Revista de la Construcción
ISSN: 0717-7925
revistadelaconstruccion@uc.cl
Pontificia Universidad Católica de Chile
Chile

Peña, Álvaro; Fuentes, Sebastián; Fournely, Eric; Navarrete, Benjamín; Pinto, Hernán

Exterior wood-concrete slabs, experimentation and modeling of mechanical behavior. Part 2.

Revista de la Construcción, vol. 14, núm. 3, diciembre, 2015, pp. 77-82
Pontificia Universidad Católica de Chile
Santiago, Chile

Exterior wood-concrete slabs, experimentation and modeling of mechanical behavior. Part 2.

Losas mixtas madera-hormigón en exterior, experimentación y modelamiento del comportamiento mecánico. Parte 2

Álvaro Peña (Main Author)
Pontificia Universidad Católica de Valparaíso, Facultad de Ingeniería. Escuela de Ingeniería en Construcción, Chile.
alvaro.pena@ucv.cl

Sebastián Fuentes
Polyech'Clermont-Ferrand, Bois HD, France.
sebastianfuentes@gmail.com

Eric Fournely
Polytech Clermont-Ferrand, Departamento Ingeniería Civil, France
eric.fournely@univ-bpclermont.fr

Benjamín Navarrete (Contact Author)
Pontificia Universidad Católica de Chile, Facultad de Ingeniería, Escuela de Construcción Civil.
Vicuña Mackenna 4860, Macul, Santiago, CP 7820436
+56 2 23544569
bnava@uc.cl

Hernán Pinto
Pontificia Universidad Católica de Valparaíso, Facultad de Ingeniería. Escuela de Ingeniería en Construcción, Chile.
hernan.pinto@ucv.cl

Manuscript Code: 563
Date of Reception/Acceptance: 01.06.2015/01.12.2015

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 model the behavior of wood-concrete slabs at an outdoor environment conditions in order to study its usage in walkways. To achieve this goal, the behavior of the wood-concrete slabs will be conducted through the use of finite element models that are going to be validated with the experimental data previously obtained from tests performed in two composite slabs, which were subjected to diverse loading configurations for 1250 days in outdoor environment (Peña, Fuentes, Fournely, Navarrete, & Pinto, 2015). According to the results, it was possible to conclude that 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; in the other hand, numerical modeling demonstrated the importance of the connection transverse stiffness, besides enabling the incorporation of wood moisture effect over its mechanical properties, allowing to quantify the effect of the connection stiffness.

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 el de modelar el comportamiento de losas mixtas madera-hormigón en condiciones ambientales exteriores de forma tal de estudiar su posible aplicación en pasarelas. Para este objetivo, se considera la utilización de modelos numéricos en elementos finitos que modelaran el comportamiento de las losas mixtas expuestas al medio ambiente, siendo contrastados y validados con los resultados experimentales obtenidos de los ensayos en dos losas mixtas, las que fueron sometidas a diversas configuraciones de carga durante 1250 días en ambiente exterior. Del análisis de los resultados se pudo concluir 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; por otra parte la modelación numérica evidenció la importancia de la rigidez transversal de la conexión, además de permitir la incorporación del efecto de la humedad de la madera sobre sus propiedades mecánicas, permitiendo cuantificar el efecto de la rigidez de la conexión.

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 a 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 a 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 an 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 modeled by different finite element model, previously validated considering the use of the experimental data previously obtained by the author. These previous experimental campaign was conducted by one of the authors of this paper with his co workers and it has consisted in several non destructive bending tests in outdoor environments, and at the same time characterizing environmental conditions where tests were performed (Peña et al., 2015). In this sense, meteorological data of the test zone is available and moisture readings of the tested specimens were recorded periodically.

The slabs modeled and considered in this studied correspond to the proposed by the Lignadal procedure, (CSTB, 2003), and are constituted by a pre-slab of 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. In this research, the experimental data considered to validate the finite element models, was obtained by an experimental campaign separated in indoor and outdoor environment.

