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Sub-ballast performance in Brazilian railway infrastructures

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HIGHLIGHTS

- Comparative analysis between two Brazilian sub-ballast specifications derived from American specifications.
- Analysis of the requirements for sub-ballast materials.
- Qualitative tests of granular materials and their results.
- Analysis of the results obtained in current requirements from non-American sources.

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ABSTRACT

In the period 1975–1985 several new railway infrastructures were built in Brazil. After this period the construction of new railways stopped. With the new railway concessions in 1996, minor maintenance work was undertaken on the old railway infrastructures and only in the last six years have new railway infrastructures begun to be constructed. In São Paulo, between 1978 and 1985, some old railways infrastructures were also rebuilt using sub-ballast or platform with granular soils in the track layers.

This paper presents a comparative analysis between two sub-ballast specifications, one used in the 1975–1985 period and another used nowadays for new railway constructions in Brazil. The main sub-ballast functions were identified, including the bearing capacity and the hydraulic conductivity. To assess the sub-ballast in terms of these technical criteria, samples were collected from two railways built more than 30 years ago, one on sandy soil and the other on stony fine aggregates. Samples of the typical fine silty soil of UNICAMP campus were also collected to evaluate the possibility of using the two types of sub-ballast on this type of soil. The samples collected in the field were tested in laboratory for evaluation of particle size, load capacity and hydraulic conductivity. Finally, the performance of each of the two granular mixtures used as sub-ballast layer in Brazilian railway infrastructures was analysed.

1. Introduction

Several new railway infrastructures were built in Brazil from 1975 to 1985. After this, the construction of new railways stopped. With the new railway concessions in 1996, minor maintenance work was undertaken on the old railway infrastructures and in the last six years new railway infrastructures have begun to be constructed. In São Paulo, in the period 1978–1985, some old railways infrastructures were also rebuilt using sub-ballast or platform with granular soils in the track layers. The ballast layer consists of granular material that supports the railway grid, consisting of rails and sleepers, preventing the displacement and providing enough elasticity for the railway, reducing impact and ensuring efficient drainage and aeration (Fig. 1). Its main functions are [11,9]:

- Distributing stress transmitted by the sleepers;
- Attenuating the majority of train vibrations;
- Resisting transverse and longitudinal track shifting;
- Facilitating rainwater drainage;
- 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. Under the ballast layer, the gravel sub-ballast is laid and has the following main functions [8,10,11]:

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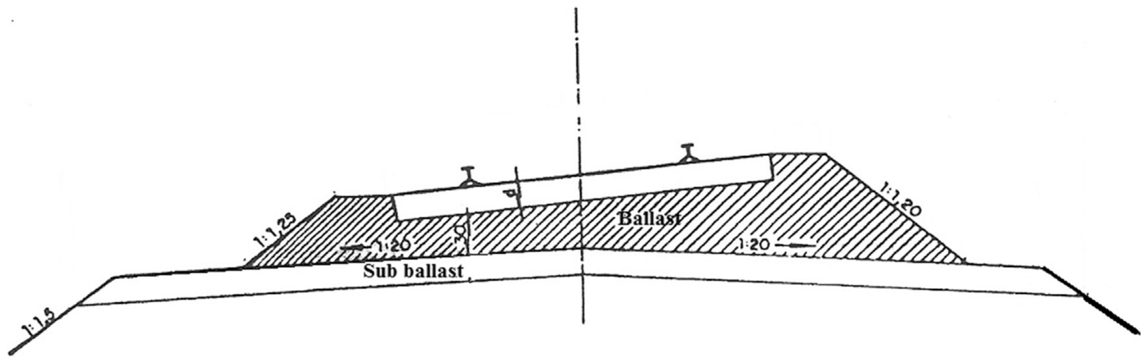

Fig. 1. Typical railway cross-section.

- Protection of the upper surface of the subgrade from the intrusion of ballast material;
- Additional distribution of stress transmitted by the sleepers;
- Additional facilitation of rainwater runoff;
- Providing a transverse slope to the upper surface of the subgrade, usually 3% to 5%, for proper runoff.

The usual thickness of the gravel sub-ballast layer is 15 cm. However, some railways do not use a sub-ballast layer and they simply use a greater thickness of the formation layer, which is placed on top of the subgrade.

