the relationship of permeability with fouling ratio on different water head for fine sand and coarse sand, respectively. From the picture, we can see that the permeability decreases with the fouling ratio increase for different water heads, and the permeability of both low and high water approximately follows a linear relationship with fouling ratio which agrees with Nayoma T. [10] and the study of Robert L. et that the permeability trends for clay and ballast fines were approximately linear and parallel to each other [6]. The permeability capacity is vulnerable impacted by water

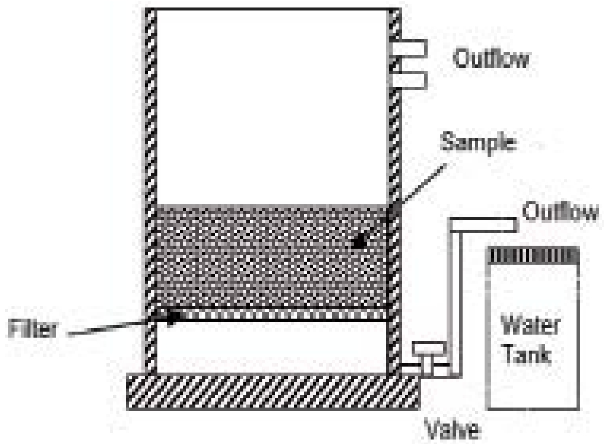

Figure 4(a). schematic diagram of the test

Figure 4(b). actual test sample

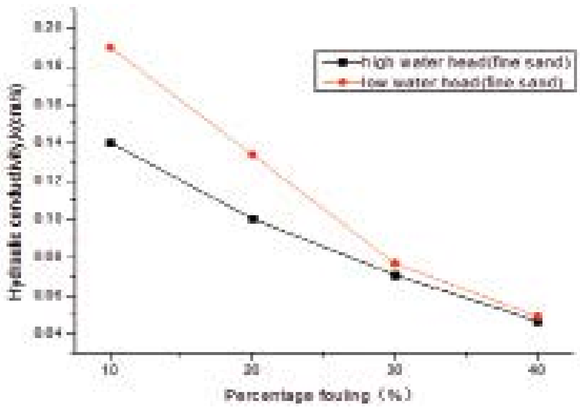

Figure 5 (a). permeability vs fouling ratio for fine sand

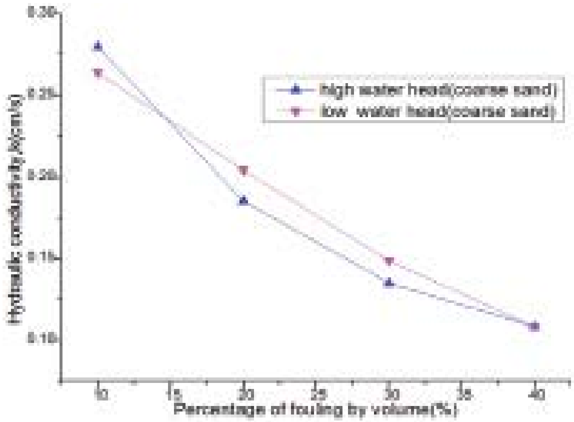

Figure 5 (b) permeability vs fouling ratio for coarse sand

heads, especially, high water head has more influence on the permeability of ballast more than low water head, however, irrespective of the water head, all permeability data move towards a common value.

Due to the permeability of fine sand and coarse sand are 0.045cm/s and 0.095cm/s, separately. It is noted in Figure 5(a) and (b) that irrespective of the water head, all permeability data move towards a common value that is nearly equal to permeability of fouling materials (fine sand and coarse sand) as the fouling ratio increases.

Figure 6(a) and 6 (b) clearly show the relationship of permeability with fouling ratio for different fouling materials (fine sand and coarse sand) on low water and high water, respectively. From the picture, we can see that the permeability decreases with the fouling ratio increase for both fouling materials, which is in agreement with Parsons R.[6], and the permeability capacity is vulnerable impacted by fouling materials, especially, fine sand has more influence on the permeability of ballast more than coarse sand which contributes to that the void space of fine sand is smaller than that of coarse sand.

Rahman A J. et found that coal dust affected the permeability more significantly at a much lower degree of fouling due to the lower specific gravity of coal [15]. The specific gravities of fine sand and coarse sand were determined to be 1.47 and 1.67, respectively, and the permeability of ballast filling with fine sand is lower than that filling with coarse sand. The finding agrees with the Rahman A J. .

Figures 5 and 6 indicate that the permeability of coarse sand under different water heads is generally similar to fine sand, except that the permeability of coarse sand under the same confinement is considerably higher than that of fine sand [1,11]. To compare the permeability of fine sand and coarse sand under different water heads directly, the permeability and water head data of Figures 5 and 6 are re-plotted together in Figure 7.

