Peña, Álvaro; Fuentes, Sebastián; Fournely, Eric; Navarrete, Benjamín; Pinto, Hernán
Exterior Wood-Concrete Slabs, Experimentation and Modeling of Mechanical Behavior. Part 1
Revista de la Construcción, vol. 14, núm. 2, agosto, 2015, pp. 86-90
Pontificia Universidad Católica de Chile
Santiago, Chile

Exterior Wood-Concrete Slabs, Experimentation and Modeling of Mechanical Behavior. Part 1.

Losas mixtas Madera-Hormigón en Exterior, experimentación y modelamiento del comportamiento mecánico. parte 1

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Manuscript Code: 563
Date of Reception/Acceptance: 09.12.2014/01.06.2015

Abstract
Structural elements of composite materials are widely used as them allow conceiving stronger as well as economic structures. In the case of wood-concrete composite slabs, the high compressive strength of concrete, together with the great performance and behavior of wood under traction, allows to obtain a resistance, weight and stiffness effective structure; features widely proven in indoor environments. The objective of this research is to analyze wood-concrete slabs behavior under outdoor environmental conditions in order to study its usage in walkways. Experimental tests were performed in two composite slabs, which were subjected to diverse loading configurations for 1250 days in outdoor environment. According to the results, was determined that the real moisture is greater than the theoretical one, which promotes the decay of wood, nevertheless, this variation did not produce a significant change in the overall mechanical characteristics of composite slabs

Keywords: Wood-Concrete Slabs; Wood-Concrete slabs outdoor behavior; Wood-Concrete slabs properties; Modeling of the Wood-Concrete slabs; Experimental testing of Wood-Concrete slabs.

Resumen
Elementos estructurales de materiales mixtos son ampliamente utilizados ya que permiten concebir estructuras más resistentes y económicas. En el caso de losas mixtas madera-hormigón, la alta resistencia en compresión del hormigón sumado al buen comportamiento en tracción de la madera, permite obtener una estructura eficaz en resistencia, peso y rigidez; siendo estas cualidades ampliamente comprobadas en ambientes interiores. El objetivo de esta investigación es analizar el comportamiento de losas mixtas madera-hormigón en condiciones ambientales exteriores de forma tal de estudiar su utilización en pasarelas. Se realizaron ensayos experimentales en dos losas mixtas, las que fueron sometidas a diversas configuraciones de carga durante 1250 días en ambiente exterior. De los resultados se determinó que la humedad real es mayor que la teórica, lo que propicia la degradación de la madera, sin embargo, éstas alteraciones no produjeron una variación significativa de las características mecánicas globales de las losas mixtas.

Palabras Claves: Losas Mixtas Madera-Hormigón; Comportamiento Exterior Losas Mixtas; Propiedades de las Losas Mixtas; Modelización de las Losas Mixtas; Ensayos de Losas Mixtas.

Introduction

A composite structure basically consists of an structural element composed by two or more different materials, where a means of connection allows the stress transmission among them. The main idea of this is to take advantage of better characteristics of each material and in this way get an effective structural element regarding resistance, stiffness and quality service.

Wood-concrete composite slabs correspond to an horizontal structural element that mainly works under bending and shear stresses. This structure is composed by a concrete in the compressed zone and wood in the tension zone. With this material arrangement, concrete only works under compression taking advantage of its high resistance and stiffness, and wood works under traction since its behavior is better than concrete under this kind of stresses. Thus, this technique allows to obtain a more resistant and stiffer slab than a structure only composed by a system of wood beams and lighter than a equivalent concrete slab (Racher, 2009).

This mechanical behavior has been widely used in buildings as well as in indoor structures construction, nevertheless, also is possible to use and take advantage of its characteristics in outdoor environments. Protection screen that contributes concrete out in open sky and dimensional temperature stability of wood, can be considered an advantage of this kind of structure in outdoor conditions. However, wood sensitivity in regards of environmental conditions variation and concrete water contribution deserve its study. Wood mechanical characteristics changes according to its moisture degree as well as concrete characteristics development, also deserve special attention in order to understand and control the impact of these phenomena over the behavior of these structures in outdoor conditions.

