WOOD-CONCRETE COMPOSITE FLOOR SYSTEM IN REHABILITATION

MARTINEZ JUAN B. *, IRLES MAS R. †

* Civil Engineer, University lecturer.
e-mail: bernardo.martinez@ua.es

† Civil Engineer, Full profesor.
e-mail: ramon.irles@ua.es

Civil Engineering Department. web page: http://www.ua.dic.es
University of Alicante. Carr. San Vicente del Raspeig, s/n, 03690
Sant Vicent del Raspeig, Alicante (Spain)

Key words: Wood-Concrete Floor System, Connector, Building Heritage

Abstract. The present communication focuses on the rehabilitation of ancient floors made of wood by means of the demolition of his not structural elements and restructuring to a timber-concrete composite (TCC) system (concrete of new contribution and wood respecting the preexisting one) connected by a new connection system, which turns out to be much **more efficient** than previous systems, reaching higher stiffness (the quotient shear/slip at interface) and a failure mode by plastification and tensile strength, without plastification of the surrounding concrete nor pull up from wood.

1 INTRODUCTION

The rehabilitation of constructed heritage is one of the important aspects contemplated nowadays in sustainability criteria of construction area. It is evident that energetic cost measured in kg of CO_2 emitted to the environment in materials manufacture and constructive process included in a new building site is higher than the mentioned cost in rehabilitation processes of already constructed work. This aspect, added to the current Spanish (and some other countries) construction crisis, gives value to the use of procedures and technologies centred on the recovery of before existing materials of construction.

Accordingly, all 40s previous floors in Spain are made of wood with a filling (usually domed) of diverse materials. From the 40s and with great profusion from the 60s, the appearance of the unidirectional floor structure re-produced mimetically the structural behavior of the previous wood one with more resistant capabilities, nevertheless there are great quantity of made of wood floors in Spain yet, some of which are part of the best exponents of our built-up heritage.

The present communication, assuming the mentioned criteria of sustainability, centres on the rehabilitation of ancient wooden floor structure by means of the demolition of his not structural elements and restructuring to a timber-concrete composite structure TCCs (concrete of new contribution and remaining the ancient wood) properly connected for its joint work, which turns out to be much more efficient on having replaced material of landfill with structural material. It manages to preserve the old wood joists, which supposes an energetic saving, besides an improvement of the aesthetic and acoustic quality against any other solutions.

2 TIMBER-CONCRETE COMPOSITE STRUCTURE. BACKGROUND

In the structures formed by elements with overlapping and not connected materials with different Young's modulus, the behavior of each material is produced separately. In case of a pure bending (or compound bending if shear deformations are neglected), each part has different curvature tending to detach, and the whole tensional diagrams are the result of each separate bending, because the materials are far from their full mechanical ability. With no connection, no shear can be transmitted between the two materials.

In case of composite structures, building each part properly sized and connected, detachment is avoided and the curvature is unified. Stresses take advantage reaching better tensional distribution that improves the separate materials behaviour, whith the consequent economic savings.

In the joint between the two materials a shear is mobilized, which must be resisted by the connection elements. If the connection is infinitely rigid (situation may be called "full interaction" or "total connection"), the deflection at midspan, the shear and the stress distribution are independent of the rigidity of the connection.

But this is an ideal and theoretical case, since there is no connector with infinite stiffness. In reality, the overall behavior of the whole, depends on the rigidity of the connector. This is evaluated by the coefficient *Kq/sq* being *Kq* the stiffness of a connector according to standard tests and *sq* the separation between adjacent connectors.

This technique is consolidated in case of mixed pieces of concrete and steel, but it is relatively new when it comes to TCCS. Since the 80s more or less satisfactorily different specific connection have been developed from research, focused on analysing the slip module (or stiffness) of the connection [1], or on the use of lightweight concrete in the process [2].