Figure 1. Lignadal composite slab configuration. Source: Self-elaboration, 2008.

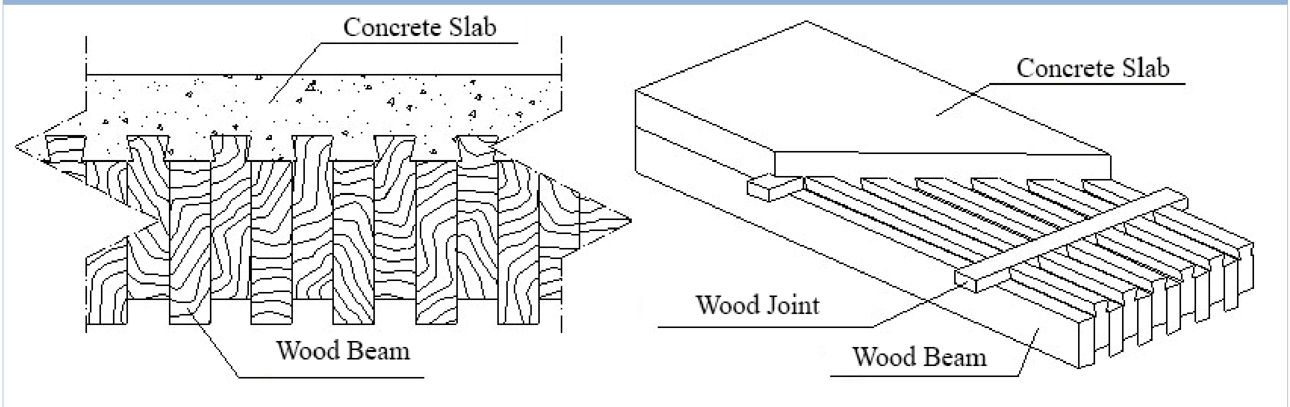


Table 1. Pre-slabs characteristics. Source: Self-elaboration, 2008.

	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]

Table 2. Compression test results. Source: Self-elaboration, 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. Source: Self-elaboration, 2008.

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

Outdoor environment experimental campaign

Regarding the outdoor experimental campaign, a study of the variation of the mechanical properties in time of the wood-concrete composite slabs was considered. To this end two of the pre-slabs were located outdoor, one of 9.4 [m] and the other cutted to 7.9 [m] length.

It is well known that composite slabs in outdoor environments, exposes wood to environmental conditions changes, which affect slabs mechanical properties (Racher, 2005). Also, there is a direct relation between wood moisture and the relative humidity of the air and temperature (Kretschmann & Green, 1995), so in order to consider this situation meteorological data (temperature, relative humidity, precipitation, pressure, insolation, wind speed and its direction) were considered. Also, before the pouring of the concrete slabs was finished, moisture reading probes were inserted in several points of wood pre-slabs (Brischke, Rapp, & Bayerbach, 2008). These probes were connected to a reading center allowing a real time data collection in any moment of the study.

Once instruments were placed in wood 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). Table 4 summarizes the concrete characteristics, and figure 6 the concrete process of the slabs.

Figure 2. Load application and configuration drawing. Source: Self-elaboration, 2008.