Research scope

The objective of the present study aims to analyze wood-concrete composite slabs behavior in real outdoor environments, in order to recognize its properties and conclude about the technical feasibility of its usage as walkways.

Methodology

Composite slabs behavior is analyzed by conducting several non destructive bending tests in outdoor environments, and at the same time characterizing environmental conditions where tests were performed. In this sense, meteorological data of the test zone is available and moisture readings of the tested specimens were recorded periodically.

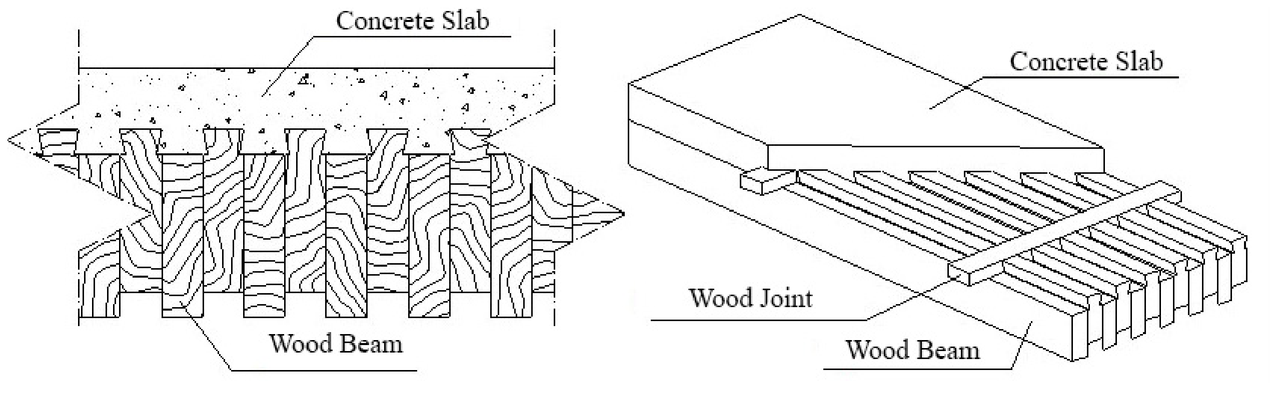
Experimental campaigns

Studied composite slabs were built according to Lignadal procedure (CSTB, 2003). These slabs are constituted by a pre-slab composed by wood joists nailed next to each other. These joists count with a vertical as well as horizontal gap among them, thus pre-slab upper surface presents an irregular "dentated" shape that ensures wood-concrete adherence.

Furthermore, wood connectors transversally nailed to the pre-slab, limit relative wood-concrete slipping. Concrete floor slab is built by laying a steel mesh over the wood and adding concrete directly over the pre-slab. Figure 1 illustrates this kind of composite slab configuration.

Experimental campaign was divided in two stages, the first one aims to determine pre-slab mechanical characteristics in indoor environment and the second corresponds to the study of composite slabs bending properties in an outdoor environment. Then, some results of this study stages are described and presented in the next sections..

Figure 1. Lignadal composite slab configuration. Prepared by the author, 2008.



Experimental campaign in indoor environment

The first stage of this study consists in the mechanical characterization of two Lignadal type pre-salbs. These pre-slabs are composed by 28 joists (21 x 4.2 cm of section), of wood that did not pass throughout a qualification process. These joists are placed next to each other, obtaining in this way a pre-salb of 1.18 m width. In longitudinal direction, the joists are placed by its edge till reach a total length of 9.4 m (Fournely, 2009) (Fargier, 2006). Pre-slabs were measured and weighed, also wood moisture was controlled. Furthermore, samples were taken to perform shear tests in order to determine mechanical properties. Table 1 summarize the three pre-slabs physical and geometrical characteristics.

Table 1. Pre-slabs characteristics. Prepared by the author, 2008.

	Pre Slab 1	Pre Slab 2	Pre Slab 3
Length	9.4 [m]	9.4 [m]	9.4 [m]
Width	1.18 [m]	1.18 [m]	1.18 [m]
Weight	1029 [kg.]	1000 [kg.]	1046 [kg.]
Mass per Volume unit	420[kg./m3]	408[kg./m3]	427[kg./m3]

In order to characterize the mechanical behavior of the pre-slabs, longitudinal and transverse bending test were performed. A mobile device composed by stiff steel shapes allowed to apply different loads configurations (punctual y linear) over the pre-slabs. Figure 2 shows this device and some load configurations considered.

