REPORT of the Short Term Scientific Mission (STSM) at the on-going COST Action FP1004

"Enhance mechanical properties of timber, engineered wood products and timber structures".

Country and centre of **origin**:

SPAIN, Polytechnic University of Madrid (UPM), ETS of Architecture. Structural Department. Coordinator at Spain: Assoc. Prof. Jose L Fernández-Cabo.

Country and centre of **destiny**:

NORWAY, Department of Structural Engineering, Norwegian University of Science and Technology, NTNU. Coordinator at Norway. Prof. Kjell Arne Malo

Early Stage Researcher for the STSM:

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Period for the STSM:

1st March 2012 – 15th April 2012

CONTENTS

1. Purpose of the STSM. Objectives.

The proposal for the STSM was oriented to be part of the work developed at the WG2, and particularly at the field of *timber composite beams* (TCB). Additionally, the question of ***Influence of connections on whole structure response in timber structures*** was also a defined goal.

The proposal for the STSM contained not only the specific task and goals of the STSM, but also the general working plan, proposed by the center of origin, to be developed at WG2. Moreover, as the ESR is finishing her graduate level, the work at this STSM could become the basis for a Master and/or a Ph. D thesis.

The general areas where the STSM was placed are:

1. **Completing the state of art with special attention to the transfer of know-how from the scientific to the professional field.**

   The center of origin has an important data base of the topic, but nevertheless any additional work is always desirable. The key question would be to reduce the gap between scientific and professional field. We think that the use of this *filter* done by the ESR and the development of the current data base by using the resources of the centre of destiny would offer interesting and unexpected results.

2. **Reducing the gap between research and Standards, with special emphasis on global analysis tools for the use at the professional field.**

   This is finally a key target of the proposal. It is widely assumed that the Gamma method is not enough and other tools must complement annex B of EC-5.

3. **Developing of parametrical studies for clarifying the role of the different connection systems in the overall structure and therefore offering rules for selecting systems and for pre-sizing.**

   There is, in general terms, a lack of parametrical studies, which are crucial to have a technical understanding of the problem. The question of the ***Influence of connections on whole structure response in timber structures*** can be understood as a parametrical study, and we consider it is a really need at this field.

   The selection of the connection systems is also totally related with the cost, and not only with their structural efficiency. The current and logical trend is to reduce the number of joints, which clearly makes no longer reasonable to work with the Gamma method (Fernandez-Cabo et al. 2011). The parametrical studies can offer a quick tool for selecting the connection system, in advance, and establishing a previous structural efficiency.

   The work at **prefab solutions** is now also the tendency, at least for new constructions. New ideas are emerging. We think that this is still an open field, and the previous work of global analysis tools and parametrical analysis would guide the search of new possibilities. The proposal of **new connection systems** is also a target of WG2, and we assume this additional work in this proposal.

4. **Exploring the possibilities of new connections systems, with special attention at prefab systems**

The center of origin has developed some proposals now under study, now still non-published as any of them would be patented.

They also have an important data base on the existing connection systems, which would be used to compile a report, along this COST, in order to try to develop new ideas and to clarify the real possibilities of connections.

A huge number of connections systems are recorded in the literature. Nevertheless it is needed to develop a rational ranking of these systems. It has no sense to have a huge theoretical catalog without knowing their advantages and disadvantages.

The coordinator of the centre of destiny teaches lectures about connections on timber structures. So the attending of this course would be a great opportunity for the training of the Early Stage Researcher and the acquirement by the ESR of a global vision on the topic of ***Influence of connections on whole structure response in timber structures***, which investigation is defined as a main goal in the work developed by the ESR´s research group in Universidad Politécnica de Madrid.

The specific tasks/goals proposed to be developed during the STSM were:

1. **HAVE A FIRST CONTACT WITH RESEARCH AND WITH A FOREIGN RESEARCH CENTRE.**

We remember that the ESR is finishing her graduate level along 2012 (5 years + a final project). It could be an especial and additional interest, as this COST has shown a particular attention at the training of ESRs. The development of this STSM was thought to be a first impulse for the research career of the ESR, who has recently joined a research group in Universidad Politécnica de Madrid.

The contact with other research groups and Ph. D. students from a really active country on the research on timber structures would greatly enrich the training of the ESR.

2. **Complete the current data base of the state of art with special focus in the four general goals mentioned before.**

As it will be commented later, the data base of the centre of origin was further developed with the literature resources of NTNU and step by step analyzed by paying special attention to the ***Influence of connections on whole structure response in timber structures***.

Although it wasn´t a defined goal at the proposal of the STSM, additional work of literature review was done in order to be useful for the writing of a paper about long-term behavior of prefabricated timber-concrete composite systems. As it will be further explained in section 2., the ESR María Bona Gallego is still writing a paper related to the long-term test currently developed in the centre of destiny of the STSM of the ESR Edurne Bona Gallego (Lund University).

3. **Collaborate in writing a report, with the possible collaboration of other member of the WG2, at the end of 2012, containing a catalog of the existing connection systems linked with criteria for their rational ranking. This report will be used for parametrical studies (to be developed as a next step and inside this COST action).**

   This Short Term Scientific Mission, and the one developed by the ESR Edurne Bona Gallego in Lund University (Sweden), could be a first step for a standing collaboration between the three working groups Spain-Norway-Sweden.

4. **Study possibilities for open Master and/or Ph. D. thesis for the ESR around the field of prefabricated timber-concrete composite systems.**

2. STSM: work, results and conclusions

First of all, it must be pointed out that the work realized during the STSM in Trondheim University by the ESR María Bona Gallego was **in collaboration with and complementary to the tasks developed during the STSM in Lund University by the ESR Edurne Bona Gallego**. Both have recently joined a research group coordinated by Prof. Jose Luis Fernández Cabo in Universidad Politécnica de Madrid. One of the defined goals of the group is the question of ***Influence of connections on whole structure response in timber structures.***

Therefore, the main topic of the ESR´s work in Trondheim University was the investigation about **connections on timber composite structures**. The work developed by the ESR María Bona Gallego complements the already developed investigations in Universidad Politécnica de Madrid. The research group´s results were presented in April 2012 in a COST meeting in Zagreb. This STSM has been an impulse in the group´s work and it is also a first step for a possible standing collaboration with other member of the WG2 in order to write that report about rational criteria for selecting the connections. This report will be used for parametrical studies (to be developed as a next step and inside this COST action FP1004).

With regard to this aim (investigation of the influence of connections on whole structure response in timber structures and the writing of a report by the end of 2012), two working lines of the ESR can be differentiated:

2.1. LECTURES

- Prof. Kjell Arne Malo, coordinator of the centre of destiny of the ESR, taught classes about connections on timber structures. The attending of this course was a great opportunity for the training of the Early Stage Researcher and the acquirement by the ESR of a global vision on the topic of ***Influence of connections on whole structure response in timber structures***, which investigation is defined as a main goal in the work developed by the ESR´s research group in Universidad Politécnica de Madrid.

