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Experimental and numerical evaluation of the ballast densification under different types of tamping operation

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Abstract

The tamping operation is essential in railways since it allows the correction of the track geometry defects. However, on tracks already consolidated by the traffic, the tamping affects the ballast layer, reducing the track stiffness, which later may yield new geometry defects. In contrast, this operation needs to densify the ballast on newly-built or renovated tracks to maintain geometry quality for longer periods. In the Carajas Railway (heavy haul line in Brazil), the practical experience of maintenance indicates that the tamping of a single insertion has not been effective on newly-built or renovated tracks. For such cases, the multiple insertion has been more efficient. Nevertheless, for the authors' better knowledge, there are no studies that evaluate/measure possible differences between these tamping types, for heavy haul lines such as the Carajas Railway. Due to these aspects, this paper aims to evaluate two types of tamping operations: single and multiple insertions of the tamping tines, to evaluate its effectiveness in promoting the ballast compaction. For this purpose, ballast density measurements were carried out in the field. Complementary simulations using a discrete element modelling were made. As results, the field tests showed that the multiple insertion generated a densification 15% higher than the single insertion. In the laboratory, it was observed that the materials used to determine the ballast density in the field presented particle size distributions and particle's shape without significant differences, meaning that the higher compactness achieved in the multiple insertion probably comes from a greater packing of the ballast particles. Through numerical simulations, an analysis of this densification throughout the ballast layer was done, so the arrangement of the aggregates may be better observed. The region underneath the sleeper, where the tamping tines operated, displayed higher densification when compared to the track axis region. Aligned to the field results, the multiple insertion indicated a better compacted zone under the rail. In this way, when applying the multiple insertions, it is expected to achieve a more stable ballast layer with a smaller number of tamping passages to keep the track within the required design limits.

Keywords: Railway track, Tamping operation, Ballast density, Discrete element modelling.

1 Introduction

The load cycles generated by traffic can generate undesirable geometric defects, which may be correlated to geometric deviations due to the ballast settlement [1]. Generally, these defects are corrected through maintenance operations of alignment, levelling and tamping. [2]. In these operations, the superstructure (rails, fastenings and sleepers) is lifted and, subsequently, the tamping tines are inserted into the ballast layer to compact it, filling the void created between the sleeper base and the top of the ballast layer [3]. Although these maintenance operations are effective for the correction of geometric defects, on railway tracks already consolidated by the traffic, these affects the ballast layer and reduces the track stiffness, which later may induce new geometry defects [4]. On the other hand, on newly built or renovated tracks, these operations need to densify the ballast to maintain the geometry quality for longer periods, since in these conditions the ballast is not very dense and tends to accumulate settlements [5,6].

The practical experience of maintenance on the Carajas Railway (heavy haul line in Brazil) indicates that the tamping of a single insertion has not been effective, for newly constructed, renovated sections or even already consolidated by traffic sections that required high lifts of the superstructure to correct geometric defects. For example, when single insertion of the tamping tines is applied in such cases, a higher number of tamping repetitions is required to obtain the desired geometric quality. Therefore, for such cases, the maintenance practice of the Carajas Railway has been a multiple insertion, since it has been reducing the number of tamping repetitions or even the need for early reworks due to irregularities resulting from the rapid ballast settlement. Although field experience indicates that multiple insertion generates better results, for the authors' better knowledge, there are no studies that evaluate/measure possible differences between these tamping types, for heavy haul lines such as the Carajas Railway.

In this context, this paper aims to evaluate/compare two types of tamping operations: single and multiple insertions of the tamping tines, in order to evaluate its effectiveness in promoting ballast compaction. For this purpose, two experimental sections were selected in the field and, subsequently, the density of the ballast layer was measured under single and multiple tamping conditions. Complementary computational simulations were performed using a calibrated discrete element model, aiming to compare the results and understand the ballast compactness profile under the proposed tamping conditions.

2 Methods

The two experimental sections were selected in Yard No. 5 of the Railway Branch Southeast of Para (Carajas Railway - northern Brazil). These experimental sections were recently built and has: (i) RE 136 rail; (ii) wide gauge (1.6 m); (iii) concrete sleeper; (iv) granite ballast with particle size distribution within the range No 24 recommended by AREMA [7] and 0.32 m thick. Subsequently, tamping operations of single or multiple insertions were performed in each experimental section, highlighting that, in the case of multiple insertion, the superstructure was lifted only once, remaining in the same position during the second insertion. The parameters of the different tamping types are presented in Table 1.