These tests are analyzed in terms of force-displacement relation, in such way bending stiffness of slabs was determined under linear load. Furthermore, steel shapes under punctual loads were located transverse over the pre-slabs, so stress distribution capacity was determined. Table 2 and 3 presents summary of the compression test results and the EI modulus for each one of the 3 pre-slabs, in Figure 3 and 4 some results of this stage are presented.

Table 2. Compression test results. Prepared by the author, 2008.

Specimen	E0[Gpa]
1B	12.7
1C	13.7
2A	14.0
2B	11.2
3A	11.1
3B	8.2
4A	8.7
4B	10.7
5A	10.2
5B	8.9
6A	11.6
6B	12.9
Mean	11.2
STD	1.9

Table 3. Pre-slabs EI modulus. Prepared by the author, 2008.

	Pre Slab 1	Pre Slab 2	Pre Slab 3
EI [KN*m2]	7804	7881	7793

Experimental campaign in outdoor environment

The second experimental stage consisted in the study of the variation in time of the mechanical properties of the wood-concrete composite slabs in outdoor environment. For this stage, two of the three pre-slabs were located outdoor, one of 9.4m and the other cutted to 7.9 m length.

Composite slabs located outdoor exposes wood to great environmental conditions changes, which affect slabs mechanical properties. Furthermore, there is a direct relation between wood moisture and parameters such as relative humidity of the air and temperature (Kretschmann, 1996). To take this situation into account, all along the study, meteorological data of slabs locations was available, provided by the Observatoire de Physique du Globe de Clermont-Ferrand (meteorological station located 200m from the studies zone). Data analyzed considered temperature, relative humidity, precipitation, pressure, insolation, wind speed and its direction. On the other hand, before slabs concrete pouring, moisture reading probes were inserted in several points of wood pre-slabs (Brische, 2008). These probes were connected to a reading center allowing a real time data collection in any moment of the study. This system was complemented with manual insertion of probes, of the same kind, in different points of the pre-slabs. In this way, periodic readings of moisture were performed which determined the wood moisture and were compared with meteorological conditions data. Figure 5 shows wood moisture lecture system, meteorological data and moisture cartography of a section of the pre-slab 2.

Figure 2. Load application and configuration drawing. Prepared by the author, 2008.

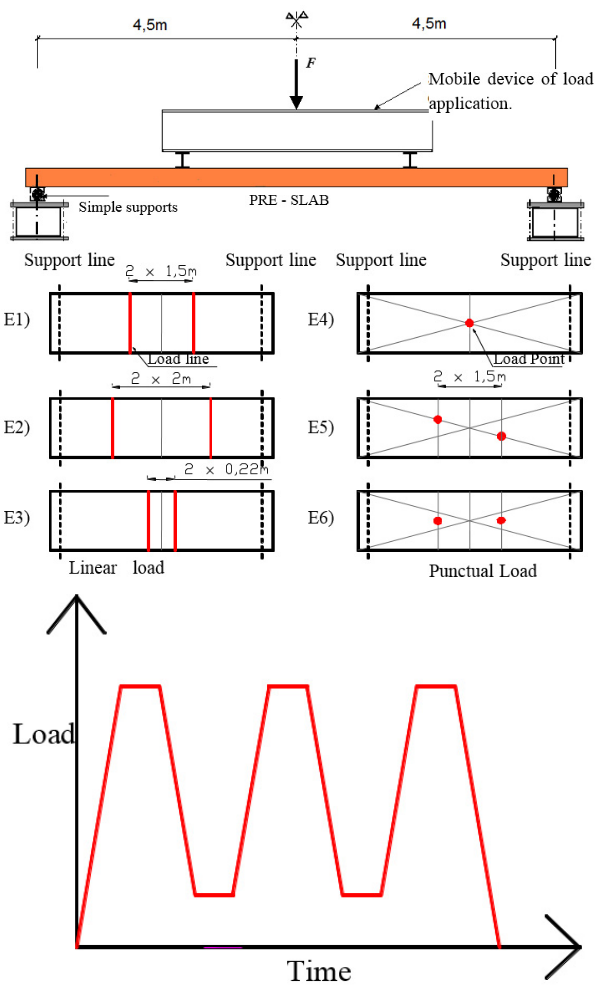


Figure 3. Pre-slabs load v/s displacement test results. Prepared by the author, 2008.