Figure 7 clearly shows that the fine sand tested by the authors has a lower permeability compared to coarse sand. Owing to void spaces between larger ballast aggregates decreasing, fine sand generally has less void space than coarse sand. Less void space and sands accumulated around the ballast particles reduce the permeability of ballast [16].

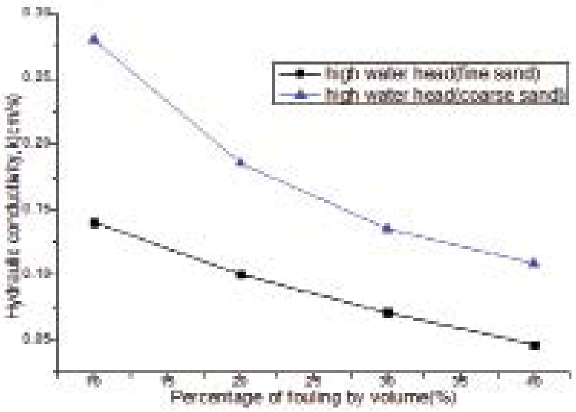

Figure 6 (a). permeability vs fouling ratio for high water

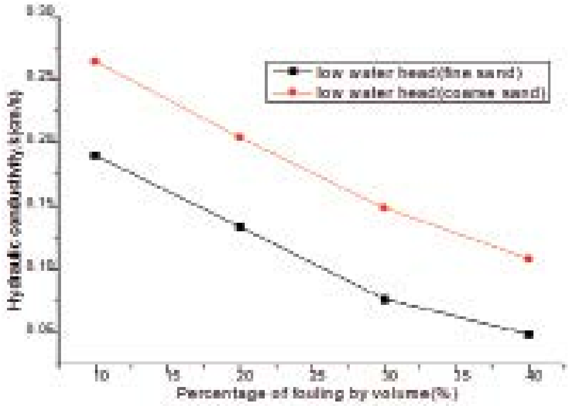

Figure 6 (b). permeability vs fouling ratio for low water

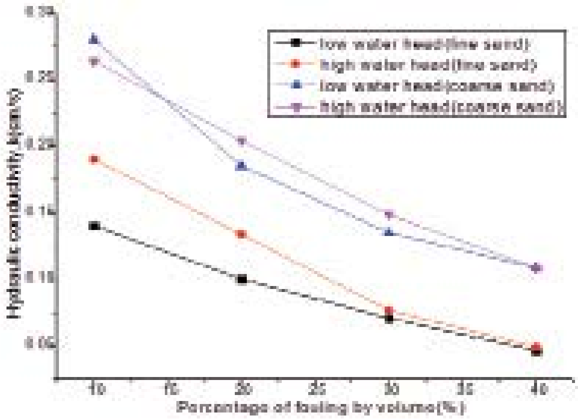

Figure 7. permeability vs fouling ratio

Conclusions

The railway ballast constant head permeability test was employed to investigate the relation between permeability and fouling ratios, as well as fouling material size effects. The test results suggested that fouling ratios and fouling materials play an important role in the performance of ballast permeability. Some important conclusions are given as follows:

The fouling ratios have significant impact on the permeability of ballast, and the results confirmed that the permeability decreased with the increase in fouling ratio.

Permeability ability is vulnerable impacted by water heads, especially, high water head result in more influence on the permeability of ballast than low water head.

The fouling materials have significant impact on ballast permeability and irrespective of the water head, all permeability data move towards a common value that is nearly equal to permeability of fouling materials (fine sand and coarse sand) as the fouling ratio increases.

Base the study, in order to have a proper maintain for the layer of ballast, a deep understanding of the function of ballast especially the mechanism of drainage when serving as a bear-capacity is of vital importance to ensure a maximum performance of the ballast layer. The design critical based on current testing and analysis offers very useful guidelines for facilitating the decision made by track engineers. Nevertheless, the contents of this paper have been based on a limited number of divisions with several conveniently selected levels of fouling and materials. To evaluate the track drainage capacity to a higher level of accuracy, then more tests having a larger number of fouling materials with a wider variation of corresponding fouling ratios will be required.

Acknowledge

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Prediction for Short-term Traffic Flow Based on Elman Neural Network Optimized by CPSO

Niu Zhonghai, Jia Yuanhua, Zhang Liangliang, Liao Cheng

School of Traffic and Transportation, Beijing Jiaotong University, Beijing, 100044, China

Corresponding author is Niu Zhonghai

Abstract
Prediction of traffic flow is an important issue of intelligent traffic system, while accurate and real-time prediction of traffic flow becomes a crucial issue in traffic control. To further improve the traffic prediction precision