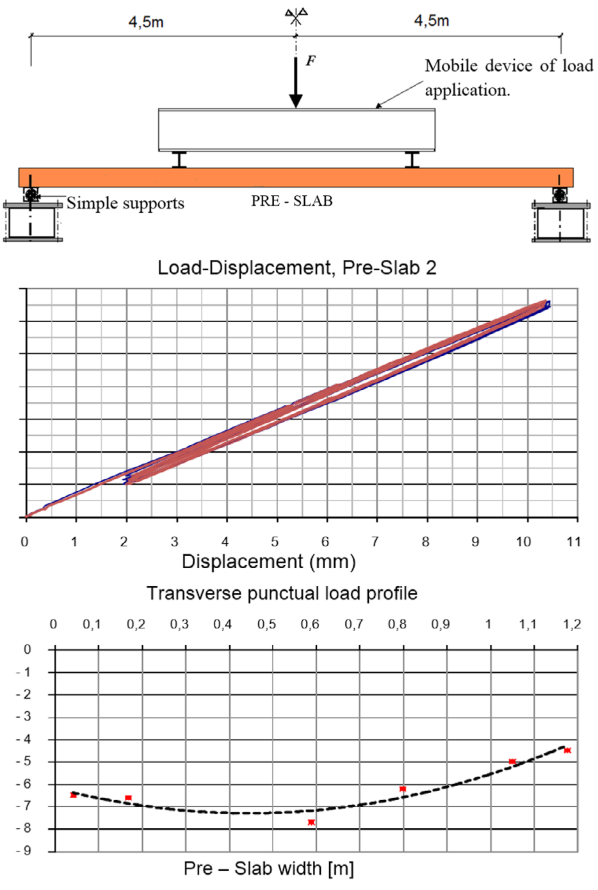


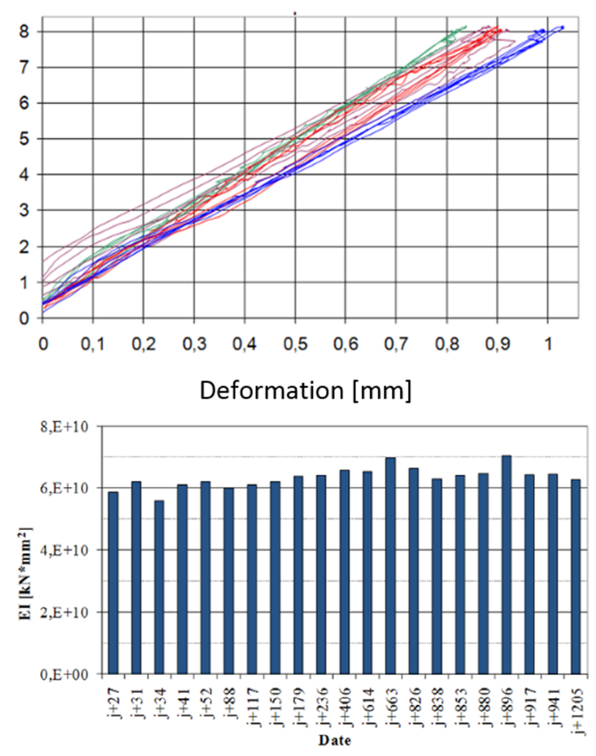
Table 4. Concrete characteristics. Source: Self-elaboration, 2008.

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

Figure 3. Pre-slabs load v/s displacement test results. Source: Self-elaboration, 2008.

The experimental campaign was conducted for a total of 1,250 days period. Loading protocol considered three pseudo-static load-unload cycles with an amplitude of 8 kN. This stress was applied with a manually controlled hydraulic jack (figure 3 right). Results of these tests are presented in figure 4 and 5.

Figure 4. Variation of the EI modulus of the pre slab 2. Source: Self-elaboration, 2008.



Numerical Modeling

3D Model

A 3D finite elements model allowed studying the theoretical behavior of wood pre-slabs. This model considered a configuration and geometry according to studied pre-slabs. Wood joists were modeled by four nodes plane square finite elements. This model disregard contact and friction effect among joists, as well the rotation in relation to its longitudinal axis. Furthermore, wood is considered an orthotropic material. Regarding the nails that connect wood beams, these are modeled as beam type elements with a linear elastic isotropic behavior and are located perpendicularly to joists. Section of these elements is calculated in a way to represent real connection stiffness. Figure 5 presents this model at different scales.

Connection stiffness is determined according to Push-Out type tests performed over shear probes composed by four nails in simple shear (Figure 6). The mean value obtained was 800 N/mm, with a standard deviation of 158 N/mm. These values are comparable with those of (Branco et al., 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.