- The contact with Ph. D. students was also a significant resource of research enrichment for the ESR. Moreover, this fact allowed the ESR to follow and to learn from the research work developed by a Ph. D. student who is involved in this COST Action FP1004 and presented the state of his thesis in the COST meeting in Zagreb, in April 2012.

2.2. LITERATURE REVIEW

- The data base of the centre of origin was further developed with the literature resources of NTNU and step by step analyzed by paying special attention to the *Influence of connections on whole structure response in timber structures.*

The center of origin already had an important data base about the topic of connections on TC structures, but nevertheless any additional work was desirable. The key question of this literature review was to reduce the gap between scientific and professional field, and to complete the state of the art of connectors in TC structures by paying special attention to the real advantages and disadvantages of the connections systems used and proposed.

- Although it wasn´t a defined goal at the proposal of the STSM, additional work of literature review was done in order to be useful for the writing of a paper about long-term behavior of prefabricated timber-concrete composite systems. As it will be further explained in section 2.3., the ESR María Bona Gallego started to write a paper related to the long-term test currently developed in the centre of destiny of the STSM of the ESR Edurne Bona Gallego (Lund University).

Therefore, an additional working line can be added to the tasks developed during the ESR´s STSM:

2.3 PAPER ABOUT LONG-TERM BEHAVIOR OF TCC STRUCTURES

- Collaboration in writing a paper about the topic and the results of the current stage of the ongoing research project (long-term behavior of new connectors on prefab solutions) developed in Lund University under the coordination of Prof. Roberto Crocetti. The test will be conducted until 3rd July 2012. The results obtained until April were compiled by the ESR Edurne Bona (STSM in Lund University, Sweden). Nevertheless, further results will be compiled and analyzed by both ESR and compared with the theoretical approach according EC-5. Final outcomes will be included in the ongoing paper that the ESRs are still writing under the supervision of Prof. José Luis Fernández-Cabo (centre of origin), Prof. Kjell Arne Malo (centre of destiny) and Prof. Roberto Crocetti (centre of destiny of the STSM of the ESR Edurne Bona Gallego).

As shown, the tasks developed by the ESR during her STSM (complementary to the work developed in the STSM in Lund University), could be a first step for a standing collaboration between the three research countries.

2.1. LECTURES

As it has been already mentioned, one of the main goals of this STSM was the training of the ESR. We remember that the ESR is finishing her graduate level along 2012 (5 years + a final project). It could be an especial and additional interest, as this COST has shown a particular attention at the training of ESRs. The development of this STSM was thought to be a first impulse for the research career of the ESR, who has recently joined a research group in her centre of origin.

Prof. Kjell Arne Malo, coordinator of the centre of destiny of the ESR, taught classes about connections on timber structures (A more detailed explanation of the contents of the course is out of the scope of this report) The attending of this course was a great opportunity for the training of the Early Stage Researcher and the acquirement by the ESR of a global vision on the topic of ***Influence of connections on whole structure response in timber structures***, which investigation is defined as a main goal in the work developed by the ESR´s research group in Universidad Politécnica de Madrid.

On the other hand, the contact with Ph. D. students was also a significant resource of research enrichment for the ESR. Moreover, this fact allowed the ESR to follow and to learn from the research work developed by a Ph. D. student who is involved in this COST Action FP1004 and presented the state of his thesis in the COST meeting in Zagreb, in April 2012.

This first contact with other research groups and Ph. D. students from a really active country on the research on timber structures greatly enriched the training of the ESR.

2.2. LITERATURE REVIEW

As mentioned before, the working group of Universidad Politécnica de Madrid (which the ESR has recently joined) has already compiled a huge literature on timber composite structures, which is still being step by step analyzed. This state of the art is being done with special attention to the transfer of know-how from the scientific to the professional field. That is, this data base would be used to compile a report, along this COST, in order to try to **develop new ideas and to clarify the real possibilities of CONNECTIONS on timber composite structures**.

Nevertheless, although the center of origin had an important data base of the topic, additional work was desirable. During the STSM, the data base of the centre of origin was expanded by using the literature resources of the centre of destiny, and analyzed by paying special attention to selecting those articles which gives information to reduce the gap between the scientific and the professional field. Once again, it must be pointed out that this literature review has been done in a complementary way by the author of this report María Bona Gallego and the ESR Edurne Bona Gallego (STSM in Lund University, Sweden).

A first step in the analysis and selection of the articles was done with special focus on those research works which provided **useful information about new connections systems in timber-concrete composite structures**. The information provided in those articles was completed with the knowledge acquired in the lectures about ´Connectors in timber´, which were taught by Prof. Kjell-Arne Malo (coordinator of the STSM). This literature review will serve as complementary information for the ESR´s group in UPM for writing a report, with the possible collaboration of other member of the WG2, at the end of 2012, containing a catalog of the existing connection systems linked with criteria for their rational ranking.

In this first filter, the data base of the centre of origin and further articles gathered from the data base of the centre of destiny were analyzed, selected and organized as follows:

(all the articles are mainly focused on the research about connection systems on TCC structures)

a) Ductility

A.M.P.G. Dias, L.F.C. Jorge. -2011 “The effect of ductile connectors on the behaviour of timber–concrete composite beams”

b) Shear tests

J. Tommola, L. Salokangas and A. Jutila. -1999 ,"Test on Shear Connectors "

E. Steinberg. -2003 ,"Connectors for timber–lightweight Concrete Composite Structures "

H. J. Blab and I. Bejtka. -"Screws with Conitnuous Threads in Timber Connections "

A. Kermani and H. Goh. -1999 ,"Load-Slip Characteristics of Multi-Nailed Timber Joints "

c) Short-term tests only (full-scale specimens)

L. Jorge, H. Cruz and S. Lopes. -2004 ,"Test in Timber-LWAC Composite Beams with Screw-Type Fasteners "

R. Capozucca. -1998 ,"Bond Stress System of Composite Concrete - Timber Beams "

E. Lukaszewska, H. Johnsson and M. Fragiacomo. -2008 ,"Performance of Connections for Prefabricated Timber-Concrete Composite Floors "

P. Clouston, L. Bathon and A. Schreyer. -2005 ,"Shear and Bending Performance of a Novel Wood-Concrete Composite System "

d) Long-term tests

M. Fragiacomo, R. Gutkowski, J. Balogh and R. Fast. -2007 ,"Long-Term Behavior of Wood-Concrete Composite floor/deck Systems with Shear Key Connection Detail "

A. Ceccotti, M. Fragiacomo and S. Giordano. -2007 ,"Long-Term and Collapse Tests on a Timber-Concrete Composite Beam with Glued-in Connection "