Bruce L. Deam, et al. [1] compared strength, stiffness, and mode of failure of different connectors. Push-out tests were conducted with many different connectors. Namely: Round and rectangular concrete plugs with and without screw and steel pipe reinforcement, proprietary screws, lag screws with different diameters, sheet brace anchors and framing brackets.

Concrete plug specimens manifested no measurable movements until higher loads causing rapid slip increase and concrete plugs fracture. The reinforced steel pipe ones produced a similar initial response until higher loads, tilted the pipe behind the concrete, crushed both materials and forced the wood to lift off the concrete.

The addition of a vertical coach screw to the plug increased stiffness, strength and ductility, and at the end of the tests the screw had developed a double curvature and the concrete was crushed near his head.

The rectangular concrete plug reinforced with a coach screw was found to provide greater stiffness and strength, as well as favorable post-peak behaviour, but his failure mode was similar.

Specimens with steel brace anchors and fasteners embedded in concrete (with plates orientation at 45º and 90º to the beam axis, respectively) have displayed that the orientation have no significant effect on the performance.

Framing brackets (Pryda brand) shown similar responses. Failure mode was by spiral nails completely extracted from the wood and very large deformations at the end of the test, with all the slip concentrated in the nailed connection between the steel bracket and the wood.

Specimens with vertical different diameter coach screws exhibited little movements until low loads but then the timber began to fail in bearing and the screw began to bend crashing the surrounding concrete and wood.

The patented SFS screws, specifically developed for connections between existing timber floors and concrete slabs, were driven at 45 and 135º to the loading direction. The screw in tension fractured during the test whereas the screw in compression broke into three parts, but with brittle fracture, crashing the around concrete and wood.

On the other hand, Steinberg E. et al. [2] researched the use of lightweight concrete (LC) with connectors from the European market, fig. 1. They made push-out tests over Timber-Concrete Composite specimens (TCCS) connected with 4 different connectors, some of them being the most used patents of the market.

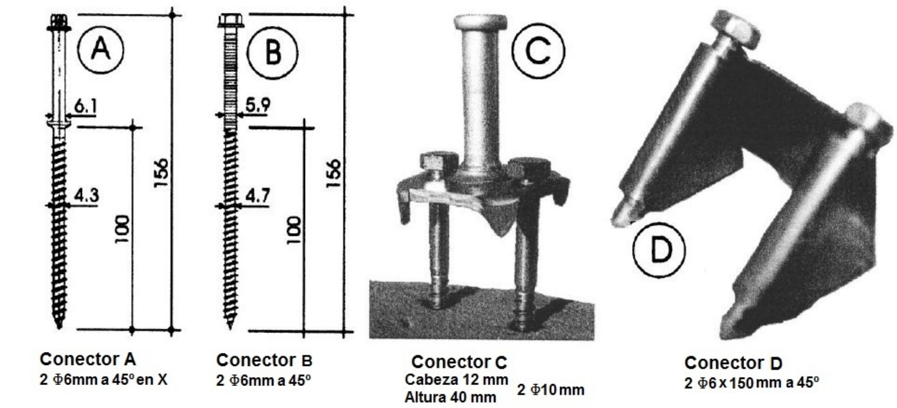

Figure 1: Overview of the connectors A,B,C and D push-out tested by Eric Steinberg et al. [1]

Push-out tests results are shown as load-slip curves for each connector in fig. 2.

Failure mode for all investigated connectors was exhaustion and crushing of the LC. The connectors themselves remained almost undamaged, but with visible bending deformations, that were severe in connector C. Furthermore, the screws in type A connectors, which were not subjected to tension, and the steel sheet of the type D connectors were affected by bending.