This paper presents a comparative analysis between two sub-ballast specifications, one used in the 1975–1985 period and another used nowadays for new railway constructions in Brazil. The main sub-ballast functions were identified, including the bearing capacity and the hydraulic conductivity. To assess the sub-ballast in terms of these technical criteria, samples were collected from two railways built more than 30 years ago, one on sandy soil and the other on stony fine aggregates. Samples of the typical fine silty soil of UNICAMP campus were also collected to evaluate the possibility of using the two types of sub-ballast on this type of soil. The samples collected in the field were tested in laboratory for evaluation of particle size, load capacity and hydraulic conductivity. Finally, the performance of each of the two granular mixtures used as sub-ballast layer of Brazilian railways infrastructures was analysed.

2. General characteristics of railway sub-ballast in Brazil

The sub-ballast layer in Brazilian railway infrastructures can be of two types: granular material or a mixture of treated granular aggregates. Its thickness can range between 0.10 and 0.30 m, depending on the railway traffic, the thickness of the upper ballast layer and the quality of the subgrade. Li et al [8] recommend 30 cm as maximum thickness for the sub-ballast.

In this study two different sub-ballast specifications are considered, one used in the 1975–1985 period and another used nowadays in new railway constructions in Brazil, i.e. the specification for sub-ballast materials used in the construction of the São Paulo Metro [4], a high frequency traffic railway in service for more than 30 years which is already in good condition; and the specification for sub-ballast materials used in the construction of federal railways [14], a heavy traffic railway. The first specification [4] was based on the ASTM D1241-68 [1] specification considering only type I materials - mixtures consisting of stone, gravel, or slag with natural or crushed sand and fine mineral particles passing through the No. 200 (0.075 mm) sieve, represented by curves A–D (Table 1). The main requirements of sub-ballast material presented in specification ES 316 [4] are the following:

- Coarse aggregate, material retained on the No. 10 (2.00 mm) sieve, shall have a percentage of wear, by the Los Angeles Abrasion test, of not more than 50;
- The fraction passing the No. 200 (0.075 mm) sieve shall not be greater than 2/3 of the fraction passing the No. 40 (0.425 mm) sieve;
- The fraction passing the No. 40 (0.425 mm) sieve shall have a liquid limit (LL) of no greater than 25 and a plasticity index (PI) of no greater than 6;
- California Bearing Ratio (CBR) equal to or greater than 20%;
- Expansion less than 0.5%;
- For protection of the subgrade layer (SG), it was required that the fraction passing the No. 200 (0.075 mm) sieve should be less than 5% and the ratios defined by Eqs. (1) and (2).

$$5 < \frac{D_{15\ SBL}}{D_{15\ SGL}} < 20 \quad (1)$$

$$\frac{D_{15\ SBL}}{D_{85\ SGL}} < 5 \quad (2)$$

where: $D_{15\ SBL}$ – sieve size passing 15% of the material of the sub-ballast layer; $D_{15\ SGL}$ – sieve size passing 15% of the material of the subgrade layer; $D_{85\ SGL}$ – sieve size passing 85% of the material of the subgrade layer.

The specification for sub-ballast materials used nowadays for the construction of federal railways [14] was also based on the ASTM D1241-68 [1] specification and considers the curves A to D, and also curves E and F (Table 2). Comparing the requirements of the two specifications it can be seen that the differences are the following: two more curves (E and F) were included corresponding to type II materials - mixtures consisting of natural or crushed sand with fine mineral particles passing a No. 200 (0.075 mm) sieve, with or without stone, gravel, or slag; the requirement for protection of the subgrade layer was withdrawn.

Other authors specified different requirements for the sub-ballast. Brina [3] stated that the minimum CBR value must be 30%. In practice, sub-ballast layers composed of materials that meet the requirements of gradations A, B, C, and D always presented CBR values greater than 40%. Selig and Waters [12] stated that the problem of the contamination of the subgrade layer with ballast material is produced primarily by repeated traffic loading, and not by infiltration. They defined the following requirements for sub-ballast material:

$$\frac{D_{15\ SBL}}{D_{85\ SGL}} \leq 5 \quad (3)$$

$$\frac{D_{50\ SBL}}{D_{50\ SGL}} \leq 25 \quad (4)$$