S. Kavaliauskas and A. Kazimieras. -2005 ,"Evaluation of Long-Term Behaviour of Composite Timber-Concrete Structures According to EC "

C. Amadio, A. Ceccotti, R. Di Marco and M. Fragiacomo. -"Numerical Evaluation of Long-Term Behaviour of Timber-Concrete Composite Beams "

A. Dias. -2007 ,"Load-Carrying Capacity of Timber–Concrete Joints with Dowel-Type Fasteners "

M. Fragiacomo, C. Amadio and L. Macorini. -2007 ,"Short- and Long-Term Performance of the "Tecnaria" Stud Connector for Timber-Concrete Composite Beams "

M. Brunner, M. Romer and M. Schnuriger. -2007 ,"Timber-Concrete-Composite with an Adhesive Connector (Wet on Wet Process)

E. Lukaszewska, H. Johnsson and M. Fragiacomo. -2008 ,"Performance of Connections for Prefabricated Timber-Concrete Composite Floors "

J. Balogh, M. Fragiacomo, R. Gutkowski and R. Fast. -2008 ,"Influence of Repeated and Sustained Loading on the Performance of Layered Wood-Concrete Composite Beams "

B. Deam, M. Fragiacomo and A. Buchanan. -2008 ,"Connections for Composite Concrete Slab and LVL Flooring Systems "

S. Takac, D. Matosevic and P. Bogicevic. -"Rheological Research of Sliding Modulus of the Wood-Concrete Connection "

A. Ceccotti, M. Fragiacomo and R. Gutkowski. -"On the Design of Timber-Concrete Composite Beams According to the New Version of Eurocode 5"

U. Kuhlmann and B. Michelfelder. -2004 ,"Grooves as Shear-Connectors in Timber-Concrete Composite Structures "

D. Sonda. -2001 ,"Experimental Verification of New Connector for Timber-Concrete-Composite Structures

A. Hanhijarvi. -2000 ,"Advances in the Knowledge of the Influence of Moisture Changes on the Long-Term Mechanical Performance of Timber Structures "

M. Fragiacomo. -2005 ,"A Finite Element Model for Long-Term Analysis of Timber-Concrete Composite Beams "

M. Fragiacomo. -2006 ,"Long-Term Behavior of Timber-Concrete Composite Beams. II: Numerical Analysis and Simplified Evaluation "

U. Kuhlmann and J. Schänzlin. -2004 ,"Time Dependent Behaviour of Timber-Concrete-Composite Structures "

e) Fatigue tests

R. Bainbridge, K. Harvey, C. Mettem and M. Ansell. -2001 ,"Fatigue Performance of Structural Timber Connections "

K. Malo, A. Holmestad and P. Larsen. -2001 ,"Fatigue Tests on Dowel Joints in Timber Structures "

J. Tommola, L. Salokangas and A. Jutila. -1999 ,"Test on Shear Connectors "

A second filter was done with special focus on the topic of the paper that the ESR is still writing and which describes the results of the test currently developed in Lund University, in order to get information and conclusions useful for the current stage of the research. In that way, a review **of long-term state of the art** was done, with special focus on new connectors in TCCB. The analysis of those articles, in addition with the lectures taught by Prof. Kjell Arne Malo, constituted an important training and acquirement of knowledge about long-term behavior on TCCB for the ESR.

This filter and expand of the available data base, in addition with the knowledge acquired from the Prof. Malo lectures about connectors on TC structures, constituted the basis for the second task developed by the ESR (and which is still in process); that is, to collaborate in writing a report about the current stage of the ongoing research project (long-term behavior of new connectors on prefab solutions) developed in Lund University, Sweden.

2.3. PAPER_ LONG-TERM BEHAVIOR OF TCC STRUCTURES

The aim of the research project (new connectors on prefab solutions), which is being developed in Lund University under the supervision of Prof. Roberto Crocetti, is the investigation of the mechanical performance (static short- and long-term, and dynamic) of **self-tapping full-threaded inclined screws** as shear connectors in full-prefabricated timber-concrete composite beams.

The results obtained until April were compiled by the ESR Edurne Bona (STSM in Lund University, Sweden). Nevertheless, although the results of the test were gathered by the ESR Edurne Bona in Lund, the theoretical contribution of the ESR María Bona Gallego greatly contributed to the writing of the paper. Moreover, further results will be compiled and analyzed by both ESR and compared with the theoretical approach according EC-5. Final outcomes will be included in the ongoing paper that the ESRs are still writing under the supervision of Prof. José Luis Fernández-Cabo (centre of origin), Prof. Kjell Arne Malo (centre of destiny) and Prof. Roberto Crocetti (centre of destiny of the STSM of the ESR Edurne Bona Gallego).

The experimental program comprised:

1. **Material testing of wood, concrete and connections** used in the composite beams
2. **Dynamic tests** on composite beams
3. **Short-term bending tests** on two composite beams (specimen A and C)
4. **(Ongoing) Long-term bending tests** on a composite beam (specimen B)

The results of the **stages 1-3** and the outcomes obtained have been discussed in the Master Thesis *´Prefabricated timber-concrete composite system´, Franco Moar, Universitá degli Studi di Trento* (finished in March 2012). A more detailed explanation of this previous stage or the research is out of the scope of this text. Nevertheless, some conclusions of these previous tests are commented in the article included in following pages.

The **current stage** of the ongoing research project is the investigation of the **time-dependent behavior** of a **full-prefabricated beam** with **self-tapping full-threaded inclined screws as shear connectors**. The beam is currently being subjected to sustained load from 3rd February 2012 in indoor, uncontrolled conditions. The long-term test is supposed to be conducted **until 3rdJuly 2012**.

The ESR´s ongoing paper includes an introduction of timber concrete composite structures, with special focus on showing the possibilities that new prefabricated systems could offer; a brief state of the art of long-term behavior of TCC structures (result of the literature review done by the ESRs); and the description of the long-term test which was carried out in Lund University. The test will go on until July 2012. Therefore, the current state of the paper only reports the results obtained until April 2012. Final results and main conclusions will be discussed and included in the paper in the next months.

Long term behavior of Prefabricated Timber-Concrete Composite Floors with Inclined Screws

(ongoing work conducted at Lund University by Prof. Dr. Ing. Roberto Crocetti)

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Abstract: The aim of the project is the investigation of long-term behavior of composite timber-concrete beams, mainly focused on the development of new prefabricated systems. Although the subject on timber-concrete composite structures has been investigated at length and considerable knowledge has been acquired, an effective yet economical connection system that takes advantage of the prefabrication process is still needed for the timber-concrete composite beams to extensively and competitively penetrate into the construction industry. Hence, this paper details the current stage of an ongoing experimental investigation of the time-dependent behavior of a full-prefabricated beam with self-tapping full-threaded inclined screws as shear connectors. Three full-scale laboratory specimens of 7,200-mm span were constructed. Two previous short-term tests were performed to determine the ultimate load carrying capacity and composite efficiency (short-term results are discussed at length in a Master Thesis (1) *Prefabricated timber-concrete composite system, Franco Moar, Universitá degli Studi di Trento*). An additional beam is currently being subjected to sustained load from 3rd February 2012 in indoor, uncontrolled conditions. The long-term test is supposed to be conducted until 3rd July 2012. Final long-term results will be discussed at length in next papers by the project´s author Pr. Dr. Ing. Roberto Crocetti.

