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Effects of Parallel Gradation Scaling Technique on Permanent Deformation of a Ballast Material

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Abstract

This paper investigates possible effects of scale-down technique on the long-term permanent deformation behaviour of the rail ballast, particularly for heavy haul rail track loadings. Two scaled down ballast specimens, of 1:2.5 and 1:2, obtained by parallel gradation from the full scale ballast standard AREMA N. 24 [10], which is widely used in this type of rail tracks in Brazil, were compared. The results for the level of cyclic loading evaluated and for the number of cycles carried out did not show significant differences in long-term behaviour due to possible effects of scaling technique. However, these results should be further investigated in order to obtain more definitive conclusions.

Keywords: ballast behaviour, scaling Technique, steel slag ballast, heavy haul rail track.

1 Introduction

The railway track ballast layer usually consists of coarse aggregates whose main functions are to distribute the train loads to the substructure layers (sub-ballast or foundation soils) at a reduced level of stress, provide lateral confinement to the track frame and free-draining conditions. The ballast layer also provides important resilient properties to the track, adding vertical elasticity and capacity to attenuate vibrations resulting from passing vehicles. The interaction between the hard particles provides high resistance to compression to the layer. However, upon repeated train loads, the ballast deteriorates and spreads laterally, leading to track instability.

The ballast is constituted by particles with similar dimensions, so that its granular structure can be easily rearranged to facilitate maintenance works. The ballast grading limits from the main international specifications generally lead to grain sizes between 10 and 63 mm [1]. Although some authors argue that laboratory tests on ballast specimens should always be done under full scale particle size distribution (PSD), it is noteworthy that there is no consensus among researchers. Varadarajan et al. [2] studied four distinct techniques for scaling crushed rock specimens and concluded that the best technique would be the scaling-down framework from the original PSD curve, in a process known as parallel gradation technique.

Considering the strength and the deformability of the materials, several researchers conducted studies that pointed out the possibility of carrying out tests in scaled specimens by parallel gradation technique, provided that the individual characteristics of the particles are similar in order to ensure that the material is at the same density level, either in full scale or reduced scale [3] [4] [5]. Aingaran et al. [6] suggest that although there may be some differences in ballast mechanical properties due to the scaling-down approach, the use of scaled down ballast specimens can give insights into the trends of behaviour that may be expected at full scale ballast, especially considering the possibility of comparing alternative materials to other currently used as ballast, since the scaling-down effects act on both materials. This way standard testing apparatus can be used and the specimens can be moulded more easily than with full scale PSD.

This paper presents a brief study, part of a broader research, to investigate possible scaling-down effects on the behaviour of a steel slag ballast material, regarding permanent deformation by repeated load triaxial tests.

2 Methods

In this work a steel slag aggregate obtained in an electric arc furnace (EAF slag), commercially called 'Inert Steel Aggregate for Construction' (ISAC), was studied. This material was previously classified as building material for some transport infrastructure applications [7]. The particles of this material have morphological parameters that distinguish them from the particles of traditional materials, in particular they have a higher value of angularity [8].

To study the influence of PSD on permanent deformation, triaxial tests were performed on large size ballast specimens to guarantee a maximum ratio of 1/5 between the maximum particle diameter and the diameter of the specimens. This value is considered adequate to assure the representativeness of the results [9]. The material was sieved and properly homogenized on a 1:2.5 and 1:2 size parallel gradation from the full scale ballast standard AREMA N. 24 [10] (Figure 1a). The coefficient of uniformity (Cu) and the coefficient of curvature (Cc) of the PSD curve were, respectively, 1.94 and 1.02, which are typical of uniformly graded granular materials. The value of the particle specific gravity (Gs) obtained in laboratory was 3.2.

The materials were manually placed in a mold, with a membrane already positioned. This mold was removed after applying a confining stress by suction (70 kPa) in the specimens, to maintain its geometry (Figure 1b). The specimens were compacted in the triaxial chamber following a procedure similar to standard EN 13286-7 [11] for specimen conditioning, applying 10,000 load cycles with a deviatoric stress value of 340 kPa, and keeping the confining stress constant at 70 kPa. The procedure showed good repeatability, allowing to obtain specimens with initial void ratio (eo) ranging from 0.70 to 0.80 [1]. These values have been reported as representative of the density of railway ballast in lines under operation [12].

The cyclic vertical stress level for the permanent deformation tests, which were performed after conditioning, were defined from empirical equations [13] to simulate a heavy haul axle load of 32.5 tonnes. A vertical stress of 350 kPa (maximum deviatoric stress of 280 kPa and constant confining pressure of 70 kPa) was adopted. The tests were performed with a frequency of 2 Hz, in sinusoidal loading, where the minimum deviatoric stress level was 10 kPa.