Figure 5. Pre slab 3D model, and push out tests. Source: Self-elaboration, 2008

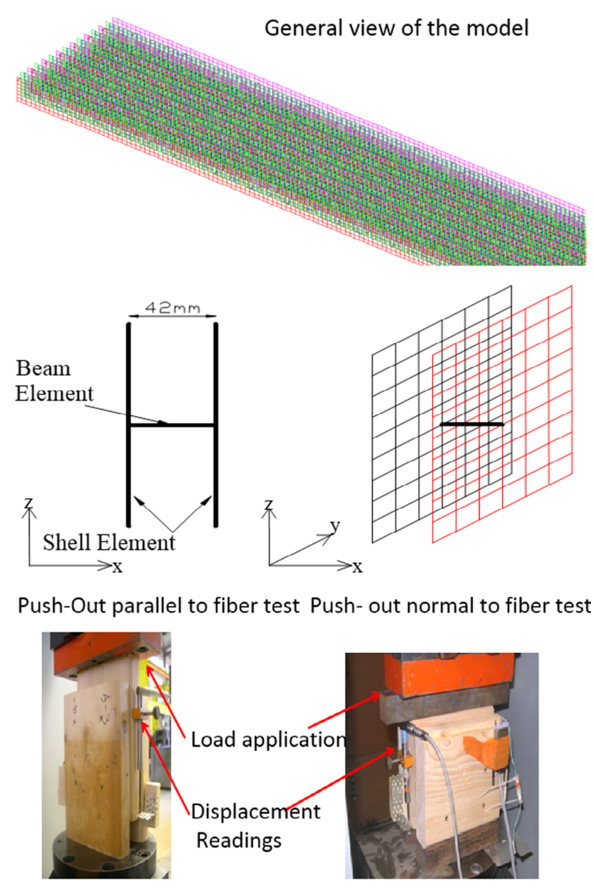


Table 5. Different Young modulus distribution. Source: Self-elaboration, 2008.

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

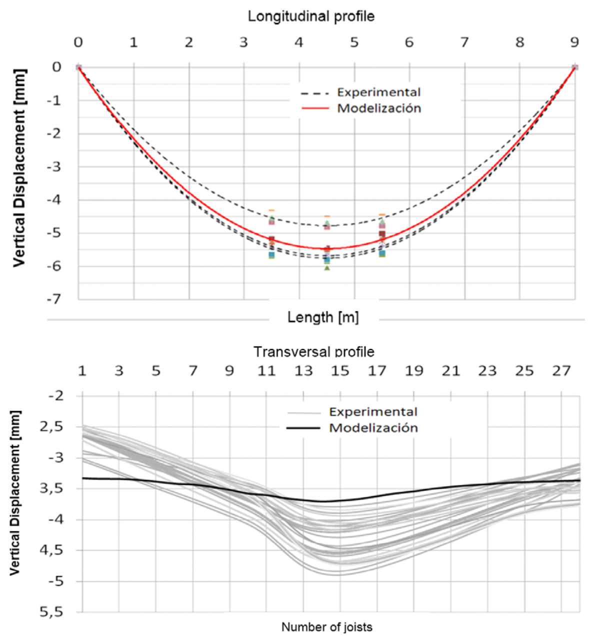
A comparison between the experimental and the numerical model results obtained shows a good correlation. In the case of linear load application, lateral deflection it is well represented by the model (Figure 7). Likewise the experimental results, the numerical model evidenced the important effect of pre-slabs joint work. This behavior is mainly due to stiffness of joists connection. In fact, different longitudinal elasticity module distributions of beams did not have a major consequence over pre-slabs global behavior under linear load.