Keywords: Composite beams; Concrete; Creep; Inclined Screws; Long-Term behavior; Mid-span deflection; Prefabrication; Timber.

1. Introduction

The timber-concrete beams are a structural solution for both new constructions and upgrading of existing buildings and short-span wooden bridges, in which a timber beam or deck is connected to an upper concrete flange. The coupling of a concrete layer on the compression side and of timber on the tension side of cross section, fully exploits the properties of both materials in terms of strength and stiffness. Hence, this structure offers many advantages over timber-only or reinforced concrete floors. The concrete slab, mainly subjected to compression, significantly increases the stiffness compared to timber-only floors; considerably improves the acoustic separation; and increases the thermal mass, important to reduce the energy consumption needed to heat and cool the building.

On the other hand, by replacing the lower part of a reinforced concrete section, which is ineffective because of the cracking induced by tensile stresses, with timber joists or a solid timber deck, it is possible to achieve the following advantages: rapid erection of the timber part, due to its lower weight, with a function of permanent formwork for the concrete topping; reduced load imposed on the foundations; reduced mass and, hence, reduced seismic action; the possibility of using the timber as a decorative ceiling lining; low embodied energy and reduced CO2 emissions because timber is carbon-neutral. For refurbishment of old buildings, the following advantages can be obtained by connecting a concrete topping of approximately 50 mm to the existing timber floor: increased stiffness and load-bearing capacity; preservation of historical buildings for future generations; and better seismic performance because of the improved diaphragm action. Therefore, it can be stated that TCC floors are significantly lighter and more economical when compared to their counterparts, reinforced concrete and steel-concrete composite floors, which are characterized by a non-regenerative manufacturing process with high energy demands and high emissions of carbon dioxide.

The third important part of such construction is a connection system (subjected to shear) between these two structural elements (timber and concrete). To make the composite system a convenient alternative to traditional timber, steel-concrete and reinforced concrete floor solutions, it is essential to use an appropriate type of connection in order to not only obtain a high composite efficiency (i.e. the relative slip between the bottom fibre of the concrete slab and the top fibre of the timber beam must be kept low), but also to ensure economic design.

Many researchers have investigated this aspect and several types of connections have been proposed so far (x-x), either discrete (coach screws, SFS screws, nail plates, dowels, rebars, stud connectors...) or continuous (steel lattices glued and milled into the timber, punched metal plates glued and milled into the timber, glued-in steel meshes, and punched steel profiles screwed into the timber). However, it must be pointed out that, although the literature contains the description of a huge amount of connectors, it is still necessary to clarify how the real advantages and disadvantages are, for the sake of updating the application of those ones in the professional field.

Cecotti (2) presented a large number of fasteners that can be used to connect the concrete slab to the timber, and provides Fig.1 a comparison of the shear force-slip relationship for different categories of connection systems. Notches cut in the timber beam and reinforced with a steel screw or dowel can be considered up to date as the best connection for TCC with regard to

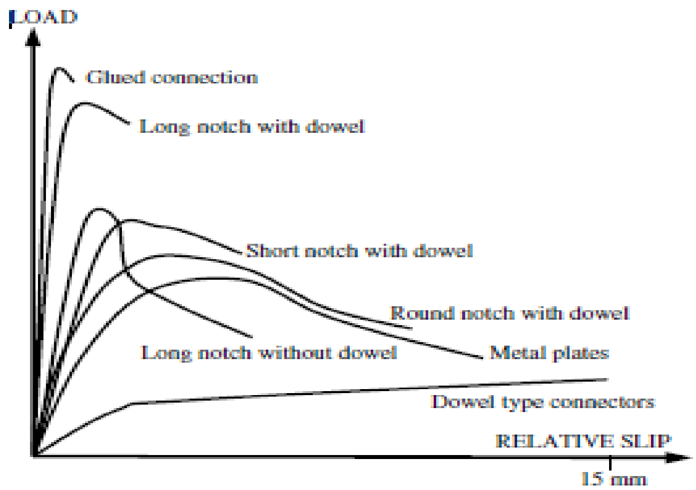


Fig. 1. Comparisons of different categories of connection systems

strength and stiffness perfomance, although it may not be as the same time economical if the notches must be cut manually. Hence, on the other hand, particular attention has to be paid to developing connection systems that are simple to produce and assemble in order to accelerate the construction process.

Taking all these points into consideration, it must be pointed out that, although the existing scientific literature in this field is huge and new ideas are also currently emerging, an effective yet economical connection system is still needed for the timber-concrete composite beams to extensively and competitively penetrate into the construction industry; i.e., a system with takes advantages of the prefabrication process characterized not only by structural efficiency, but also by cost and time efficiency.

1.1. A commitment to prefabrication

The current and logical trend of new ideas (3) is to focus on developing semi- or full-prefabricated timber-concrete composite panels.

As mentioned, timber-concrete composite systems in which ´wet´ concrete is cast on top of timber beams or wooden decking with mounted connectors offer many advantages over timber-only or reinforced concrete floors. Nevertheless, it has also drawbacks that can be eliminated by prefabricating a concrete slab with shear connectors already inserted, and connecting it to the timber beams on the building site. The most notable disadvantages of traditional concrete-composite systems are as followed: the time needed for the concrete to cure; the lower stiffness and higher creep of the system while the concrete cures, particularly if the beam is unpropped; the higher cost of cast-in-situ concrete; and potential quality control problems.

A significant benefit of prefabricated systems is that most of the concrete shrinkage will occur before the slab is connected to the timber beam, which consequently reduces the deflection and flexural stresses in the composite beam. Prefabrication off-site of the concrete slab results also in a reduction of the long-term deflection if the slab is cured for at least 56 days before it is connected to the timber beam. Furthermore, the long-term deflection of the prefabricated systems tested so far is hardly affected by the time between the end of construction and the live load application. Additional advantages of prefabrication include: reduction of construction times, since no time is needed for curing concrete onsite; avoidance of use of ´wet´ components during the generally ´dry´ process of constructing timber buildings, so no separating layer-foil are required; the elimination of lost formwork reduces the self-weight of the structure; props need to be left only for one day; and the realization of the full stiffness of the timber-concrete composite structure as soon as the concrete slab and timber beam are connected (in contrast to traditional wet systems, which require time to develop sufficient stiffness to sustain the full self-weight of the concrete slab).