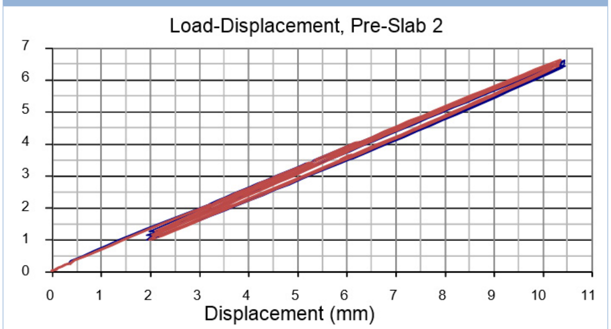


Figure 4. Pre-slabs punctual load v/s slab width test results. Prepared by the author, 2008.

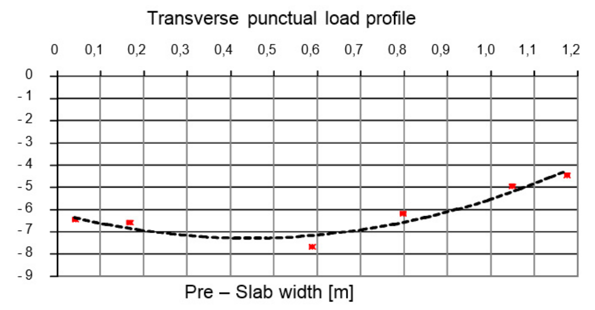
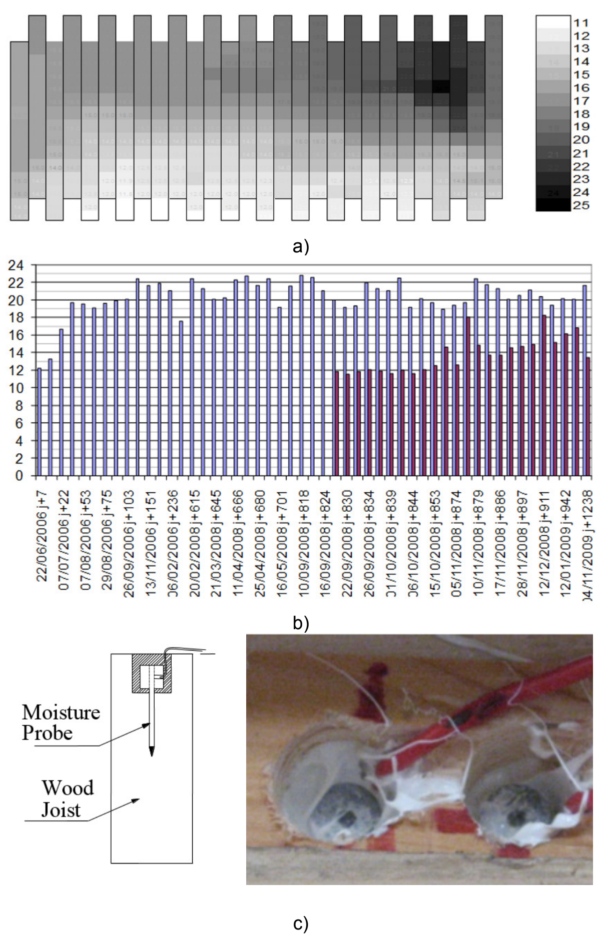


Figure 5. Pre slab Nº2 moisture data: a) moisture cartography, b) moisture evolution and c)moisture probe. Prepared by the author, 2008.



