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Structural behavior evaluation of Brazilian glulam wood sleepers when submitted to static load

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A B S T R A C T

This work is about the behavior evaluation of structural wooden sleepers through experimental stress analysis. The wood used for the glulam sleeper was *Eucalyptus Citriodora* with 9.9 kN/m^3 density. The experimental program includes the assay system assembly which simulates the real situation. The static loading assay determined the deformations, through strain gages (single-element gage, two-element gage and three-element rosettes), and the displacements along the sleeper, using linear displacement transducers. Applying the elasticity theory for orthotropic materials, tensions in various parts of the sleeper were determined until 200 kN load limit and compared with a numerical model that uses MEF. The results are acceptable. The Brazilian glulam wood sleeper has a elevated performance as the collapse maximum load, when compared with predicted formula values presented by several researchers, was 110% higher.

1. Introduction

The rail transport system has been used since the beginning of the XIX century in Europe. In Brazil, the first railroad built was the Mauá Railroad in 1854 [1]. In 1820, the sleepers, or crossties, were made from stone blocks but later they were banned and replaced by wood due to hardness problems and their inability to hold the railway gage. The reason to choose wood as a replacement material is because its lower mass compared to stones being easier to handle, easier to install while has good insulate properties, as well as a capacity to resist to high vibrations.

In Brazil, are normally used high density wood sleepers [2]. In the US, they are manufactured with hard treated wood, while in Europe they are usually made of concrete [3]. Concrete sleepers have a more defined geometry which allows better alignment and standardized measures. However, they are relatively more expensive than wood sleepers, even being designed for a 40 years life time in service [4]. In contrast, steel sleepers have a superior resistance and longer durability than wood and concrete sleepers but, due to its high cost, they are moderately used [5].

Studies have indicated that wood is being used and will continue to be used as railroad sleepers [6]. The main reasons for this are: (a) adequate availability of timber resources; (b) experience that track engineers and maintenance crews have with wood sleepers; (c) compatibility of existing track equipment with wood sleepers; and (d) manufacturing and handling simplicity. Wood sleepers are cost-effective in relation to concrete and steel sleepers and their field-performance has been reasonably acceptable [3].

Some wood sleepers disadvantages are known nowadays. The most important is that they are susceptible to xylophages organisms attack that could lead to its collapse. On the other hand, the damage caused by the load distribution plaque [7] (crushing to the normal fiber compression) and by the gravel (abrasion) combined with wood fissures, caused by wood drying, results in the sleepers premature collapse and its consequent service removal. This is evidence for a need to develop modern technologies improving the performance and increasing the life time in service of wood sleepers.

According to Qiao et al. [3], many efforts are been made to improve the wood sleepers performance such as the use of more efficient and ecological preservatives and screws to avoid wood fissures. Reinforcement with fiberglass grille (FPR) increases considerably the rigidity and the resistance of wood sleepers however, a special concern should be taken in the glued interface resistance which is influenced by the wood surface texture and by the characteristics of the resin used [8,9].

A typical railroad track consists on four main elements: subgrade, ballast, sleepers (or crossties) tie-plates and connectors, and two parallel steel rails. The sleeper is the key element among these structural components. The main functions of the sleepers are: (a) transfer and distribute the rail loads to the ballast, (b) transversely secure the rail and maintain them to correct gage-width and (c) resist the cutting and abrading actions of bearing plates and ballast material.

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The sleeper sizing as a structural element according to Rives et al. [10] is a notable difficult problem, which brings us to use close methodologies. Two aspects of the problem are needed to know: the ultimate loads transmitted by the rail and the reaction forces due to ballast. As the vertical load is the main influence parameter affecting the railway, it is usually consider alone to the sleepers static load analysis. One of the most commonly used methods to determine the maximum force transmitted to the sleepers is the Eisenmann method that uses the Eq. (1), [1].

$$P_{máx} = \frac{(Q \cdot a)}{2} \cdot \sqrt[4]{\frac{b_d \cdot c}{4 \cdot E \cdot I}} \cdot \left[1 + t \cdot \delta \cdot \left(1 + \left(\frac{V - 60}{140}\right)\right)\right] \quad (1)$$

where $P_{máx}$ is the load on rail basis (kN); Q is the applied load per wheel (kN); a is the spacing between sleepers (cm); b_d is the sleeper's width (cm); c is the compact range (cm); E is the modulus of elasticity (kN/cm^2); I is the inertia moment (cm^4); t is the multiplier factor, tabled value, dimensionless; δ is the coefficient that depends on the track conditions, dimensionless; and V is the speed (km/h).

The authors indicated that the maximum force on the rail basis shall be increased in 40% or 50% due to the superposition of the other railroad trucks [11,12].

In this study glued laminated wood (glulam) sleepers were used, manufactured with high density eucalyptus wood (*Eucalyptus Citriodora* with 10 kN/m^3 basic average density) and a water resistant adhesive (resin resorcinol formaldehyde).

