Geotechnical and structural behavior of the railroad track in Large-scale Apparatus

Géotechnique et Comportement Structurel de la Voie Ferrée dans Appareil à Grande Échelle

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ABSTRACT
This paper analyses the static and dynamic behavior of the railroad track model in laboratory. Measurements of stresses and strains on a large-scale railroad track apparatus were studied. The model includes: compacted soil, representing the final layers of platform, ballast layer, and ties (steel, wooden, and pre-stressed concrete). The soil and soil ballast interface were instrumented with pneumatic stress gauge. Settlement measurement device were positioned at the same levels as the load cells. Loads were applied by hydraulic actuators, statically and dynamically. After the prescribed number of load cycles, in pre-determined intervals, stresses and strains were measured. Observations indicate that stress and strain distributions, transmitted by wooden or steel ties, behave similarly. A more favorable behavior was observed with pre-stressed concrete mono block ties. Non-linear response was observed after a threshold numbers of cycles were surpassed, showing that the strain modulus increases with the numbers of cycles.

RÉSUMÉ
Cet article analyse le comportement statique et dynamique d'un modèle de voie ferrée en laboratoire. Les tensions et les déformations furent étudiés sur une appareillage de voie à grande échelle. Le modèle inclut: du sol compacté, de façon à représenter les couches finales de la plate-forme, une couche de pierre concassée et les dormants (faits en acier, en bois et en béton précontraint). Le sol et la surface de séparation entre le sol et le pierre concassée ont été instrumentée au moyen des cellules de charge totaux. Les dispositifs de mesure furent positionnés au même niveau des cellules de charge. Les charges furent appliqués avec chargeurs hydrauliques, statique et dynamiquement. Les tensions et les déformations furent mesurés après le numero des cycles de charge préconisé et en intervalles prédéterminés. L'observation des résultats indique que la distribution de tension et de déformation, transmise par les dormants en bois ou en acier, ont comportement similaire. Le comportement plus favorable observé a été le des dormants en béton précontraint. Une réponse non linéaire a été observée aprés le dépassement d'un numero critique de cycles, en démontrant que le module de deformation augmente avec le numero de cycles.

Keywords: railroad track, railroad ties, railroad large scale apparatus

1 INTRODUCTION

The railroad infrastructure is composed of soil layers, placed below the ballast layer. Tracks consist of two parallel steel rails, which are laid upon railroad ties (or cross ties) that are embedded in ballast to form the railroad track. The rails are fastened to the ties with rail spikes, lag screws or clips. Additionally, the sub-ballast is included in some railroad track.

The group formed by the infrastructure and superstructure is denominated railroad permanent way or railroad track; the group formed by the rails and ties is denominated track of the railroad. Periodically, ballast must be removed and replaced with clean ballast to ensure adequate drainage, especially if wooden ties are used.

The track is not rooted in the soil despite it is partially embedded in the ballast. The static or dynamic aspects, under general conditions, usually differ enough from those that are verified in the civil construction.

The rails, fastening, and ties, are defined as structural elements, in spite of the great variety of types, they are made of materials from certain mechanical properties. On the other hand, the study of the ballast, which is composed of crushed stone as a part of the railroad track, did not suffer a parallel development such as other components.

Several models that represent the behavior of the elements of the railroad track, separately or together, were proposed by several authors. (Talbot 1919), (Pita 1976), (Schramm 1977), (Raymond 1978), (Sauvage & Richez 1978), (Castro & Mori 1979), (Sauvage 1981), (Mattner 1986), (Queiroz 1990), (Queiroz & Gaioto 1994), (Indraratna 1998) and (Queiroz 2002).

The studied model, in natural scale, is constituted of a traverse section of railroad track. It is separately composed, for steel tie, wood tie, and pre-stressed concrete mono block tie and is installed on a ballast layer and compacted soil inside on a reinforced concrete box. The physical model is wrapped up for a reaction system and application of static and dynamic loads.

Constituting of rehearsals of railroad track, in laboratory, pioneer in Brazil. A consequence of the aforementioned, it is reasonable to disclose the importance of the following considerations, which constitute the objectives of the present paper:

1. To quantify through instrumentation the development of the stresses and strains in the contact ballast-soil, through the application of representative static and dynamic loads of the rail operation.
2. To analyze the acting of the three main types of ties comparatively, relative to the stresses and strains produced in the railroad track application of the loads. The following section

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-279

presents details of the stress distribution induced by the external loads.