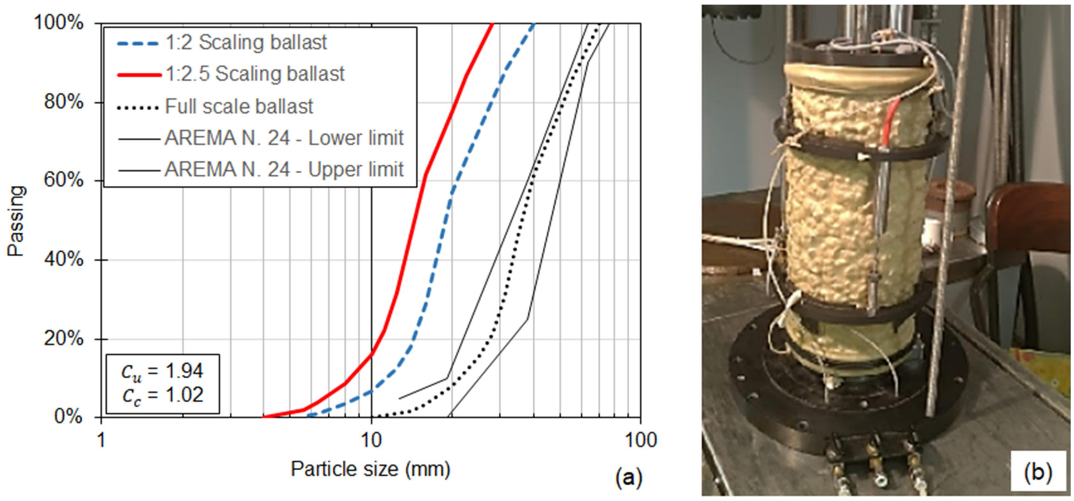

Figure 1: Aspects of the tests: (a) particle size distribution of 1:2.5 and 1:2 scaled ballast specimens from full scale ballast and (b) 1:2 scaled ballast specimen (200 mm diameter).

3 Results

Figure 2a shows the result of permanent vertical strain against the number of load cycles, both in 1:2.5 and in 1:2 scaled specimens. In general, it is observed that the permanent strain curve obtained for the ballast on the 1:2 scale does not differ significantly from that obtained for the ballast specimen on the 1:2.5 scale. In the first 1E5 cycles, both specimens showed similar behaviour. Subsequently and until reaching 3E5 cycles, the 1:2 scaled specimen showed slightly higher permanent deformation.

Figure 2b allows for shakedown evaluation [14] of the studied steel slag ballast, both in 1:2.5 and in 1:2 scaled specimens. The method proposed in EN 13286-7 [11] for the evaluation of the Shakedown behaviour, following Werkmeister's work [14], suggests that a given material has reached Shakedown (Range A), for a particular stress level, if the difference in vertical permanent strain, calculated between load cycles 3000 ($\varepsilon^1_{p,3000}$) and 5000 ($\varepsilon^1_{p,5000}$), is lower than 0.045E-3. In this study, those strain differences ($\varepsilon^1_{p,5000}$ - $\varepsilon^1_{p,3000}$) yielded 0.042E-3 and 0.055E-3, respectively, for 1:2.5 and 1:2 scaled specimens. Although the obtained values were very close and near the Plastic-Shakedown limit criteria, this indicates that, for the tested stress level and considering that established criteria, the 1:2.5 scaled specimen had entered Shakedown, while the 1:2 scaled specimen is undergoing Plastic Creep, though both specimens seem to exhibit comparable long-term behaviour. It is noteworthy that both specimens, although on different scales, had the same initial void ratio (0.79).

The results obtained seem to be in agreement with the studies by Raymond and Diyaljee [15], for which uniformly graded ballasts generate larger permanent deformations the larger the grain size. However, these results differ from those obtained by Sevi and Ge [16], for which the total permanent ballast deformation values showed a tendency to increase in three distinct parallel grain sizes, as the average grain size was reduced. The results obtained by these researches and those obtained in this study highlight the need for further studies for a comprehensive understanding of the main factors that affect the degradation of the ballast material made of different grain sizes.

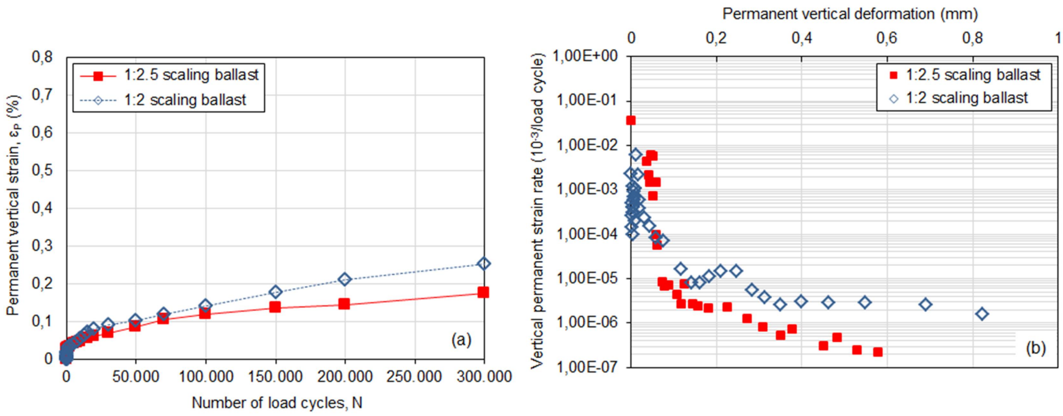

Figure 2: Permanent deformation behaviour for 1:2.5 and 1:2 scaled ballast specimens: (a) permanent vertical strain and (b) shakedown occurrence evaluation.

4 Conclusions and Contributions

The influence of particle size distribution and maximum particle size on the resilient behaviour and permanent deformation of granular materials, when tested under cyclic triaxial loading, is a subject that has been studied by several researchers.

In this work, we use the parallel gradation scaling technique to prepare large scale railway ballast specimens for cyclic triaxial load testing. This technique makes it possible to perform tests faster and using smaller equipment, thus more economically.

The permanent deformation results obtained in the cyclic triaxial tests with 3E5 cycles performed in this work on two rail track ballast specimens seem to show that the effect of changing particle size distribution using this technique is not very relevant.

However, for a more accurate analysis of the permanent deformation behaviour, it is important to perform more tests to achieve a higher statistical significance level and with a much higher number of load cycles, for example one million cycles [1]. Moreover, for higher scaling ratios and more severe stress states, this difference may be accentuated, as higher contact forces between particles may occur (contact forces increase with the average particle diameter) leading to higher levels of particle breakage, consequently, to different values of permanent deformation.

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