Field Load Test Behavior of Composite Log-Concrete Bridge – P01

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Abstract

In Brazil, the composite log-concrete bridges are being considered as a viable alternative for municipal and rural use, mainly because of their low construction cost, low maintenance needs and their high strength and stiffness. The system consists in a thin concrete slab over round timber beams. Materials are thus used to their best abilities where timber is in tension and concrete in compression. The connection between the two components is realized through glued steel bars. This paper presents the field performance of a composite log-concrete bridge constructed in December 2004 at São Paulo University Campus. This two-lane bridge is 12 m long, 10 m wide, with a skew of 15 degrees. The load tests consisted of positioning fully loaded, three-axle trucks on the bridge and measuring the resulting deflections at a series of locations along a transverse cross section at midspan. In addition, an analytical assessment using computer modeling was completed to predict the response of the bridge. The field tests indicate that the composite log-concrete bridge is performing adequately with no structural deficiencies.

Keywords: field behavior, timber bridges, composite structures, concrete slab, round timber

Introduction

The timber-concrete composite beams are a structural solution for both new constructions and reconstruction of existing buildings and bridges. The composite action that these system offer results in a substantial improvement to stiffness and strength of the overall structure in comparison to when the materials act independently. In a timber and concrete system, the concrete component (slab) is designed to resist primarily compression stresses, while the timber component (a beam or plate) is used mainly in tension providing exceptional strength relative to added weight of the overall composite.

A primary application for the timber and concrete composite is in the use of floor systems – in housing units, schools and public buildings. In this setting, advantages are found through improvement of sound and vibration performance as a result of the added mass of the concrete. The system also performs well in terms of fire resistance. Concrete is naturally insulated both the timber core and the shear connector from direct exposure to fire. Acknowledgement of these advantages has prompted an increase use of timber and concrete composite systems in residential, commercial and industrial applications over recent years (Natterer et. al. 1996, Yttrup 2002).

In the use of road or pedestrian bridge decks, durability is improved. A solely timber bridge deck can suffer enhanced deterioration from exposure to wear and tear, rainwater, and road salts. In a timber and concrete composite, the concrete slab is able to protect the wood beams beneath, provide water runoff, and a wear-resistant surface. Also, the potential for concrete cracks is reduced as it is designed to experience compressive stresses exclusively.

Other important characteristic of the timber and concrete composite decks are the costs advantages in comparison to reinforced concrete decks. The timber is used both as permanent formwork and as a construction element in the composed decks, and in some cases the falsework is unnecessary, reducing the costs and saving time.

The degree of composite action between the timber and the concrete depends primarily on the stiffness of the shear connectors. Many types of shear connectors have been investigated, including lag screws, high strength nails, smooth steel bars and glued continuous steel mesh (Brody et. al. 2000, Ahmadi and Saka 1993, Gelfi et. al. 2002, Clouston et. al. 2005). The challenge lies in developing a shear connection system that provides minimal slip between the two components while at the same time allowing a simple and inexpensive assembly. The glued steel bars connectors were studied at the Laboratory of Wood and Wooden Structures (LaMEM) at the São Paulo University, Brazil (Pigozzo 2004). The connector consists of two steel bars forming "X", fixed into the timber with epoxy resin at an angle of 45º. This type of connector produces a higher slip modulus and strength, and it is indicated for heavy constructions like bridges.

In order to analyze a timber-concrete composite beam and to determine internal forces and displacements, it is necessary to take into account the connection deformability. Because of its complication this problem can be solved in closed form only under simplified hypotheses. Current codes like DIN 1052 (1988) and Eurocode 5 (1995), adopt the Möhler´s simplified formulation. In this theory a linear-elastic behavior of the composite structures may be assumed. Frangi and

Fontana (2003) show that in beams at higher load levels and displacements the outer connectors deform plastically and a non-linear behaviour of the composite structures should be considered. Although the nonlinear behavior should be considered to calculation of the ultimate load capacity of timber and concrete composed members, the linear-elastic model according to Eurocode 5 (1995) give an excellent accurate prediction of the stress, strain, displacement and shear force on the connector (Góes 2002).

In Brazil, the composite log-concrete bridges are being considered as a viable alternative for municipal and rural use, mainly because of their low construction cost, low maintenance needs and their high strength and stiffness. This paper presents the design, construction and field performance of a composite log-concrete bridge constructed in December 2004 at São Paulo University Campus. The main goals are to evaluate the feasibility of log-concrete bridges technology and prove accuracy of previous numerical analysis results.