Types of insertion	Squeezing time (s)	Frequency (Hz)	Amplitude (mm)	Track lifting (mm)	Tamping depth* (mm)
Single	1.0	35	5	20	420
Multiple	0.8				
	0.6				

*15 mm below the sleeper.

Table 1: Tamping parameters

After the tamping operations, two measurements of ballast density were performed for each insertion type: the first on the track axis and the second close to the rail, both measured in the region between the concrete sleepers. The measurement technique used was similar to the water method developed by Yoo, Chen and Selig [8] and used by Fortunato [9] and Liu et. al [10], which is considered a satisfactory/adequate method for determining the field density of railway ballast (Figure 1). Basically, this method obtains the ballast density through the ratio between the mass of particles removed from a hole made in the ballast and the volume of this hole obtained through the water. Subsequently, in the laboratory, the removed ballast was subjected to particle size distribution and shape tests.

Figure 1: Water method for measuring ballast density

Rocky DEM was the commercial Discrete Element Method (DEM) chosen to conduct the tamping computational analysis, respecting the geometry and motion of the operation, furthermore, benefiting from an own digitized ballast library of the studied railway. To obtain the density in different regions of the ballast layer, it was developed a technique that consists of selecting the particles within a control-volume through their centroids (Figure 2a) and digitally coating this sample with a heat-shrinkable material tool provided by the software SpaceClaim (Figure 2b), intending to determine the volume occupied, in a similar way to the procedure done in the field.

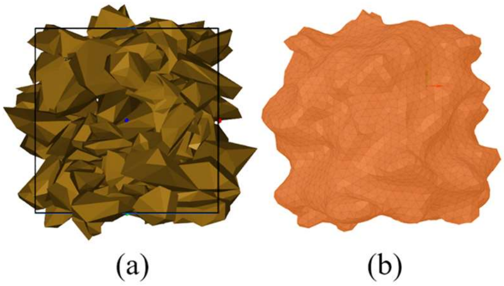

Figure 2: (a) control-volume selected by particles' centroid and (b) volume obtained by a heat-shrinkable material tool

3 Results

From the results obtained in the field, it was observed that the track axis presented a ballast density around 1.64 g/cm³ for both single and multiple insertions, a value similar to that found by Yoo, Chen and Selig [8]. In contrast, in the region close to the rail, the values were 1.64 g/cm³ and 1.94 g/cm³ for single and multiple insertion, respectively. Therefore, the multiple insertion presented a 15% higher ballast density than the single insertion. Furthermore, the value corresponding to single insertion was similar to that found by Yoo, Chen and Selig [8], while the value of multiple insertion was similar to that found Liu et. al [10]. Finally, the results of the laboratory tests showed that all materials from the holes used to determine the ballast density presented similar particle size distributions. Likewise, no significant differences were detected in the shape of the ballast particles for the materials tested.

As a result of numerical simulations, an analysis of this densification throughout the ballast layer was done, so the arrangement of the aggregates may be better observed. Furthermore, the region underneath the sleeper, where the tamping tines operated, displayed higher densification when compared to the track axis region. Aligned to the field results, the multiple insertion indicated a better compacted zone under the rail.

4 Conclusions and Contributions

This study aimed to evaluate/compare two types of tamping operations that apply single or multiple insertions of the tamping tines, in order to assess their efficiency in promoting better ballast compaction. It is noteworthy that, for best of authors' knowledge, there are no studies that evaluate or measure possible differences between these tamping types, for heavy haul lines such as the Carajas Railway.

In general, the field measurements of the density of the ballast layer showed that the multiple insertion provided a higher compactness when compared to the single insertion. Furthermore, the laboratory tests showed that the particle size distribution and the shape of the ballast particles were very similar, meaning that the higher compactness achieved in the multiple insertion probably comes from a greater packing of the particles and not due to the greater presence of fine or non-cubic particles. Consequently, when applying the multiple insertions, it is expected to achieve a more stable ballast layer with a smaller number of tamping passages to keep the track within the required design limits.

The results obtained in the field tests could be reassured throughout the computational model. It was possible to extrapolate the data collected by measuring the ballast density in a variety of regions and understand the compactness profile.

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