3 NEW CONNECTION SYSTEM

3.1 Previous connection systems disadvantages.

In order to determine the effectiveness of any of these connectors, it is important to analyse the push-out tests carried out in any investigation into two different aspects:

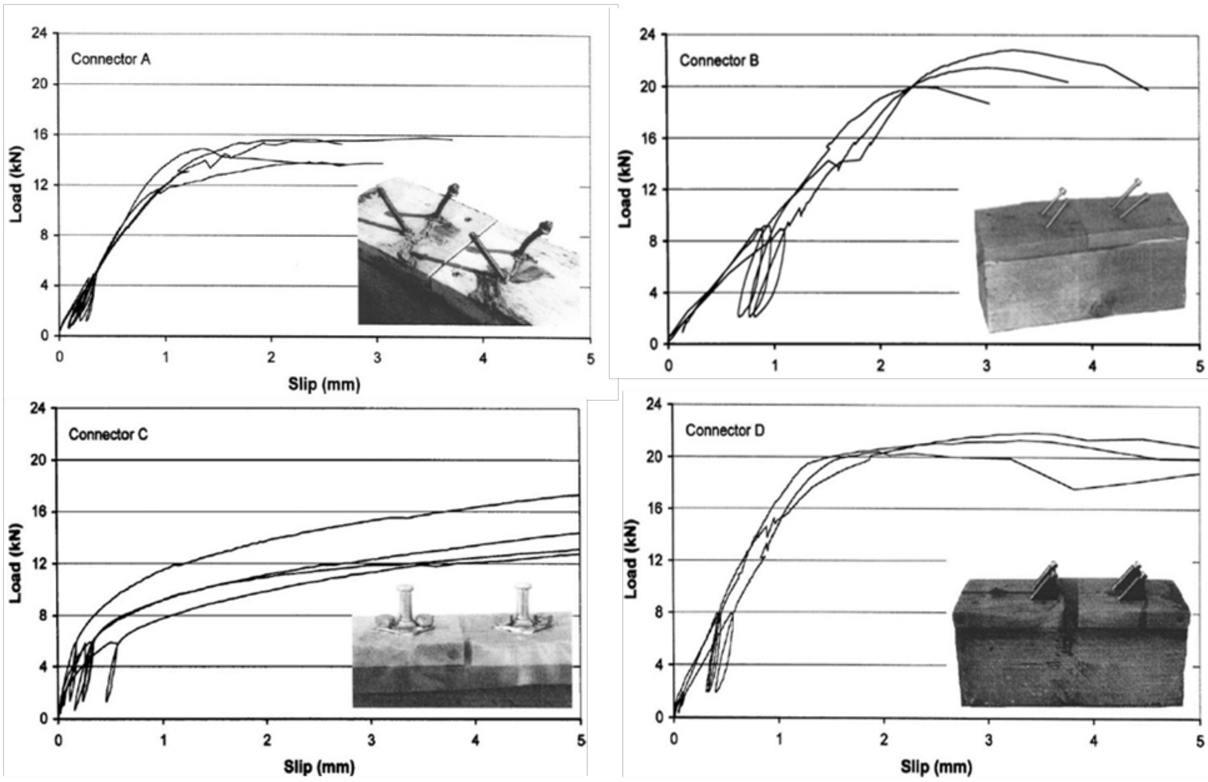

Figure 2: Load-slip curves for connectors of fig. 1. [2]

1st-Failure mode of the mixed structure set mounted with the connection when it is subjected to extreme loads. Analysing consulted literature, the failure modes of the investigated connections are shear connection failures, failure by crushing the surrounding concrete, pull-out the connection from the wood, separation of the surfaces; or in some cases, failure by crushing wood (when there are notches in the wood).

2nd- The other indicator of connection effectiveness is its slip modulus throughout the loading process until breakage. Normally, it is considered as initial modulus the ratio of the load corresponding to 40% of the ultimate load versus the corresponding slip. Usually the corresponding stiffness to 60% and 80% are also calculated, giving an idea of the load-slip behavior throughout the full load range.

If we classify the studied connectors by its resisting mechanism, we could speak of shear connectors, glued joints and connectors resisting mainly axial force.