The main purpose of this work is to evaluate the structural behavior of *E. Citriodora* glulam sleepers when submitted to static load, through experimental stress analysis using uniaxial electrical extensometers (SG), rectangular rosettes (SGR) and displacement transducers (DT) to determine tension distribution and deformations through the sleeper. Aiming to reproduce the real conditions, a wood box was used filled with sand (20 cm depth) simulating the sub-grade with gravel number 3 (41 cm depth) to simulate the ballast bed. Using ANSYS, version 9.0 Software, the numerical simulation analysis found the highest deformation and stress points to a static load produced by 115-RE rail type (AREMA standard steel rails), where electrical strain gages, bi-axial and tri-axial rosettes have been installed and the data collected. The tension and displacement experimental values were compared to the numerical values.

2. Materials and methods

2.1. Experimental program

The sleeper static testing was carried out on a sand box of the Geotechnical Laboratory of the Federal University of Minas Gerais, Brazil. The box was designed to resist a maximum load of 500 kN and has the following dimensions: 2.76 m length, 0.78 m width and 1.20 m height.

2.1.1. Materials

The materials used to simulate the railroad track were: sand sub-grade, gravel ballast, sleepers, rail pad, connector and a 115-RE rail type (AREMA standard steel rails).

2.1.1.1. Sand sub-grade. The sub-grade consists of a thin sand with properties listed below following the characteristics mentioned by [1] and a 20 cm height. To determine the specific sand weight (unit weight) "a sand bottle test" was done and produced a 19.10 kN/m^3 value. Using the depth value, the Talbot Method was used to calculate the stress that the loading produces in the sub-grade. A 0.13 MPa value was obtained, value below 0.14 MPa (recommended maximum value). So the sub-grade depth adopted was according to the demanding requirements and also according to the California Bearing Ratio (CBR) which is 30%.

2.1.1.2. Gravel ballast. According to Brina [1] specifications, a choice was made to use Gravel number 3 Gneiss type, as raw material for the ballast. In Table 1 are the average results of characterization tests for three samples.

Table 1
Results obtained in the gravel.

Data	Value	Unit
Mass per volume unit	27.16	kN/m^3
Los Angeles wear abrasion	28	%
Clay content	0	%
Powdery material content	0	%
Water absorption	0.19	%
Apparent porosity	0.14	%
Friable soft fragment content	0	%
Impact strength TETRON	4	%

Fig. 1. Plaque assay.

Analyzing the results obtained and considering several bibliographies, it is noticed that all demanding specifications are satisfied. The ballast depth was 22 cm and according to Brazilian Standard NBR 7914 [13] the ballast shall involve the sleeper and its depth shall be 5 cm below the sleeper superior face, thus the ballast height became 33 cm. Also [13] recommends that the tension in the sub-grade shall not exceed 0.14 MPa. Thus it was decided to increase the ballast height to 30 cm below the sleeper and add 11 cm to involve it, thus the total depth is 41 cm.

The modulus of deformation of the gravel was determined by plaque assay, according to the guidelines of ASTM D 1196. Fig. 1 shows this test, there are three DTs for measurement of displacement. In Fig. 2 shows the results in a graph load versus displacement. The modulus of deformation was determined through a linear regression considering the linear part of the curve, 0–70 kN (modulus of deformation is 227.50 N/cm).

2.1.1.3. Sleeper (wood). The *E. Citriodora* glulam Sleeper has 22 cm width, 16 cm height and 200 cm length, satisfying the NBR 7511 standard requirements [14].

The sleeper was sent by the "Ferrovia Centro Atlantica/Companhia Vale", including fasteners for correct installation of the rail, Fig. 3.

To characterize the wood specimens were tested under compression parallel to grain, compression perpendicular to grain and bending, following [14,15]. The compression tests were made by the Universal Testing Machine EMIC DL 30.000 and the bending tests by Universal Testing Machine DL 3.000. Three specimens were used in each testing. Table 2 shows the resulting test data.

According to Ref. [14] the relation between the modulus of elasticity parallel (E_P) and perpendicular to grain (E_N) is $E_P/E_N = 20$. Many authors [2,4,6,21] consider this ratio (E_P/E_N) at around 12.5. This value is close results of the tests ($E_P/E_N = 12.4$).

2.1.2. Testing box

To carry on this test, the box was filled with 20 cm of sand simulating the sub-grade of a Railway and afterwards it was filled with approximately 30 cm of gravel number 3 reproducing the ballast and then 11 cm of the same gravel was added involving the sleeper, Fig. 4.

2.1.3. Sleeper instrumentation and assay preparation

To determine the deformations, unidirectional strain-gages (SG) were used to measure in one direction, two-element rosette (SGB) formed by 2 SG to measure in two perpendicular directions and three-element rosette (SGT) formed by 3 SG to measure in three directions (two perpendicular and one at 45°), Fig. 5. To mea-