2 MATERIALS AND METHODS

2.1 *The studied model*

The model formulated in the current study considers a traverse section of the railroad track composed by an only tie, which receive loads from the rails and transmitted to the ballast and the platform.

The tests were carried out in the laboratory of the Grouping of Infrastructure and Geotechnical Works, and the Center of Railroad Development, of the Institute of Technological Researches of the State of Sao Paulo, Brazil. The model, in natural scale, was constituted of a box built of reinforced concrete in the dimensions 3.7 x 1.3 x 1.0 m, length, width and height, respectively, with walls that are 10 cm thick.

The box of tests was assembled with screws comprised of a steel structure system for reaction and application of the loads. The equipment of application loads was MTS - Testing System, and operates in segments with the dynamic application of the loads.

In the tests preparations, were thrown inside the box several soil layers compacted and instrumented with pneumatic stress gauge and tassometers. Soon after, a ballast layer was thrown, composed by crushed stone, to receive the tie with the applied loads. The ballast was only compacted in the layer under the rails, with special equipment used in railroad track.

2.2 *Characteristics of the materials*

The soil (also known as sandy clay) used as bottom layer (platform), was characterized with deformed samples, obtained by the standardized Liquid Limit (NBR6459-ABNT), Plastic Limit (NBR7180-ABNT), Grain Size distribution (NBR7181-ABNT), Compaction (NBR7182-ABNT – Brazilian Association for Technical Standardization), and CBR (California Bearing Ratio) (DNER-ME254 – Department of Brazilian Roads).

After the characterization, the soil was thrown in the box and compacted under control, in layers of 10 cm thick, until it reaches the total height of 50 cm.

Together with the compaction of the soil in a definitive way, were installed measurement instrumentation of the pneumatic stress gauge (Figure 1), and displacements system (tassometers), positioned as shown in the Figure 2.

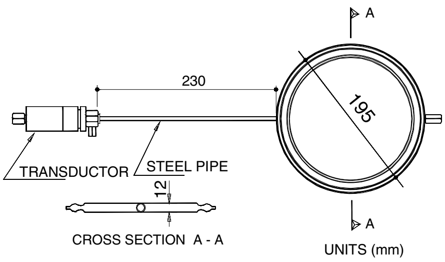
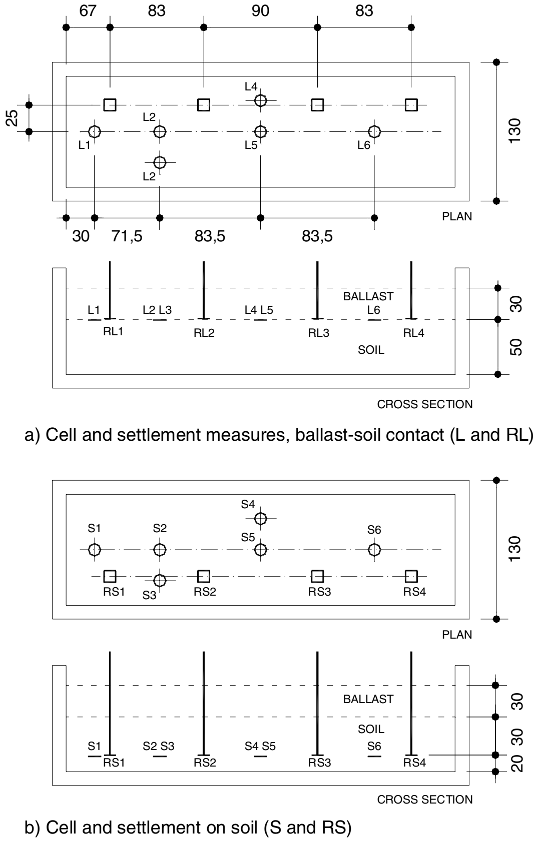


Figure 1. Pneumatic stress gauge model IPT.

The ballast was composed by crushed stone formed by granitic rock, possessing the geotechnical characteristic in agreement with the Brazilian standards of ABNT (Brazilian Association for Technical Standardization) and ASTM (American Society for Testing and Materials), and was laid on box with a layer of 30 cm in height. The ballast was compacted in a region with width around 45 cm to the left and the right of each rail, which required special equipment for ballast compaction in railroads.



a) Cell and settlement measures, ballast-soil contact (L and RL)

b) Cell and settlement on soil (S and RS)

Figure 2. Positions of the pneumatic stress gauge and tassometers.