Shear connectors results in more or less large slides involving the described failure modes. Glued joints are very rigid, but provide no ductility at all. Axial connectors provide the highest slip modulus with desirable ductility.

This axial behavior is only possible placing connectors inclined to the contact surface. For inclined lag screws connections, the viewed reports shown failure modes that are either failure by removing the screw, crushing of concrete subjected to compression around the lag head or surfaces separation. It never reaches a breaking strength of the lag without damaging the head or the concrete surrounding it, unless the lag screw was made by low resistant quality, in which case the lag is not appropriate.

Based on these considerations, the main hypothesis of the research is **that axial connections can be developed overcoming all connectors' failure modes above exposed.**

The objectives to achieve by new connectors design are:
-**To get working mainly in tension**. This configuration avoids problems arising from excessive slip (in shear working connections) or buckling (in compression working ones). To achieve it, inclined placed screws are designed, and so, the shear sense resulting from the subjected loads, makes them work primarily in tension. The elements usually change the tilt direction according to the position or nature of the loads, as shown in fig.3.

- **To avoid crushing in the concrete area next to the element**, and in particular close to the connector head. Screws are used to achieve it, as the one shown in Fig. 4 with a widening washer-shaped head wider than the tightening bolt dimensions.

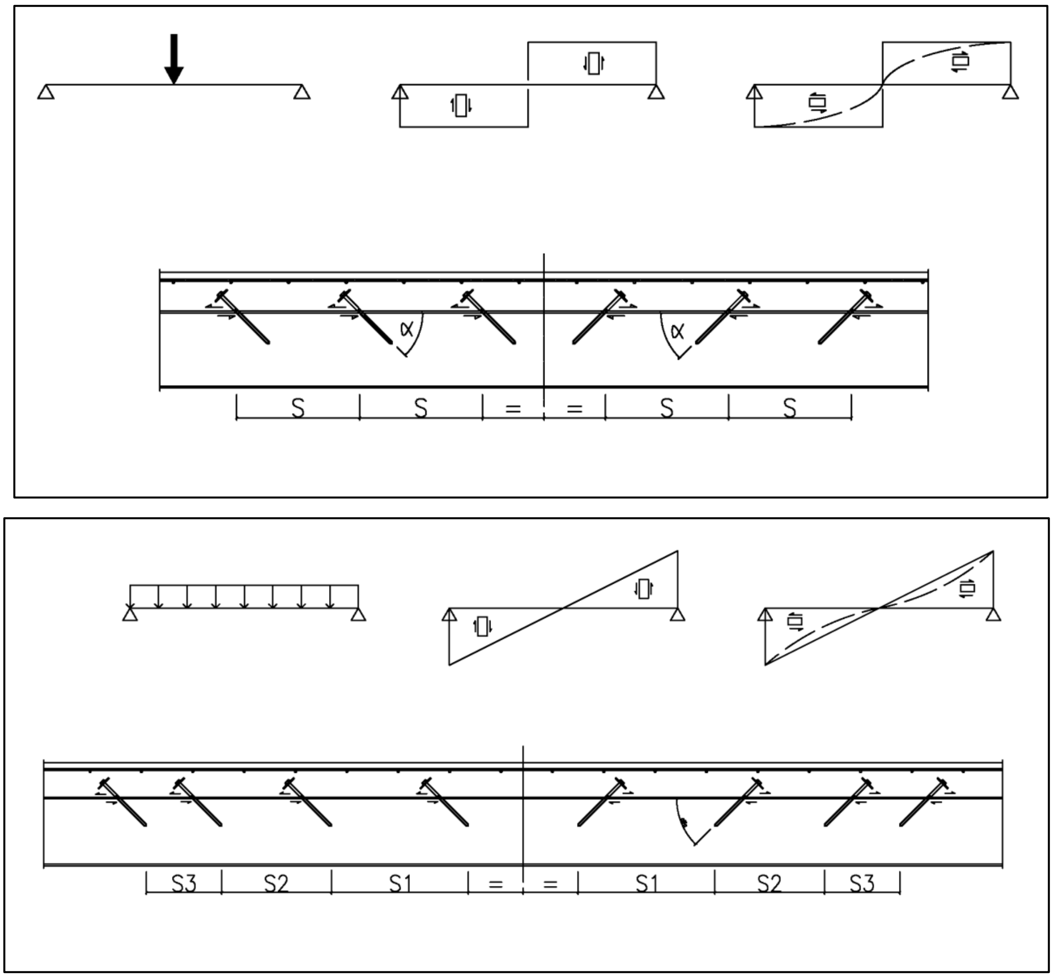

Figure 3: Inclined position of the connectors in a mixed wood-concrete beam to ensure that connectors are always in tensile strain.

Figure 4: Connecting element widening washer-shaped head

- **To avoid failure modes pulling-out the connection from timber**. Consequently it will be studied lag screws with adequate thread bolts in terms of depth, angle of the thread, pitch length and embedded depth in the wood.

If the element is properly designed, it should enable the shear stresses transmission process from the wood to the connector and it must be able to mobilize the corresponding tractions without pulling-out. It should channel these efforts, predominantly tension, to the head and it transmits them to a large mass of concrete that will not suffer plastifications. If connections are placed inclined and in tension, transverse load to screw shaft is much minor than when it is placed perpendicular to the contact plane, and no crushing will occur in concrete. The ultimate goal is to break the steel lag before crushing the surrounding concrete and to reach a failure mode by ductile tensile exhaustion of the connecting element, using the most efficient possible way to transfer shearing stresses from one material to another.