The outcomes of recent experimental tests (1)(3) show that it is possible to achieve good structural performance with a prefabricated system, specially using coach screws and timber notches as connectors. Experimental-numerical investigations indicate that new shear connectors for prefabricated systems achieve high load-carrying capacity and stiffness (up to 98% of composite efficiency).

1.2. Long term

Basic principles and advantages of joining timber and concrete, with special attention to prefabricated systems, have already been exposed. Nevertheless, from a theoretical point of view, the problem of the composite beam is really complex with regard to both collapse and long-term behavior. The TCC is an internally statically indeterminate system where the solution depends on the stress-strain law adopted for timber, concrete and connection system. When subjected to sustained load, composite beams demonstrate an increasing trend of deformations, because of the different time-dependent behavior of component materials. Concrete is in fact characterized by significant creep and shrinkage phenomena, timber by creep, mechano-sorptive and shrinkage/swelling; and connection by creep and mechano-sorptive effect.

Therefore, the most important phenomena to assess in long-term testing include the combined effects of loading and moisture changes. In fact, the effect of changes in moisture on the deformation (the so-called ´mechano-sorptive´ effect) is generally more significant than the effect of time. The effect of moistures changes on creep in wood was first discovered and reported by Armstrong & Kingston (4); since then, much work has been done on this subject (5-8). In addition, thermal variations in timber and concrete shouldn´t be neglected since they induce both stress and strain distributions in the composite structures. These rheological phenomena may cause excessive deflections at the serviceability limit stage, particularly for medium to long-span beams.

The complexity of the behavior of composite beams with regard to long-term behavior leads to the fact that to solve the problem only under the simplified hypotheses proposed in Eurocode 5 is not longer reasonable. In order to model the creep and shrinkage behavior of a composite timber-concrete cross-section, several rigorous numerical methods have been proposed to date, including the following. Mungwa and Kenmou (9) proposed a relaxation method based on Dischinger´s equations. The equations incorporate creep in both concrete and timber, as well as shrinkage in the concrete, but ignore the mechano-sorption and assume a rigid connector without any time-dependent variations in responses. Schänzlin (10) developed a 1D numerical model based on the finite difference method, in which the rheological model proposed by Hanijärvi (11) was used for timber. Fragiacomo (12) developed a 1D finite element beam model in which the rheological model proposed by Toratti (13) was used for timber and the connection. Chassagne (7) and To (14) implemented an external user subroutine in a 3D finite element model implemented in the Abaqus software package to account for the rheological phenomena. Grosse (15) used ISOBEAM element with a framework-model to simulate the long-term behavior of composite beams connected at a few discrete points. Schmidt (16) used ANASYS to model the long-term behavior of composite beams including allowances for creep and shrinkage of concrete according to Eurocode 2 (17), creep of timber depending on the stress level, and creep and the non-linear shear-slip relationship of the connectors.

Given the complexities of the phenomena involved, as mentioned above, closed form solutions will have limited validity in real conditions. The range of permutations of environmental conditions that may be encountered is huge, so numerical modeling applied must ideally incorporate as many of the significant variables as possible. Thus, experimental tests are the key to keep on implementing the current literature. Although there is still a need for further information about long-term tests, a number of such tests have been performed on various (mainly ´wet´) systems, including the following. One of the first long-term tests was performed in 1943 by Richart and Williams (18). In 1990, Bonamini (19) performed push-out tests in controlled, variable relative humidity conditions on mechanical connectors, recognizing the significant increase in creep coefficient because of variation of moisture content (mechano-sorption). In 1992, Meierhofer (20) presented results form a 450-day test performed on a composite beam made of solid timber with SFS screw connectors. In 1993, Ahmadi (21) tested composite beams with two different types with two different types of high-strength nails for approximately four months. A 5- year test of composite beams with inclined SFS screw connectors was performed in 1998 by Kenel and Meierhofer (22). Another 5-year test was performed in Italy on a 6-m beam with glued rebars (23). Also in Italy, push out tests were carried out by Amadio (24) on Tecnaria connections in 2001. In 1998, Capozzuca (25) used a spring apparatus to investigate the stress losses that might occur in the connector, both in the case of high humidity levels and when humidity and temperature change. , showing a loss of stress estimated as 6-10% of the initial load after 3 months. Long-term shear tests have been also performed in 2004 by Kuhlmann and Michelfelder (26) with grooves as shear connectors, and timber-concrete composite floor with shear key connection details have been subjected to long term tests in Colorado (27)(28). A similar type of floor had also been tested in a real building constructed in Germany (29) in 2001. In 2004, Bou Said (30) monitored for two years a composite beam with glued-in mechanical connectors loaded in sheltered outdoor conditions. Further long-term tests in both uncontrolled and controlled climatic conditions were performed on dowel-type fasteners and notched connections by Dias in 2005 (31), concluding tha the creep coefficients after 285 days in uncontrolled climatic condition were approximately twice the values measured in controlled climatic conditions. In 2005. Cecotti (32) performed long-term test on a TCC beam with glued-in rebar connectors subjected to sustained load in unsheltered, outdoor conditions. The mid-span deflection increased in the first two years of the test with fluctuation of all quantities throughout the five-year period of monitoring. In 2007, Fragiacomo performed long-term tests on the head stud Tecnaria connector, recognizing that the connection system is influenced by the hygroscopic behavior of wood at the interface between the timber and the connector. Besides, eight floor system beams with shear-key connection details were tested in an uncontrolled indoor environment under sustained load applied at the thirds of the span for a period of 133 days.

All of these studies showed that composite beams have promising qualities, but the composite (mainly ´wet) systems tested all had limitations. Recent tests (33)(34) showed that the long-term deflection of TCC structures is most effectively minimized by reducing the initial deflection as much as possible through different methods, including propping or precambering of the timber joist, use of low-shrinkage concrete, or the introduction of prefabrication. In this line of work, some studies have been performed so far. In 2009, Lukazewska performed long-term test on prefabricated TCC with mounted connectors, showing that the specimens increased the instantaneous deflection by approximately 50-80%, whereas the slip only increased very little. Further push-out tests and full-scale long-term tests were performed in New Zealand (35) on semi-prefabricated LVL-concrete timber floors. Both normal weight concrete and low-shrinkage concrete are being used. After 1 year, the mid-span deflection of the beam with normal-weight concrete was approximately 20% larger than the beams with low-shrinkage concrete. Tests also show that the connection creep coefficient has no significant effect on the deflection of the TCC beams.

Within this context of new active proposals on prefab solutions, the aim of the ongoing project developed at Lund University by Prof. Dr. Ing. Roberto Crocetti is to work on this still open path of researching on prefab timber-concrete composite beams, with special focus on long-term behavior of the composite system.

