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Structural Performance of a Timber-Concrete Bridge Prototype

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***Abstract*—**Timber-concrete structures were recently introduced in Brazil as a viable option for bridge construction on side roads. Binding between timber and concrete is fundamentally important to assure the rigidity and performance of this structural system. The objective of this study was to assess the structural performance of a timber-concrete bridge prototype with width of 170cm and span of 400cm, whose binding among timber beams and concrete slabs was made with metal pins, obtained from CA 50 construction steel bars of 12.5mm diameter. It was possible to conclude, from the results obtained experimentally in laboratory, that the timber-concrete bridge prototype showed a good structural performance. This structural system provides an economical, rapid implementation solution, which may be used on side roads, favoring regional integration and agricultural production flow.

***Keywords*—**Binding, bridge prototype, timber and concrete.

I. Introduction

BRIDGES may be defined as works of art, intended for transposing obstacles – natural or unnatural –, making possible safe and comfortable locomotion of vehicle and pedestrians. On side roads, these works are fundamentally important for regional integration and for providing traffic conditions for trucks and machinery (on the agribusiness sector), during the harvest season, as well as favoring final agricultural production flow [1], [2].

Brazil, a country of continental dimensions, has a large number of narrow rivers which need bridges construction or renovation of the existing ones. Using timber-concrete structures may be the solution for problems related to economic viability of construction or reformation of these structures, to bring them more durability. However, these structures are more frequently and trustfully used when they are supported by normative guidelines, concerning structural design and implementation [3].

According to [1] and [2], the timber-concrete mixed structure technique distinguishes itself from the other techniques of structural systems for bridge construction on side roads, for it provides a rational solution for the use of such materials, which results in benefits on the constructions' durability. It is important to notice that timber parts used to (partly) build the board structure are also part of the formwork for concrete placement – this way exempting the use of shoring. Finally, the timber-concrete mixed structure technique provides a viable solution for bridges constructions or renovations, which contributes with improvements to the network of side roads.

This work's objective was to assess the structural performance of a bridge prototype built with timber and concrete, with nominal dimensions of 170 cm width and 400 cm span, whose binding among the timber beams and the concrete slab was made with metal pins.

II. Materials and Methods

The kind of timber which was used in the timber-concrete bridge construction was Eucalyptus Urophyla – *Eucalyptus urophylla*, classified according to [4]. The metal pins used for binding (Figs. 1 (a) and (b)) were made of construction steel bars CA 50, cut on 12.5mm diameter, 150mm length, riveted with 15cm spaces among each other, on pre-drilled holes of 11mm diameter and 100mm depth. A minimum reinforcement was adopted for the concrete slabs, referring to 0.15% of the cross-sectional area to support the efforts, according to [5]. Four timber beams were used for building this bridge prototype. They were characterized through a non-destructive test of static bending, according to [4]. The concrete used for the slab of the timber-concrete bridge prototype was characterized according in compliance with [5].

(a)

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(b)

Fig. 1 Metal pins put on the wood beams (a) and (b)

During the timber-concrete bridge prototype assembly, timber beams were arranged according to their connectivity and modulus of elasticity. Timber beams which presented higher modulus of elasticity were place longitudinally at the center of the bridge prototype. The beams were arranged with inverted connectivity, then leveled, so that the thickness of the reinforced concrete slabs were even, when the concreting was carried out; all the slab reinforcement was raised on average 1 cm from the bottom of the mold, by using mortar spacers. Before reinforcement was set, the form was covered with a plastic tarp, to facilitate the form removal after the 28 days of concrete cure. The concrete mix which was used for the bridge prototype construction was made of CP II F 32 cement, coarse sand and number 1 gravel. A total of 550 liters of concrete was prepared, with a mix of 1:3.8:2.4 and a water/cement ratio of 0.60.

Experimental tests on the timber-concrete bridge prototype were performed in laboratory. To obtain data on vertical displacement, timber and concrete deformation, instruments were placed on the central section of the timber-concrete bridge prototype (Fig. 2). An Iotech DAQbook 120 data acquisition system was used to obtain data from 0.001 mm precision dial gauges, KC70–A1–11 and KFD5–C1–11 strain gauges (SG), and a 1000kN capacity load cell; this system was loaded on a DASYLab 5.0 data acquisition software interface.

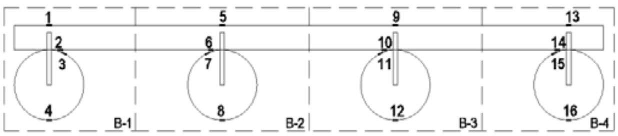

Fig. 2 Localization of instrumentation used for measuring displacement and deformation of the bridge prototype's central section

The timber-concrete bridge prototype essays were carried out with applied concentrated loads simulating a vehicle axis on reduced 1:2 scale, located on the central section, according to Figs. 3 (a) and (b).

(a)

(b)

Fig. 3 Timber-concrete bridge prototype test (a) and (b)

III. Results and Discussion

The characterization data of timber beams and concrete slabs are shown on Tables I and II.