The new concrete slab can be lightweight. This involves less resistance to local compression and cracking tendency respect to a heavier concrete, but it is no yet a problem for the new wider head.

The formwork system concrete slab may be a provisional boarding supported on the sides of existing wooden beams. Fig.5

Figure 5: Possible formwork systems for concrete slab.

3.2 Tests program

To design the new connection some tests series have been made.

- Previous tests with the necessary material:

Regarding the lag, tests are performed to know (fig. 6):

- *The type of lag screw used to form the connection,* in terms of type of material, its tensile strength and diameter. Simple tensile tests with different lags screws types and diameters are made to find the appropriate diameter and resistance.
- The embedding depth on wood, neck and thread, in terms of depth, angle of the thread, pitch length and length of the thread. Pull-out tests inspired in UNE 1382 [3] helped by a specific load device were performed.
- The connector washer, in terms of diameter and thickness required. It is calculated with a simple load balancing.

Figure 6: Tensile tests of lags, specific device and pull-out test.

Concerning timber (sawn or laminated), tests are conducted to know (fig. 7):

- The tensile elastic modulus of wood, and its tensile and compression strength. Therefore load-unload flexural tests are performed, tensile strength from bending tests and compression tests with strain gauges were performed.

Figure 7: Wood bending tests in elastic range and at breakage.

Regarding the concrete (normal or LC), compressive strength tests are performed.

- Push out tests with connection specimens:

They consist of a series of tests intended *to reveal the sliding load curve until breakage and the failure mode* of the TCCS.

So, connections from 3 different types of screws were manufactured, and push-out tests are performed. (fig 8). The shape and dimensions of tests pieces are inspired by the standard specimens of Annex B of Eurocode 4 [4].

In these tests an unexpected contribution of friction in resistance sliding of the connection is discovered, so it was decided to investigate the friction between wood and concrete, due to the compression component normal to the contact, and a new series of tests has been programmed.

Figure 8: Manufacturing steps of a specimen connection and push-out test.

- Real scale prototype tests::

They consist in manufacturing a stretch of TCCS to real scale, with the designed connection, taking *measurements of the deflection at midspan* not only for elastic loading conditions but also in anelastic phase. It aims to analyse their behaviour upto break.