2. Research study

This paper details the current stage of an ongoing experimental investigation of the time-dependent behavior of a full-scale beam specimen with self-tapping full-threaded inclined screws as shear connectors, which final results will be submitted for publication in a future paper. The purpose of this research project is to explore the mechanical performance of an innovative ´dry-dry´ connection system in a full-prefabricated timber-concrete composite floor. Therefore, a brief explanation of the previous results obtained from the short-term tests (1) is also pertinent to this paper.

The experimental program comprised: (1) material testing of wood, concrete and connections used in the composite beams (2) dynamic tests on composite beams; (3) short-term bending tests on composite beams (specimen A and C); and (4) long-term bending tests on composite beams (specimen B).

All load tests have been performed in the LTH laboratory at Lund University, Sweden, under the supervision of R. Crocetti.

2.1. Specimen Configuration

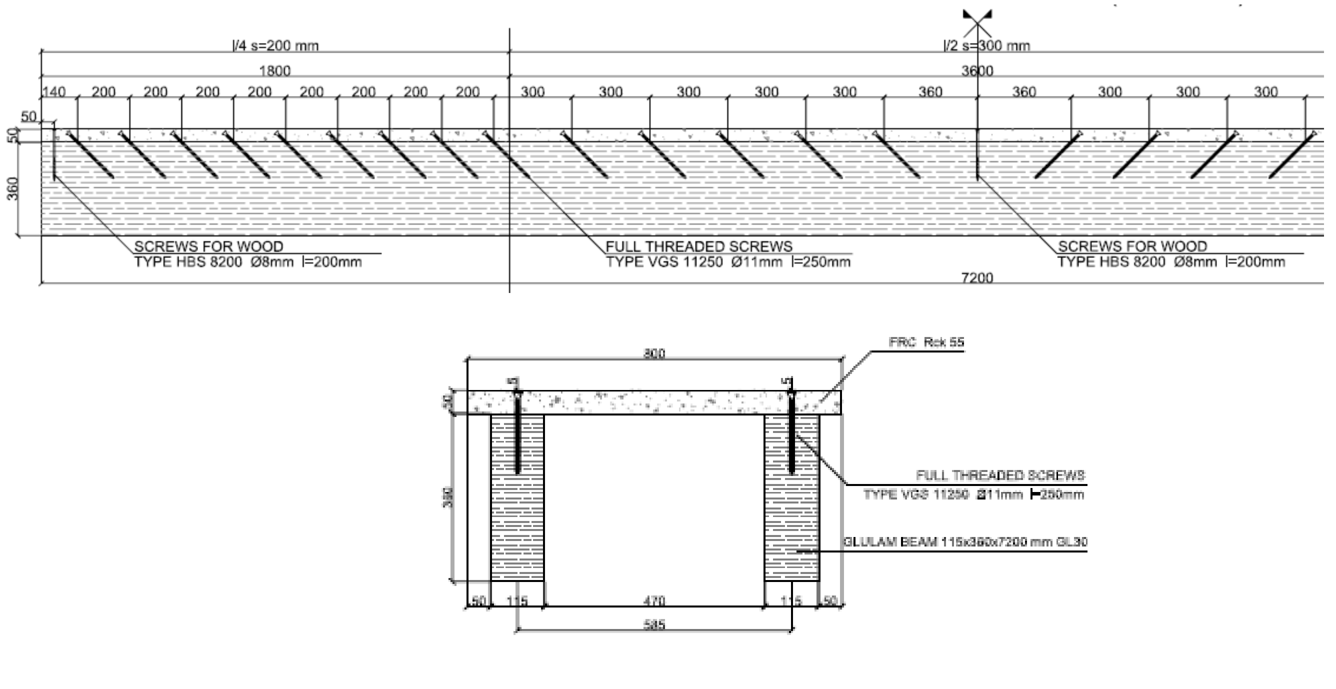


Fig. 2 . Elevation an cross section of the glulam-concrete composite beam with self-tapping full-threaded inclined screws as shear connectors

The layout of the specimens used both in short and long-term tests are depicted in Fig.2. The design procedure used to configure the specimens was based on a FEM analysis in agreement with ´γ-method´ included in Eurocode-5.

Fig. 3. displays the trend of the maximum shear force on the shear connector and the maximum tensile stress in the lower edge of the timber beam of different dimensional schemes of slab-beam-connector spacing.

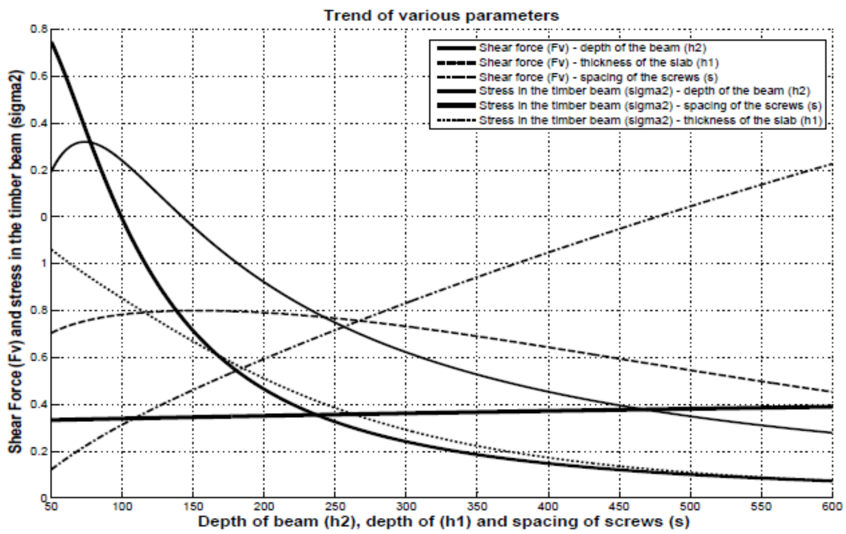


Fig. 3. Trend of the shear force Fv and the maximum tensile stress in the timber-concrete composite beam (sigma 2)

Dimensions and Parameters chosen for the full-scale specimens		
Depth of the beam	Thickness of the slab	Spacing amongst the screws
[mm]	[mm]	[mm]
360	50	20+30+20

Fig. 4. Selected dimensions

The dimensional parameters chosen (Fig.4.) ensure economic efficiency and meet serviceability requirements; i.e. maximum instantaneous mid-span deflection (0,0065m achieved - 0,018m required) and natural frequency (13.4Hz achieved-10.0Hz required).

The specimens were constructed from two 360 cm glued laminated timber GL30c. Each glulam beam was composed by eight overlapping lamellae characterized by a depth of 45mm. Physical tests were performed on the wood in order to evaluate its mechanical properties. The obtained statistic values are reported in Fig.5.