The following three types of ties were used: steel, wood, and pre-stressed concrete mono block, for broad gauge of 1600 mm.

The first test was accomplished with the steel tie, type UIC-865-1 manufactured in Brazil by CSN (Companhia Siderúrgica Nacional) dimension of 2,65x0,27x0,09 m, length, width and height, respectively. The second test was accomplished with wooden tie, composed by the essence Jatobá (*Hymenaea courbaril L.*), in the, standard dimension of 2,80x0,24x0,17 m, length, width and height, respectively. The third test was accomplished with the pre-stressed concrete mono block tie pattern used by railroads in State of Sao Paulo, Brazil dimension of 2,76x0,27x0,25 m, length, width and height, respectively.

The loads jacks were fastened in the structure of reaction on test box in such as way to apply the loads exactly in the vertical (Figure 3).

The rails segments, TR-68 were fastened on the tie with the base plates and elastic rail clip, *Pandrol*. The rails received static and dynamic loads, in phase, with a maximum variation of 100 kN and minimum of 5 kN.

The frequency of dynamic loads was two cycles per second which is similar to a frequency of two trucks passage under an average speed of 80 km/h.

The tests with the three types of ties were accomplished in a similar way. The two rail segments were submitted, simultaneously, to dynamic loads with 500,000 cycles, for each tie.

The static loads and the readings in the instrumentation were accomplished before and after the application of each load interval with the following values: 33 kN, 66 kN and 100 kN (Table 1).

The maximum load of 100 kN corresponds to adopt the following conditions:

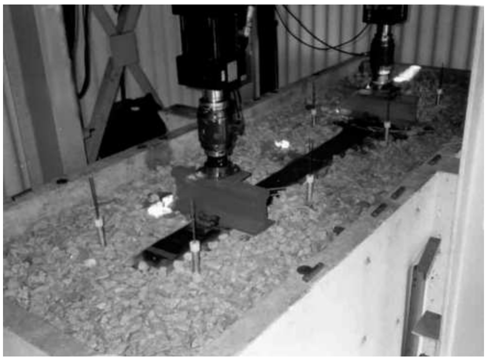


Figure 3. Showing the tie and the system of load applications in the test box (Photo: Author).

a) Wheel load: P = 150 kN (load train),
b) Load distribution coefficient per tie: $\alpha_1 = 0.5$ (medium value calculated for rail TR-68 and the conditions of the railroad model),
c) Dynamic coefficient: N = 1.30 - method of the AREA (American Railroad Engineers Association), for speed V = 80 km/h.
Therefore, it has:

$$P_d = a_1.N.P = 0.5 \times 1.3 \times 150 = 97.5\,kN \tag{1}$$

Value approached for 100 kN.

Table 1. Load intervals and number of load cycles (N).

Tests	Load cycles number (N)
1	0
2	25,000
3	50,000
4	100,000
5	150,000
6	225,000
7	300,000
8	400,000
9	500,000

3 OBTAINED RESULTS AND ANALYSIS

With readings from the pneumatic stress gauge installed in the contact ballast-soil and inside the soil, the stress distributions are showing in Figures 4, 5 and 6, for 500,000 cycles and 100 kN load.

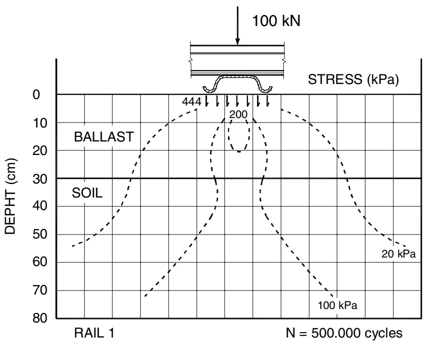


Figure 4. Stress distribution in the ballast and in the soil by steel tie, for N = 500,000 cycles.

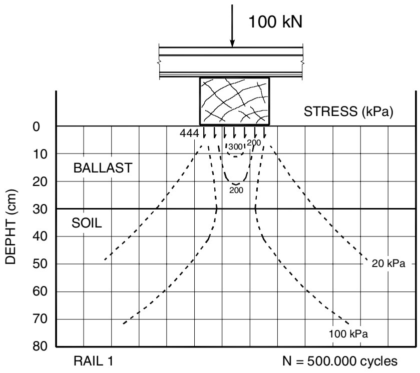


Figure 5. Stress distribution in the ballast and in the soil by wooden tie, for N = 500,000 cycles.