Bridge analysis and design

The bridge was designed for a Class 30 truck loading based on Brazilian Code NBR 7188 (1988) – "Live load in highway bridges and sidewalks for pedestrians". The design geometry of the deck provided a total 12 m length, a 9,8 m width, and a skew of 15 degrees (Fig. 1, 2). The two-lane, simply supported deck has 11 m of clear span. The bridge was constructed with a thin concrete slab (150 mm medium thickness) over 24 round beams of Eucalyptus Citriodora treated with CCA (343 mm medium diameter). The connectors consists of two galvanized steel bars forming "X", each 500 mm, fixed into the timber with epoxy resin at an angle of 45° (Fig. 3).

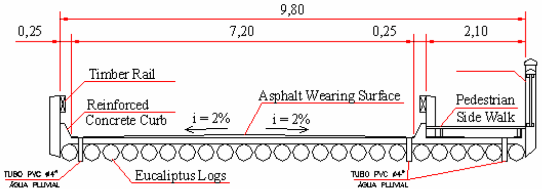

Fig. 1: Cross-section of the deck (dimension in meters)

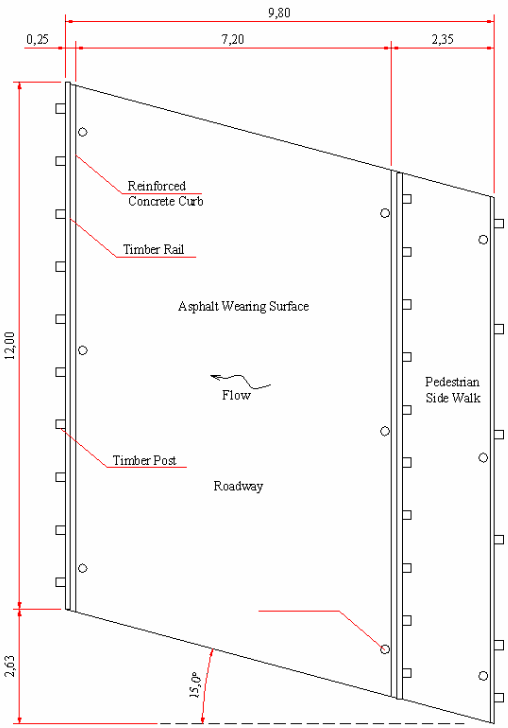

Fig. 2 - Top view of the deck (dimension in meters)

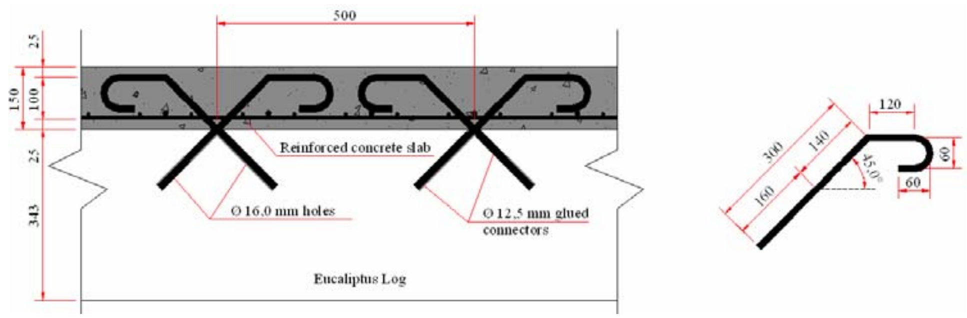

Fig. 3 - Connectors anchorage details (dimension in millimeters)

Discusses about the design model and the finite element model used for behavior analysis of the P01 Bridge are given in the next sections.

Finite element model

The numerical study was performed with finite element commercially available software package (ANSYS 5.7). A three-dimensional geometric model was used with eight-node orthotropic 3-D brick elements for both the slab and the curb. The element has a node at each of this corner with three degrees of freedom, corresponding the displacements to the X, Y and Z directions at each node.

The global elastic properties of equivalent orthotropic plate (slab) where calculated previously. With 15 cm thickness the slab elastic properties are given:

$E_{L,eq}$: 56507 kN/cm^2
$E_{T,eq}$: 2800 kN/cm^2
$G_{LT,eq}$: 1120 kN/cm^2

Besides, the reinforced concrete curb was considered in the model because of this influence in the structure behavior. Figure 4 shows the finite element model used in the analysis.