In punctual load case, transverse deformation profile shows a light asymmetry, this phenomenon was evidenced in numerical as well as experimental results and can be explained by pre-slabs longitudinal discontinuities asymmetry. In the other hand, curvature obtained from numerical model is less pronounced than the experimental one, this difference can be due to modeling does not consider joist rotation in relation to its longitudinal axis.

2D Model

A second numerical model allowed us to analyze the mechanical behavior of composite slabs. The significant effect of the joint work noticed in wood pre-slabs modeling validates the implementation of a 2D model instead a 3D one. A composite slab can be considered as two overlayed beams with an interface where connection stiffness produces mechanical join between the two components. In this way, a 2D model was created considering beam type elements (three degrees of freedom per node). In this case, an inferior beam element represents the pre-slab translating mean behavior (joint work effect). An upper beam element represents the reinforced concrete slab. A high stiffness series of vertical beam elements models pre-slab and concrete floor slab rotation effect. Finally, a semi rigid beam element join vertical beams two by two, representing the connection stiffness according to its axial stiffness. Concrete module of elasticity is calculated according to its characteristic resistance (NF EN1992-1.1., 2004), while pre-slabs elasticity module is determined by the mean of the values obtained in the bending tests, however, this value can vary in order to take into account the evolution of wood moisture. Wood pre-slab and reinforced concrete floor slab connection stiffness is based on performed Push-Out tests over this kind of connection in indoor environment. Limit conditions and the model loads correspond to those of longitudinal bending tests in outdoor environment, figure 9 is an example of this model.

Figure 6. Pre-slabs modeling-experimentation comparison. Source: Self-elaboration, 2008.



Obtained values throughout modeling are compared with experimental results. Furthermore, composite slab is analyzed according to calculation method proposed in Annex B of norm Eurocode 5 (NF EN1995-1.1., 2004). Table 6 presents overall obtained results. As can be noticed, results between experimental and numerical are very similar, nevertheless, code proposed lower values.

In a first stage, this modeling allows to give a qualitative answer about cracking issues found during concrete setting. The qualitative character of these elements is considered in the measure that concrete retraction data along setting are not available and crack development is not taken directly into account by the modeling. Figure 8 (upper), shows global deformation of the 9.4 [m] slab with two or three supports produced by an estimated retraction of 0.02%, this retraction is associated with mechanical characteristic summarized and presented in table 2 and concrete age, generates a normal tension stress of 3.4 MPa (three supports) in the concrete floor slab's top fiber, which is greater than concrete tension resistance and its exactly in the zone were the first crack is located. Observed cracking impacts constructive system stiffness. Figure 8 (mid and low) shows crack location in composite slabs.

Figure 7. Wood-Concrete slab modeled with beam elements. Source: Self-elaboration, 2008..

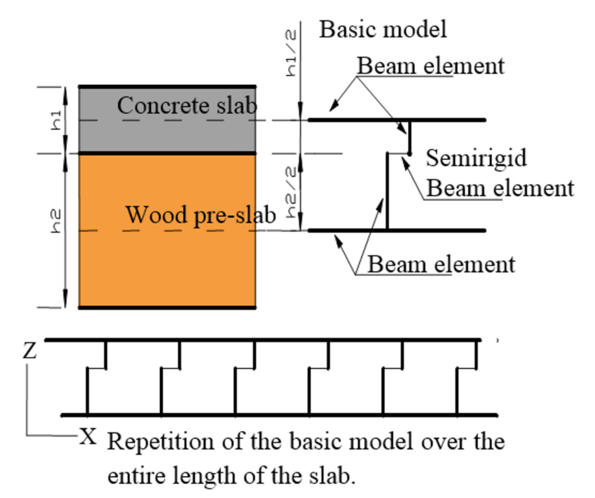


Table 6. Stiffness results comparison, numerical values, normative and experimental. Source: Self-elaboration, 2008.

