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Ballast drainage in Brazilian railway infrastructures

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HIGHLIGHTS

- Comparing clean ballast samples with samples contaminated with different volumetric percentages of soil.
- Analyzing the reduction in permeability of the ballast layer due to the presence of soil through laboratory tests.
- Analyzing the hydraulic conductivity of the ballast for different contamination rates.
- Verifying the necessity of ballast cleaning maintenance works.

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ABSTRACT

The main objective of this research work was to analyze the reduction in permeability of the ballast layer due to the presence of soil through laboratory tests. Granulometry and permeability tests were done comparing clean ballast samples with samples contaminated with 10%, 15%, 20%, 25% and 40% volumetric percentages of soil. The hydraulic conductivity of the ballast for different contamination rates was also analyzed. Finally, an equation was defined that can be used to predict the hydraulic conductivity for different ballast contamination rates.

1. Introduction

The construction of railways in Brazil began in 1854 in the imperial period, known as the second Reign, linked essentially to coffee production and other agricultural products. It reached its peak in the year 1930, in the Republican period, when more than 30,000 km of railways were built all over the country. Recently, in particular since the 1990s, many rural railways have begun being privatized. Currently, all national rail freight transport in operation is under private management. Most of the State Railways were built in the 19th century. The oldest, São Paulo Railway (SPR), was built by British engineers and opened in 1867, linking the port of Santos to Jundiaí, passing through São Paulo. Nowadays, the central segments that connect the municipalities that make up the metropolitan region of São Paulo operate in mixed traffic with a huge predominance of metropolitan trains and little cargo traffic. The end sections of these railway lines were ceded to concessionary companies primarily interested in industrial cargo transport to the port of Santos. These railways have undergone some modifications during their lifetime, such as, for example, the increase in length and the substitution of rigid fastenings for elastic ones. At no time, with the exception of one, have these railways been rebuilt to improve their load capacity or to remove the contaminated ballast. This situation, coupled with the interests of railway concessionaires in maximizing profits by increasing the axle loads and by using a maintenance process which involves merely adding new ballast on top of the existing ballast layer, has led to several changes in the quality of the railway lines. The old ballast was buried into the soil layer and the fine particles of soil climbed up to the ballast layer, closing it and creating “mud pockets” in rainy seasons. This process of ballast contamination has affected its properties as well as railway safety.

A typical cross-section of this type of railways is presented in Fig. 1, where we can see the layers of clean ballast, usually as a result of leveling operations, and the contaminated ballast. The water that falls on the railway track does not drain directly into the drainage ditch. It infiltrates and remains inside the ballast,

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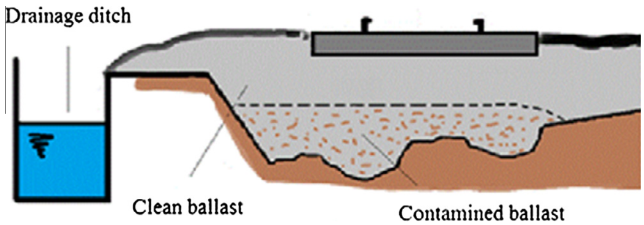

Fig. 1. Typical railway cross-section.

facilitating the climbing process of the fine particles of soil up to the ballast layer. This problem is very common in all Brazilian railways built before 1970. The low permeability of the contaminated ballast can be seen in Fig. 2, which shows the amount of water retained in the ballast and the state of the platform after water infiltration. These photos were taken one day after the day of the rainfall.

2. General characteristics of railway ballast

The ballast layer consists of granular material that supports the railway grid, which consists of rails and sleepers, preventing their displacement and providing enough elasticity to the railway, reducing impacts and ensuring efficient drainage and aeration. Its main functions are [1,2]:

(a) Distributing stresses transmitted by the sleepers.
(b) Attenuating the majority of train vibrations.
(c) Resisting transverse and longitudinal track shifting.
(d) Facilitating rainwater drainage.
(e) Allowing track geometry to be restored and correcting track defects by using track maintenance equipment.

The surface of the ballast should be as flat and uniform as possible. Generally, its optimum thickness is around 25–30 cm, measured from the bottom of the sleepers. Special attention should be given in placing the ballast layer over the subgrade to ensure uniform settlement. Differences in the vertical settlement must not exceed 10 mm [3]. Ballast specifications are not the same all over the world. In Brazil, the NBR 5564 standard [4] defines the requirements for the ballast granulometry (Table 1).

Particle size distribution has a significant influence on the deformation behavior of railways. The elastic stiffness of the ballast increases with an increasing uniformity of the particle size. Density and friction angle decrease with a greater uniformity of particles. Ballast with a more varied granulometry contains fewer voids content, making it stronger than uniform ballasts. In conclusion, the optimal gradation of ballast must be intermediate between uniform and widely varied. This gradation should provide sufficient drainage, density, shear strength and elastic modulus acceptable for the railway [5].

Table 1
Ballast granulometry [4].

Sieve size (mm)	Grading category	
	Percentage passing by mass	
	A	B
76.2	–	100
63.5	100	90–100
50.8	90–100	–
38.0	35–70	25–60
25.4	0–15	–
19.0	–	0–10
12.0	0–5	0–5

The response of ballast to the degree of saturation is quite varied. Water influences the ballast settlement, disruption of particles and can lead to traffic problems. Soils in saturated conditions form mud which can contaminate the ballast layer. The degree of water saturation of soils can lead to an increase of 40% of the railway platform settlement [5]. What is more, the contamination of the ballast with clay and silt particles reduces its drainage. These fine particles can combine with water to form an abrasive mud, creating so-called "mud pockets". This contaminant material with low humidity can harden inside the ballast, preventing proper penetration of the maintenance equipment [6]. According to Selig and Waters [7], ballast contamination can occur in different ways, which can be divided into five categories:

- Breaking of ballast (13%).
- Infiltration coming from the surface of the ballast (1%).
- Wear of sleepers (3%).
- Infiltration coming from the lower granular layers (7%).
- Infiltration coming from the platform (76%).

According to Al-Qadi et al. [8], the most important form of contamination is the breaking of the ballast. Tests have determined that after performing track maintenance works twenty times, particle size is reduced considerably, up to 50% for granite ballast and 5–10% for limestone ballast, on average [9]. Selig and Waters [7] presented findings on the permeability reduction due to ballast contamination. The permeability of reasonably clean ballast is about 10% of that presented by clean ballast. As contamination of the ballast increases, permeability is rapidly reduced [10].

For better comparison of results, the level of ballast contamination will be assessed according to two indexes, one proposed by Selig and Waters [7] and another proposed by the South-African Railway Spoornet [9]. The first index, called fouling index, or ballast contamination index, is defined by Eq. (1).

$$F_1 = P_4 + P_{200} \quad (1)$$

where P_4 is the percentage of material passing in sieve no. 4 (4.76 mm); P_{200} is the percentage of material passing in sieve no. 200 (0.075 mm).

Fig. 2. Water retained in the ballast (left) and state of the platform after water infiltration (right).

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