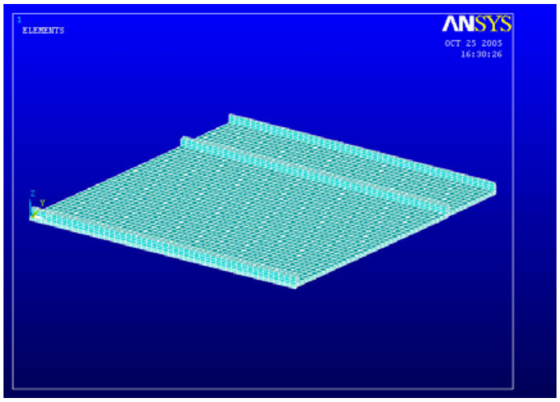

Fig 4 – Finite element model

Construction

The P01 Bridge at São Paulo University Campus construction began with the reinforced concrete abutments and wingwalls, constructed by the local contractor. During construction of the substructure, the LaMEM employee team began the works on the superstructure preparing the Eucaliptus Citriodora logs treated with CCA previously. The edges of the logs were cut for the 12 m long and painted with a bituminous solution for water protection. Additional Gang-Nail steel plates were installed on the top surface to prevent the splitting.

The 12 m logs were lifted and place on the abutments by a light truck crane. The logs were fixed into the abutments by a galvanized glued steel bar with 19 mm diameter. A steel net was placed on the deck as prevent fissure. The 10 mm reinforcement bars distanced each 200 mm were placed in the top and bottom of the slab in transversal direction. The connections were constructed by first drilling a 16-mm-diameter hole into the logs. A premeasured quantity of liquid epoxy was introduced into the hole, and the 12,5-mm-diameter galvanized reinforced bar was placed in the hole. Concluding the construction, the deck was casted using normally strength concrete (25 MPa). Fig. 5 shows the construction stages.

After 30 days of casting the asphalt wearing surface was installed and the timber railing was constructed. The P01 Bridge construction was completed in December 2004 (see Fig. 6).

Fig. 5 - Superstructure bridge construction

Fig. 6 - The completed P01 Bridge

Load tests

Static-load tests of the Bridge P01 were conducted nine months after complete construction to determine the response of the bridge to full truck loading and verify that the bridge was performing as expected. Load testing involved positioning fully loaded truck on the bridge span and measuring the resulting deflections at a series of locations along the bridge midspan. A surveyor's level was used to read deflection values from calibrated rules suspended from the underside of the bridge. Deflection measurements were obtained prior to testing (unloaded), after placement of the test trucks for each load case (loaded), and at the conclusion of testing (unloaded). In addition, analytical assessments using computer modeling were completed to predict the response of the bridge.

The load test was conducted September 24, 2005, utilizing one fully load truck with a gross vehicle weight of 349 kN. Fig. 7 shows the truck axle weight and dimensions. Three different load cases were used as shown in Fig. 8. For Load Cases 1 and 3, the truck was positioned transversely 0,63 m from the roadway edge (left for Load Case 1 and right for Load Case 3). For Load Case 2, the truck was positioned on the roadway centerline. For all load cases, the rear truck axles were centered longitudinally over the skewed midspan cross section.

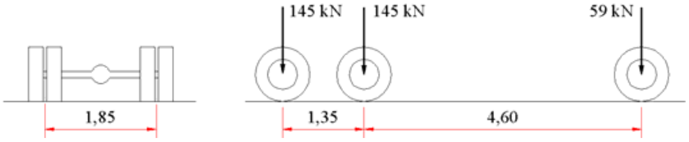

Figure 7 – Load test truck configuration (dimensions in meters)

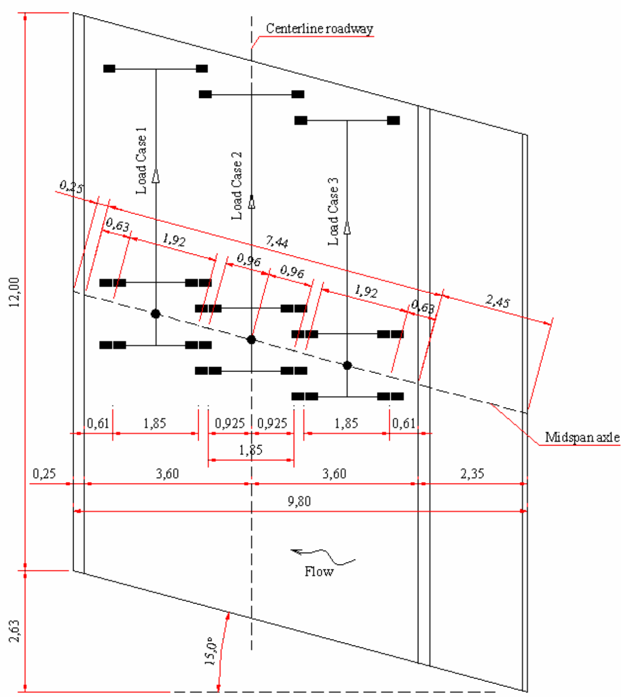

Figure 8 – Truck positions for each Load Case (dimensions in meters)

Comparison between the finite element model and tests results

In this section, results of the static load tests and numerical assessment of the P01 Bridge are presented. For each Load Case, transverse deflection measurements are given at the skewed midspan cross section. No permanent residual deformation was measured at the conclusion of load testing. The theoretical and numerical results of the three load cases are shown in Fig. 9, 10 and 11.