Description	Symbol	Units
Bending strength	$f_{m,g,k}$	30 MPa
Tensile strength parallel to the grain	$f_{t,0,g,k}$	20 MPa
Tensile strength perpendicular to the grain	$f_{t,90,g,k}$	0.5 MPa
Compressive strength parallel to the grain	$f_{c,0,g,k}$	25 MPa
Compressive strength perpendicular to the grain	$f_{c,90,g,k}$	2.5 MPa
Shear strength	$f_{v,g,k}$	3.5 MPa
Mean elastic modulus parallel to the grain	$E_{0,g,mean}$	12500 MPa
Charac. elastic modulus parallel to the grain	$E_{0,g,0,05}$	10417 MPa
Mean elastic modulus perpendicular to the grain	$E_{90,g,mean}$	300 MPa
Tangent modulus	$G_{g,mean}$	650 MPa
Specific gravity	$\rho_{g,k}$	390 kN/m^3

Fig. 5. Timber characteristic strength and Elastic moduli

The moisture content of each timber beam was also measured, monitoring an average value of 10.5 % and 9.8 % respectively for beams B1 and B2 (specimen B subjected to long-term test).

The concrete used in the experimental tests is classified as steel-fiber reinforced concrete C45/55 with ZP 30/0.40 fibers. The slab was reinforced with steel fibers in order to prevent the cracks due to internal stresses derived from the shrinkage of the concrete. Furthermore, fibers improve the strength parameters of the material, consequently benefiting the composite system behavior. The proposed system is full prefabricated, thus concrete cannot shrink freely. Therefore, a special attention must be paid to the concrete composition. A destructive compression test was performed on concrete cubic specimens to evaluate the mechanical characteristics of the steel-fiber concrete (Fig.6.).

Description	Equations	Value $[MPa]$
Characteristic compressive cylinder strength of the concrete	$f_{ck} = 0,83 \cdot R_{ck}$	42,19
Mean value of concrete cylinder compressive strength	$f_{cm} = f_{ck} + 8$	50,19
Mean value of axial tensile strength of the concrete	$f_{ctm} = 0,3 \cdot (f_{ck})^{2/3}$	3,64
Characteristic value at 5% fractile of tensile strength of the concrete	$f_{ctk,0,05} = 0,7 \cdot f_{ctm}$	2,54
Characteristic value at 95% fractile of tensile strength of the concrete	$f_{ctk,0,95} = 1,3 \cdot f_{ctm}$	4,73
Mean value of tensile strength of the concrete due to bending	$f_{cfm} = 1,2 \cdot f_{ctm}$	4,36
Secant modulus of elasticity of the concrete	$E_{cm} = 22000 \cdot (\frac{f_{cm}}{10})^{0,3}$	35695

Fig. 6. Mechanical characteristics of concrete according to Eurocode 2

Physical tests were also carried out on connectors, in order to evaluate the optimum depth of anchor of the screws in the concrete matrix. The obtained statistical values are reported in Fig.7. Such values measure the ultimate tensile capacity of the screws depending on the depth of insertion, which allowed to estimate the withdrawal capacity. Tensile tests on the screws were also performed in order to obtain the failure load of the screws when acting in tension. The average resulting value was 42.03kN.

Description	Symbol	Dimension
Major diameter	d_1 [mm]	11
Head diameter	d_k [mm]	19, 30
Core diameter	d_2 [mm]	6, 60
Shank diameter	d_s [mm]	7, 70
Threaded length	$L - L_s$ [mm]	$L - 35$
Head thickness	t_1 [mm]	8, 20
Screw length	L [mm]	250
Torx	TX	50
Characteristic yield moment	$M_{y,k}$ [Nm]	45, 90
pre-drilling hole diameter	d_p [mm]	7, 00

Fig. 8. Characteristic dimensions of the VGS screws

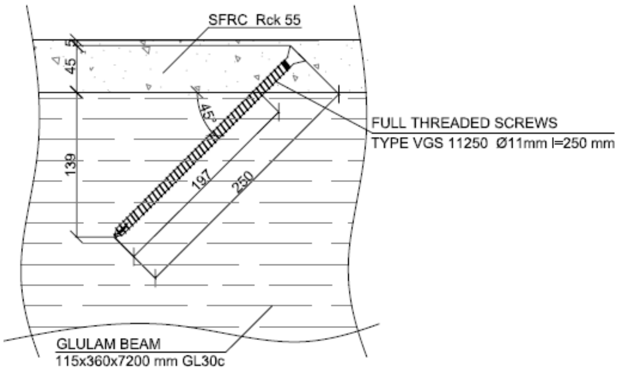


Fig. 9. Inclined screw connection detail

The choice of the connection was crucial in order to make this innovative full prefabricated composite system structurally effective and economically competitive. The screw used as shear connectors are self-tapping full-threaded screws, type VGSϕ250mm, as depicted in Fig.9. The layout and spacing of screws in the timber-concrete composite floor is depicted in Fig.2. As shown, the connectors were screwed at angle of 45º. Due to this inclination, compression stresses appear between timber and concrete. Such compression stresses generate friction between both materials, which contributes to increase the stiffness and the strength of the composite action.

2.2. Specimen Construction

The commitment to prefabrication leads to an easy and fast production procedure. The most decisive aspect while constructing the composite system, was the rotation of the specimen after the mounting. After having placed the VGS screws into the glulam beams (with additional insertion of HBS 8200 in order to inclined screws don´t suffer deformations by touching the lower part of formwork), the two beams of each specimen were temporary connected with transversal and diagonal planks, in order to be lift and to inserted into the formwork as soon as the concrete is cast.

Fig. 10. Insertion of the glulam beams in the fresh concrete

The concrete was reinforced with four rows of fiber-glass bars in order to be able to bear the stresses appeared during the final rotation of the system. On the 28th day after the assembly phase, the composite system was rotated 180 degrees in order to be set in the position as it is on site. Two steel frames fixed on both ends of the beams were placed in order to lift the specimen by a crane and to rotate it by hand in the air, as shown in Fig.11.