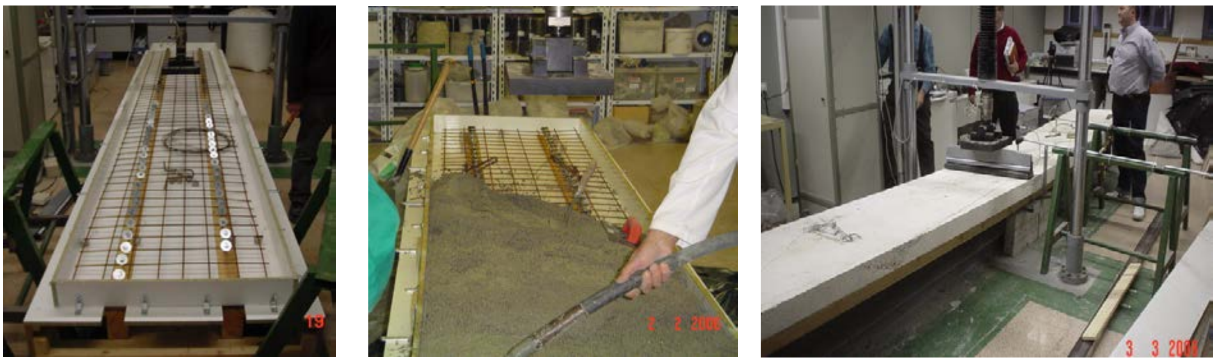

Figure 9: Production of full-scale prototypes and testing of prototype in elastic range and until failure.

Two trials with two kinds of manufacture of the same dimensions are performed:

- Timber concrete composite floor with regular aggregates.
- Timber lightweight concrete (LC) composite floor.

3.3 Initial results.

The new connection system has been successfully designed. The new dimensions of washer-shaped head, thread, and neck diameter ensure failure mode by tensile yielding, which does not exhaust the surrounding concrete and connector is not extracted from the wood. The breaking load in push-out specimens with 6 screws and separation of 10 cm was 120 kN while the tensile strength of a ∅8mm lag screw was 14 kN (that corresponds to 10 kN in the contact plane direction if the angle is 45 °). The only plausible explanation for the additional 60 kN can be attributed to friction.

The stiffness of the new connection is higher than previous connections. This difference is greater especially in the initial stiffness (elastic phase), fig 10.