Load Case 1 produce the highest deflection measured 10 mm, as expected. For Load Cases 2 and 3, the maximum deflection location was centered under the truck and the magnitude was 9 mm and 7 mm, respectively. The accuracy of the experimental procedure method for repetitive readings is ±1 mm.

Measured deflections were compared with the theoretical deflections for all load cases. The results show very good agreement between the theoretical and experimental measured deflections. As shown in Fig. 9, 10 and 11, the two plots are nearly identical with only minor variations, which are within the accuracy of the measurements. The theoretical results for Load Cases 1 to 3 were 10,2 mm, 8,3 mm and 7,8 mm, respectively. For all load tests, the reinforced concrete curb stiffen the edge bridge significantly, as expected.

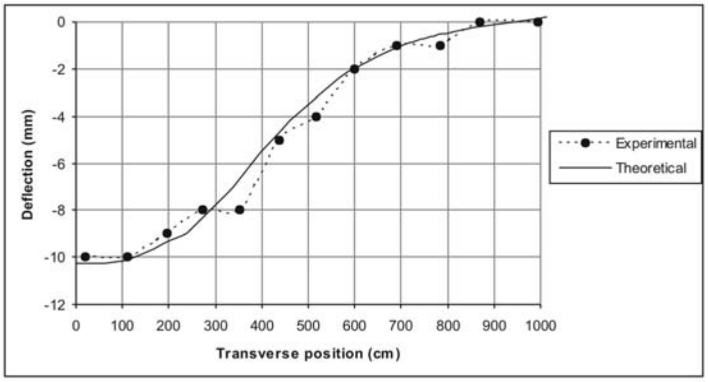

Fig. 9 - Comparison of the measured deflections at the midspan – Load Case 1

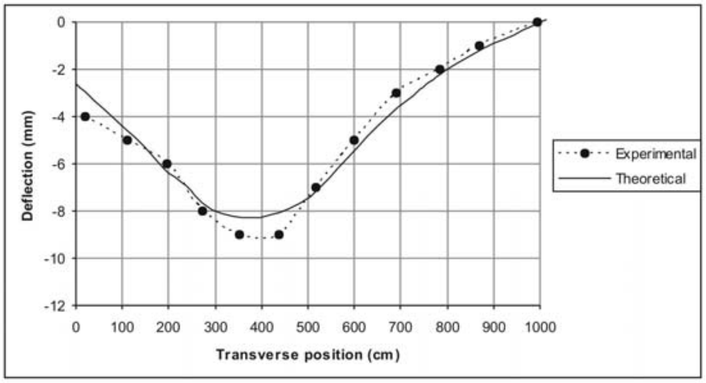

Fig. 10 - Comparison of the measured deflections at the midspan – Load Case 2

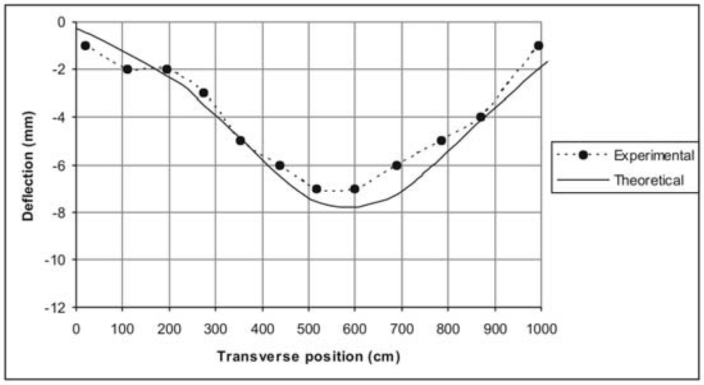

Fig. 11 - Comparison of the measured deflections at the midspan – Load Case 3

Conclusions

The theoretical and experimental displacements comparisons show a very good performance of the deck bridge. The sensibility of the equipment used for the acquirement of experimental displacements does not allow a more accurate comparison but it is enough for the load test. However, the relevance of the results showed that, with the elastic parameters obtained to the equivalent plate, it is possible to have a significant accuracy of the real movement of the bridge.

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