	Slab 1		Slab 2	
	Keq [kN/mm]	Eleq [kN.mm2]	Keq [kN / mm]	Eleq [kN.mm2]
Numerical Model	7,99	6,21.1010	4,38	6,65.1010
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

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. Figure 9 illustrates W - E0 relation proposed by (Kretschmann & Green, 1995). Nevertheless, results exposed in Figure 4 and Figure 5 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.

Beside the 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 EN1995-1.1., 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.

Figure 10 expose connection stiffness effect over bending modulus of the composite slab. This graphic also details the stiffness considered in the numerical simulation. As can be seen, studied composite slabs connection stiffness is located in a zone where a small connection stiffness variation can carry non irrelevant consequences over bending stiffness tension of the ensemble. In this way, slab 1 with wood moisture of 19%, presents connection stiffness of 700 kN/mm and of 1100 kN/mm with 23% of moisture.

Figure 8. Deformation and crack location in wood-concrete slabs. Source: Self-elaboration, 2008.

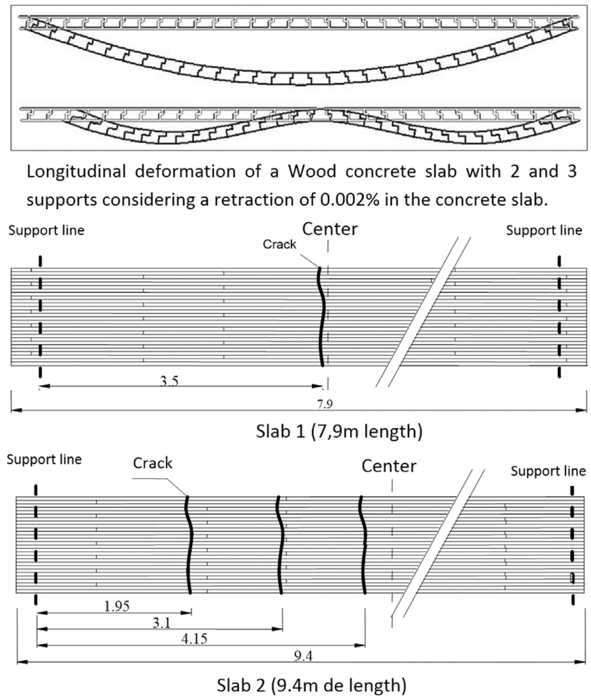
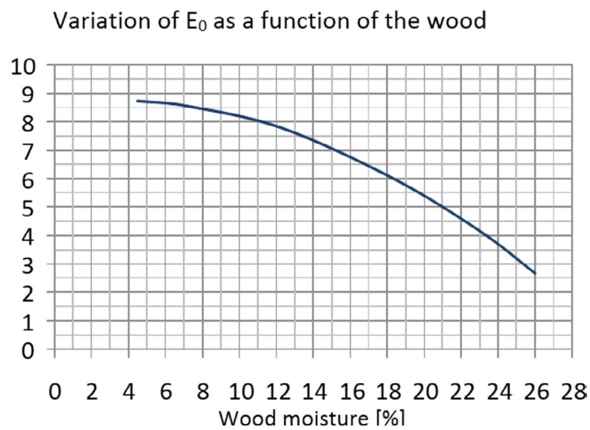
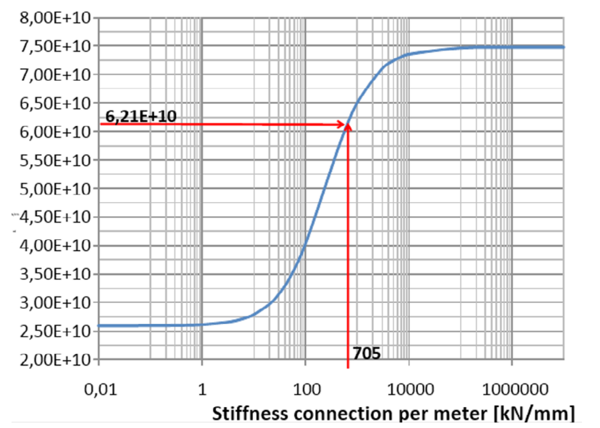


Figure 9. Relation between wood moisture and E0 (Kretschmann, 1996).