Once instruments were placed in pre-slabs, slabs were poured with concrete, and despite slabs thickness was increased, steel mesh was placed with a concrete sheath corresponding to indoor environment usage (CSTB, 2003). In order to avoid concrete concentration in the center of the pre-slabs, a temporary central support was placed (28 days since concreting). Lateral forms were nailed directly over pre-slabs sides and concrete was elaborated in a external plant without any kind of additive. Table 4 summarizes the concrete characteristics, and figure 6 the concrete process of the slabs.

Along concrete setting time, several cracks arise over the upper face of the two slabs, in a early stage over central support line and later in its sides, being the slab of greater length (9.4m) the one that presented the most important cracks, also was noticed a lateral sag in composite slabs (transversal profile deflection). These two situations have origin in concrete retraction effect which implies early stresses on it. Temporary central support and relative distant location of steel mesh regarding upper concrete slabs face amplified this phenomenon. As a consequence, standing water over the concrete in rainfall periods, infiltrate towards wood pre-slab through the concrete cracks.

Table 4. Concrete characteristics. Prepared by the author, 2008.

Cylinder Strength (28 days)	25 [Mpa]
Maximum aggregate size	12 [mm]
Abrams cone	6 [cm]

Figure 6. Concrete process of the slab. Prepared by the author, 2008.

Figure 7. Load application. Prepared by the author, 2008.

To determine composite slabs mechanical behavior development, periodical longitudinal flexion tests were performed in a 1,250 days period. In order to measure deflections during the tests, displacement sensors were placed in several points of the slabs. Moreover, further displacement sensors were placed in a longitudinal discontinuity zone below the pre-slab and in its opposite sides in order to measure relative displacement among wood and concrete. Loading protocol considered three pseudo-static loads-unload cycles with amplitude of 8 kN. This stress was applied with a manually controlled hydraulic jack. For vertical reaction, this device utilized two concrete blocks supported by a forklift and applied force was controlled by a force sensor. These tests were exploited in terms of load-deflection, which allowed determining bending stiffness modulus EI. Furthermore, throughout topographic control, deflection development in account of materials creep was determined.Figure 8 presents displacement sensors locations, load application and obtained results.

Figure 8. Displacement sensors locations and set up of the push out test. Prepared by the author, 2008.

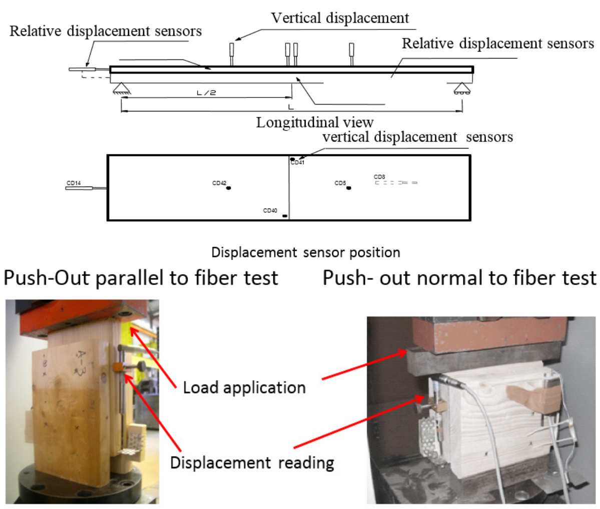


Figure 9. Variation of the EI modulus of the pre slab 2. Prepared by the author, 2008.

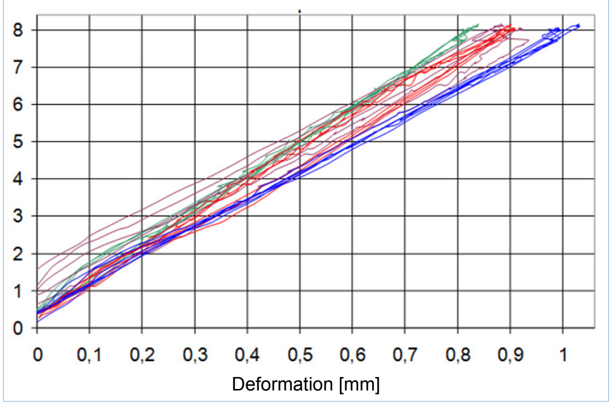


Figure 10. Variation of the EI modulus of the pre slab 2. Prepared by the author, 2008.