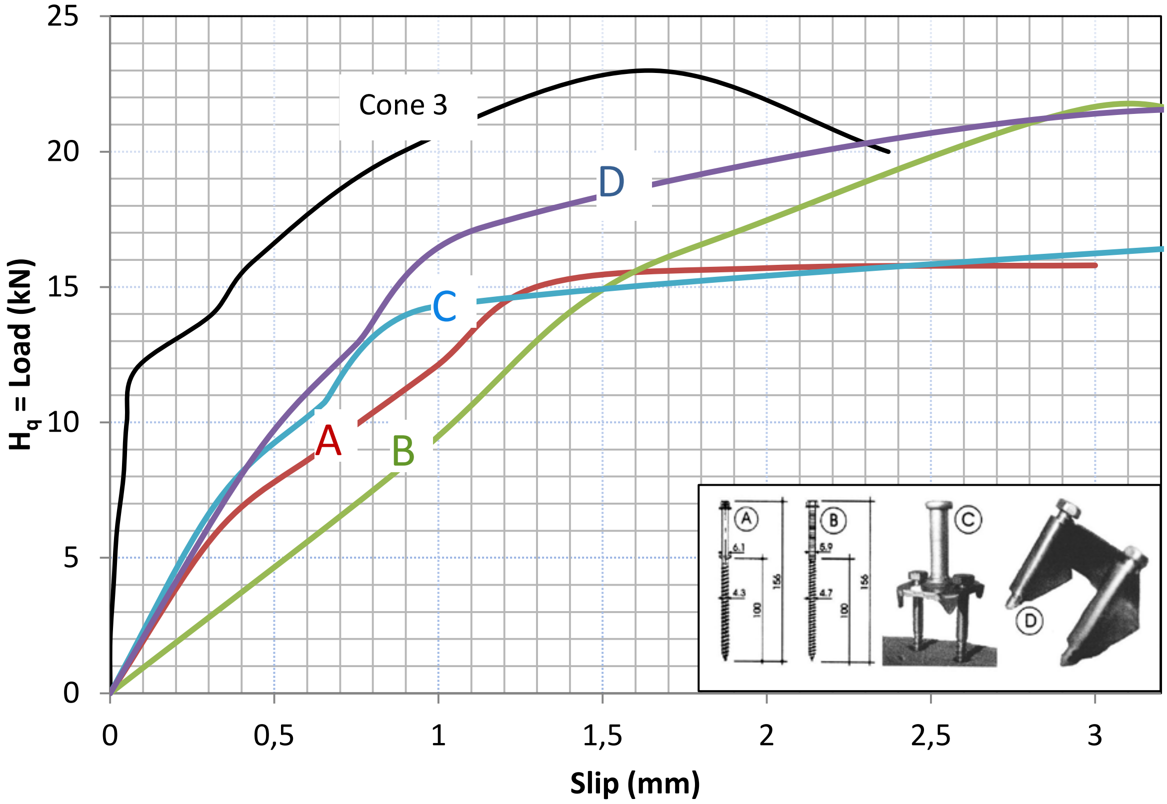

Figure 10: Load-slip curves obtained superimposing the designed connection (Cone 3) and the obtained from push-out tests conducted by Eric Steinberg et al. [2]

By placing the screws with inclined arrangement, if the load increases, the component that compresses the wood against the concrete also increases growing the friction too. Initial results suggest that the friction coefficient can reach values close to 1, so that the breaking loads can double the load that the lag screw resists alone.

All dimensions of new connector have been obtained from mechanical characteristics of used materials by mechanical considerations. The design process can be used for other material characteristics leading to different geometrical values for a specific similar connection.

We are currently working on a mathematical model able to predict in terms of load and static and mechanical material parameters, the floor internal tensions and movements; not only in linear phase behavior, but also in non-linear one, although nonlinear phase model resolution must be numerical.

4 EXPERIMENTAL REHABILITATION OF A TERRACE FLOOR.

This system has been implemented in the rehabilitation of a floor terrace of a manor house, whose original building dates from the 20s of the last century, performing successfully. (fig. 11),

Figure 11: Rehabilitation works with the proposed system and connection.

Ancient 4 m length timbers with a 14x7 cm^2 cross section were furnished with connectors every 15 cm. Lightweight concrete was used for the 8 cm thick slab. Old look was preserved but strength and stiffness were substantially increased, saving ancient timber.

5 CONCLUSION

A new connection system for timber-concrete structures has been developed, able to avoid some inadvisable features of previous systems. It can be used either for rehabilitation of ancient timber floors and for completely new ones.

Connector is a special steel screw with a large diameter head able to avoid the local concrete crushing, even using lightweight concrete. It is screwed in the wood with an inclination to work mainly in tension and yields plastically prior to pull out.

Tests have shown a higher stiffness for this system retaining ductility for ultimate loads and leading to a more effective connection when compared with previous ones.

System has been successfully used in the rehabilitation of an 80 years old floor, preserving ancient timber and look.

REFERENCES

[1] Bruce L. Deam, Fragiacomo, M. y Andrew H. Buchanan. Connections for composite concrete slab and LVL flooring systems. *Materials and Structures* (June 2007).

[2] Steinberg E.; Selle R. and Faust. Connectors for Timber–Lightweight Concrete Composite Structures. *Journal of structural engineering@ASCE*. (Nov 2003): 1538-1545.

[3] EN 1382:2000 Timber structures. Tests methods. Withdrawal capacity of timber fasteners.

[4] Eurocode 4: Design of composite steel and concrete structures.