Exposed results are coherent with the ones of (Racher & Founely, 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.

Figure 10. Composite slab stiffness variation under bending regarding wood-concrete connection stiffness. Source: Self-elaboration, 2008.



Conclusions

In order to obtain a valid numerical model to consider Lignadal's composite slabs to be used as walkways in outdoor environments, experimental results from different tests performed along a 1250 days period were considered. After an analysis of these results it can be concluded that it did not show a deterioration of composite slabs bending properties.

Different wood moisture lectures presented an important temporal and space variation, being greater than theoretical. This difference can be explained due to moisture contribution of concrete; since the concrete is cracking and having a double curvature of the concrete floor slab, it allows the rainfall to generate 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.

3D numerical models allowed to evidence the importance of the connection transverse stiffness over the system effect that present pre-slabs. 2D modeling allowed to approximate real composite slabs behavior taking into account the global behavior of pre-slab, concrete floor slab and wood - concrete connection. Moreover, this model allows considering the effect of wood moisture increase regarding its mechanical properties and to quantify the effect of connection stiffness over the bending stiffness of the ensemble. Thus, this method allows explaining some noticed phenomena along the experimentation. However, the quantification of the moisture effect over wood-concrete connection stiffness is pending, besides to assess concrete cracking effect over the constructive system stiffness. The present study constitutes an important data base for this purpose.

References

Branco, J. M., Cruz, P. J. S., & Piazza, M. (2009). Experimental analysis of laterally loaded nailed timber-to-concrete connections. Construction and Building Materials, 23(1), 400–410. http://doi.org/10.1016/j.conbuildmat.2007.11.011

Brischke, C., Rapp, A. O., & Bayerbach, R. (2008). Measurement system for long-term recording of wood moisture content with internal conductively glued electrodes. Building and Environment, 43(10), 1566–1574. http://doi.org/10.1016/j.buildenv.2007.10.002

CSTB. (2003). Centre Scientifique et Technique du Bâtiment. Avis technique avec Plancher Lignadal. France.

Fargier G. (2006). Dalle Bois-Béton En Ambiance Extérieure, Etude Des Planchers Lignadal, Mémoire d'Ingénieur en Génie Civil, Polytech Clermont-Ferrand, Université Blaise Pascal, France. [Thesis in French]

Fournely E. & Fuentes S. (2009). Connaissance de l'interaction entre l'environnement et Comportement des Ouvrages Extérieurs - Connexions Bois Métal Et Bois Béton. Convention interrégionale Massif Central N°37-2007.

Kretschmann, D. E., & Green, D. W. (1995). Modeling moisture content-mechanical property relationships for clear southern pine. Wood and Fiber Science, 28(3), 320–337.

NF EN1992-1.1. (2004). Calcul des Structures En Béton – Partie 1-1 : Règles Générales et Règles pour les Bâtiments. In Eurocode 2.

NF EN1995-1.1. (2004). Conception et Calcul des Structures en Bois – Partie 1-1 : Généralités – Règles Communes et Règles pour les Bâtiments. In Eurocode 5.

Peña, A., Fuentes, S., Fournely, E., Navarrete, B., & Pinto, H. (2015). Exterior Wood-Concrete Slabs, Experimentation and Modeling of Mechanical Behavior. Part 1. Revista de La Construcción, 14(2), 86–90.

Racher, P. (2005). Effet de L'humidité au Sein des Structures Bois Extérieures, Variation de Résistance et Contraintes Internes.

Racher, P. (2009). Structures en Bois aux Etats Limites, Introduction à l'Eurocode 5 – Calcul de Structures. Editions Eyrolles.

Racher, P., & Founely, E. (2002). Comportement en zone sismique du plancher Lignadal, rapport de contrat MSGC-Lignalith.