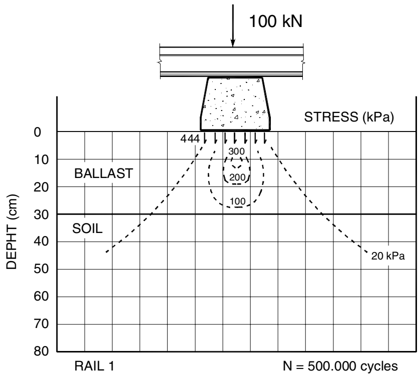


Figure 6. Stress distribution in the ballast and in the soil by pre-stressed concrete mono block tie, for N = 500,000 cycles.

In agreement with Figures 4, 5, and 6, for the concrete tie, the stress resulted in an approximate value of 120 kPa, at 25 cm deep in the ballast. In the steel tie and wooden tie the value of 120 kPa was going reached in 30 cm deep in the ballast.

Based on the results, it is possible to consider, as expected, that the pre-stressed concrete mono block tie requires a smaller ballast height when compared with the steel tie and wood tie, resulting in considerable economy in the volume of ballast material in the railroad track.

The results of the displacements system positioned in the ties' surface, after the application of 500,000 load cycles, are displayed in the elastic behavior of the Figure 7.

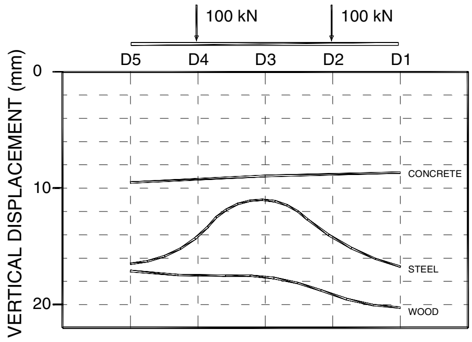


Figure 7. The pre-stressed concrete mono block, steel, and wooden ties elastic deformations, with 100 kN and after 500,000 load cycles.

With base in those results, it can be verified that:

a) The steel tie suffered a larger flexion than the others which resulted in a smaller vertical deformation in the axis of the railroad than in the extremities;
b) The wooden tie is comprised of a small deflection that stays in the extremities which is approximately in the same settlement

level as down of the steel tie. There was a larger displacement in the right extremity which is, probably due to non-homogeneity of the ballast and of the application of the static loads;

c) The pre-stressed concrete mono block tie was verified in a smaller deflection and deformation (approximately half) in relation to the steel and wooden ties. That is due to, probably, to a larger area of the ties' contact with the ballast and to its largest rigidity in relation to the other rehearsed ties;

d) Based on the results, it can be considered that the distribution of stress in the inferior face of the three types of tested ties should not be the same. Results indicate that the pre-stressed concrete mono block tie, using a more efficient ballast layer, should produce a distribution more uniform of the stress in the contact tie-ballast;

e) The steel and wooden tie, due to its flexibility, should concentrate its efforts in the compaction lane below the rails; however, the pre-stressed concrete mono block tie, because of larger rigidity, should receive the compaction in a larger lane than the steel and wooden ties. Inside the soil (30 cm from surface), they registered maximum deformations as: Steel tie = 0.72 mm; Wooden tie = 0.85 mm; Pre-stressed concrete mono block tie = 0.36 mm.

4 CONCLUSIONS

1. The stress and strain reached by the steel and wooden ties showed a similar behavior. The pre-stressed concrete mono block tie displayed favorable results regarding the others ones studied;
2. On the similar loads conditions, the pre-stressed concrete mono block ties require a smaller ballast height and a wider dynamic compaction than the other ties studied, which results in a great economy of ballast material in railroad of great extension;
3. Finally it can be considered a pioneer research for these ties and model studied for the stress and displacements in railroad track in a similar condition.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to Fapesp (The State of Sao Paulo Research Foundation), and IPT (Institute for Technological Research), Sao Paulo. In addition, the authors would also like thanks the Department of Civil Engineering of Unesp (Sao Paulo State University), Bauru, (SP), Brazil.

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