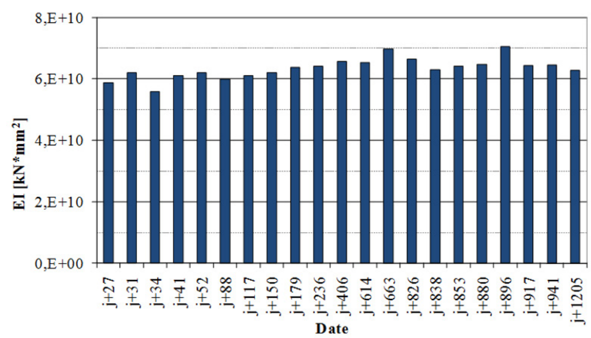


Table 5. Diferent Young modulus distribution. Prepared by the author, 2008.

	Test 1	Test 2	Test 3
Young modulus mean	11000[Mpa]	11000[Mpa]	11000[Mpa]
Standard Deviation	0[Mpa]	2000 [Mpa]	3000 [Mpa]

Table 6. Stiffness results comparison, numerical values, normative and experimental. Prepared by the author, 2008.

	Slab 1		Slab 2	
	K_{eq} [kN/mm]	EI_{eq} [kN.mm²]	K_{eq} [kN / mm]	EI_{eq} [kN.mm²]
Annex B, EC5	7,37	5,73.1010	4,04	6,14.1010
Experimental mean	8,11	6,34.1010	4,46	6,78.1010

Connection stiffness is determined according to Push-Out type tests performed over shear probes composed by four nails in simple shear. The mean value obtained was 800 N/mm, with a standard deviation of 158 N/mm. These values are comparable with those of Branco (2009) or with Stiffness values proposed by the Eurocode 5 (NF EN1995-1.1, 2004) and are independent of the stress direction.

To take into account the variability of the mechanical characteristics of the wood that compose the pre-slabs, for a fixed mean value of Young modulus, three different standard deviation values were considered, one close to classified wood value, one lower and other greater, for these cases a Gaussian distribution model was considered (Table 5). Moreover, several connection stiffness values were considered in order to determine the sensitivity of this parameter.

Results Analysis and Discussion

In order to integrate pre-slabs moisture variability effect over mechanical behavior of composite slabs, several bibliography models regarding moisture and module E0 relation can be taken into account, such as the W - E0 relation proposed by Kretschmann (1996), nevertheless, results exposed in Figure 5a, 5b, 9 and 10 show that composite slabs stiffness increase together with wood moisture content. This situation cannot be solely explained based on W - E0 relation of the wood pre-slab.

Apart of influence over mechanical properties, wood moisture variation also affects its transversal dimensions. An increase of 1% in wood moisture implies a transversal expansion of 0,25% (mean value according to norm NF EN 1995-1.1, 2004). In the case of study, dentated form of wood-concrete interface that presents the pre-slab favors containment and in this way produces wood-concrete friction increase.

As consequence, if connection degree between wood and concrete is located in a semi-rigid zone with great influence, connection stiffness variation can have a significant effect over the composite slab mechanical behavior.

Connection stiffness effect over bending modulus of the composite slab results are coherent with the ones of Racher (2002) where demonstrated that connection stiffness decrease in function of wood moisture, in this way the hypothesis to take into account stiffness variation in function of moisture seems to be right. However, to correctly quantify this parameter, is required an experimental validation on a large scale which require equipment and a specific experimental device.

Conclusions

Experimental campaign conducted in this work, aimed to determine Lignadal's composite slabs properties to be utilized as walkways in outdoor environments. For this purpose, different tests performed along a 1250 days period, did not show a deterioration of composite slabs bending properties.

Different wood moisture lectures presented an important temporal and space variation. Moreover, according to wood hygroscopic balance curves, in this case real moisture is greater than the theoretical. This difference can be explained due to moisture contribution of concrete, its cracking and the double curvature of the concrete floor slab, which allows rainfall standing water over the concrete. In this way, observed moisture get proper conditions for wood decay, which was noticed in some zones of the pre-slab, nevertheless, these alterations did not caused a significant variation of composite slabs overall mechanical characteristics.

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