TABLE I
DIMENSIONS AND EXPERIMENTAL RESULTS OF WOOD BEAMS CHARACTERIZATION

Beams	d_w (cm)	$E_{c0,m}$ (kN/cm^2)
B-1	18.0	1089.3
B-2	15.5	1536.0
B-3	14.5	1510.8
B-4	16.0	1301.0

TABLE II
DIMENSIONS AND EXPERIMENTAL RESULTS OF CONCRETE SLABS CHARACTERIZATION

$E_{c,m}$ (kN/cm^2)	$f_{c,m}$ (kN/cm^2)	h (cm)	w (cm)	l (cm)
3800	2.6	7	170	410

On Figs. 4 (a) to (e) the obtained results from the experimental tests on the timber-concrete bridge prototype are presented. These results show vertical displacement and deformation arising from simulations with load train on reduced 1:2 scale. Experimental results were obtained with care not to exceed an L/500 deflection value (8mm vertical displacement) on the central section of the timber-concrete

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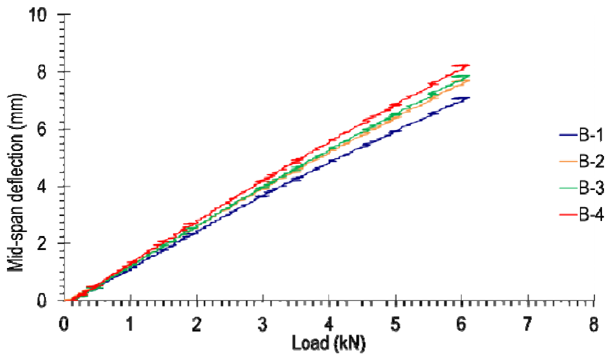
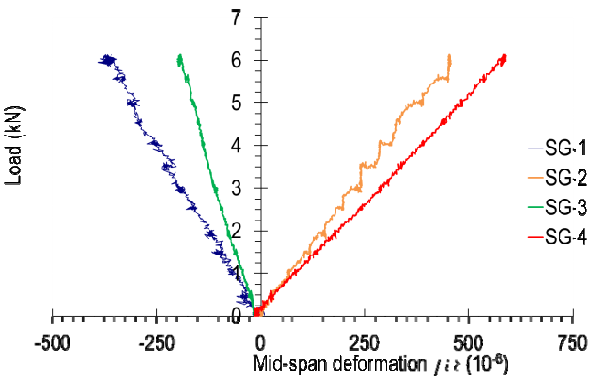
bridge prototype. The L/500 vertical displacement limitation was due to the serviceability limit state for reinforced concrete structures, according to [5], being lower than the L/200 vertical displacement limitation on the serviceability limit state of timber structure designs, according to [4].



(a)



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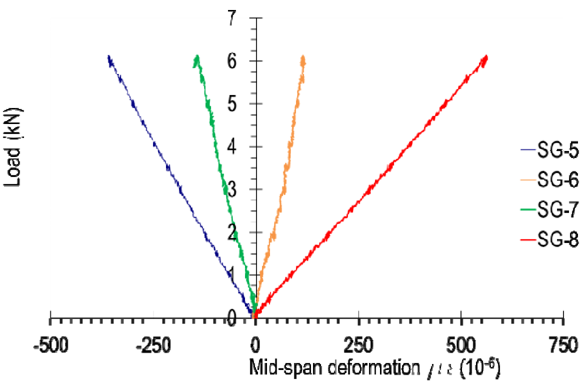

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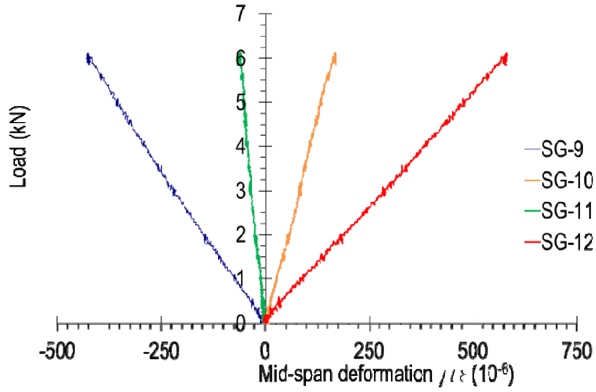

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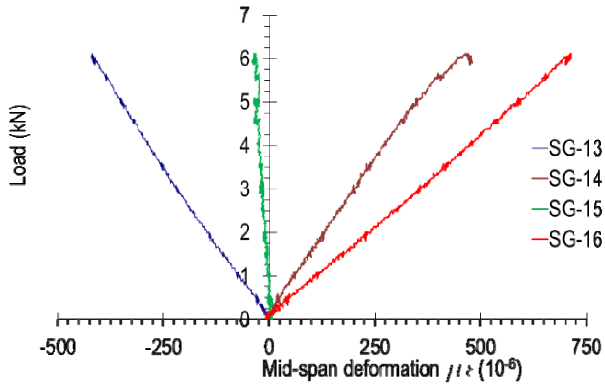

(e)

Fig. 4 Mid-span deflection (a), deformation (b) B-1, (c) B-2, (d) B-3 and (e) B-4

In this experiment, the bridge prototype was taken to rupture by means of the same loading, simulating a load train (Figs. 5 (a) and (b)); the rupture occurred because of a puncture on the concrete slab with a load value of 285kN (142.5kN per wheel) and 8cm vertical displacement. Under these conditions, concrete had also ruptured because of compression on the central cross section of the timber-concrete bridge prototype.

(a)

(b)

Fig. 5 Rupture of the bridge prototype's central section (a) and (b)

IV. Conclusions

From these laboratory experimental results, it is possible to conclude that the values of vertical displacements and deformations are linear up to an L/500 serviceability limit deflection of the reinforced concrete, which confirms the good performance of this structural system.

The study of the timber-concrete bridge prototype also contributes to a better understanding of the binding between these two materials by metal pins tacked with no glue. Certainly, metal pin connectors bounded as an "X", with smaller spacing, may provide greater efficiency for this type of binding. Besides that, further studies about cyclic loading in this type of binding are needed, in order to assess the service life of this structural system.

The timber-concrete structural system may be used for bridge construction on side roads, once it provides an economical, rapid implementation solution, favoring faster regional integration, and consequently an agiler agricultural production flow.

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