Fig. 11. Rotation of the composite system

3. Long term test (ongoing work)

3.1. Test set-up

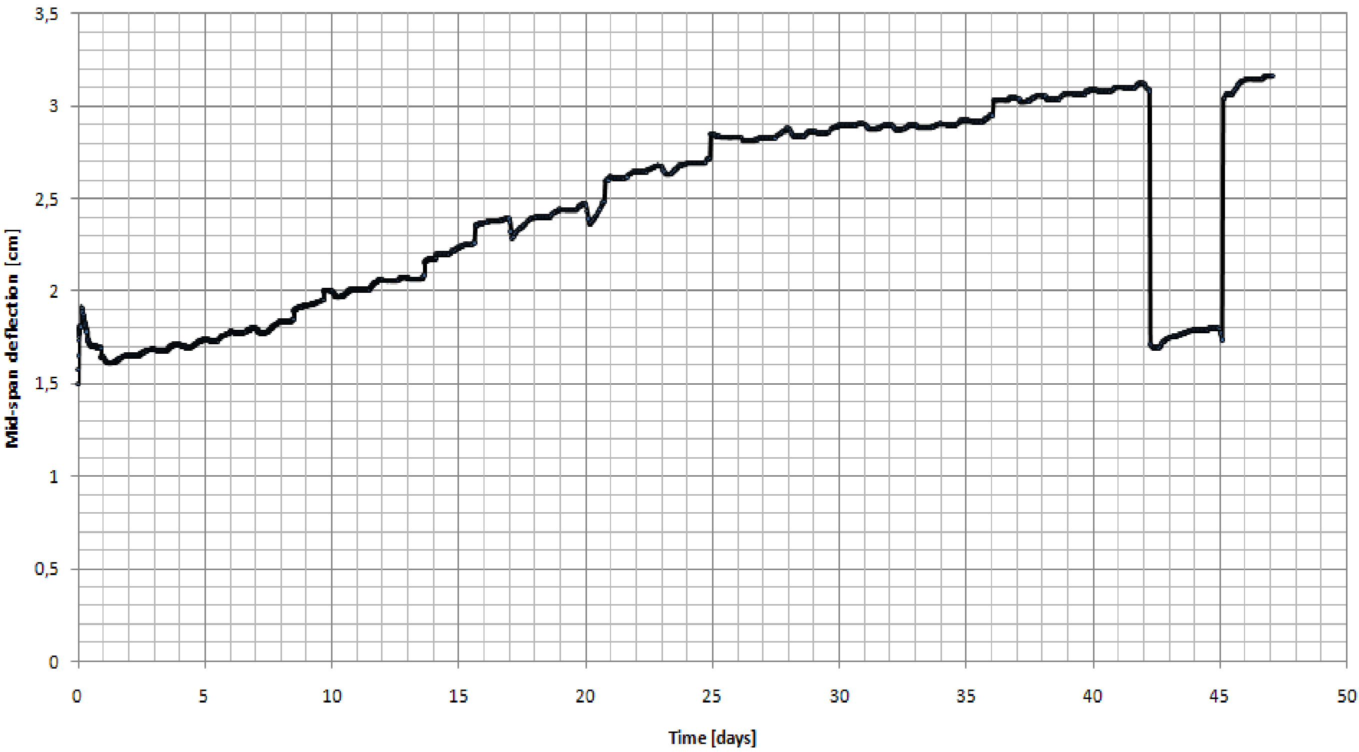
The ongoing long term test started on 3rd February 2012 and will last until the 3rd July 2012. The test is being conducted inside the laboratory, in uncontrolled environmental conditions.

The purpose of the test was to monitor the increase in deflection over the time due to the construction process and the application of a sustained load. The specimen B was loaded with sack of cement in order to apply a uniformly distributed load of 100 kg/m². After 6 weeks, the load was removed during three days in order to analyze the creep recovery of the TCCB.

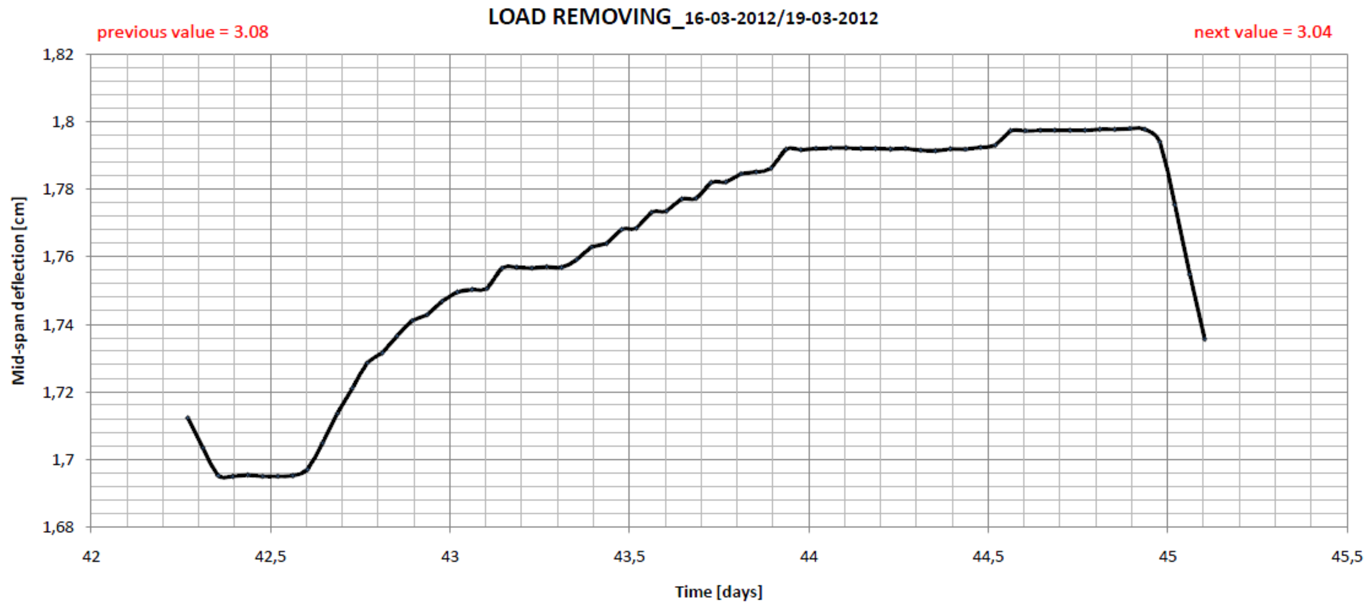
3.2. Results and analysis

As it has been already mentioned, the long-term test will be conducted until the 3rd July 2012, whereas the ESR left Lund on 15th April 2012. Therefore, the current state of the paper only reports the results obtained until April 2012. Final results and main conclusions will be discussed by the ESR with Prof. Crocetti and included in the paper in the next months. The ESR will also compare the experimental results from the test with the mid-span deflection obtained by applying the EC-5 approach.

The trend in time of mid-span deflection of the TCC subjected to maintained load is depicted in the graph below. The ESR is still waiting for getting the results obtained during the last month. The analysis of further results of the test and its comparison with the theoretical ones will be done by the ESR under the supervision of Prof. Jose Luis Fernández-Cabo and Prof. Roberto Crocetti.



The data obtained during the load removing (3 days) after 6 weeks are depicted in the graph below. The reasons of these results are still being discussed by the ESR with Prof. Cabo.



4. Conclusions

Conclusions about long-term test will be discussed in the following months. Nevertheless, some comments on the previous stages of the research project can be made. The connection system used in both full-scale tests (short- and long-term) was the same and the configuration of the 3 beams tested (short-term_specimen A and C , and, long-term_specimen B) as well.

Therefore, based on the results of the short-term tests, the following remarks can be made:

-Both the two full-scale specimens tested at a short-time can be considered highly resistant, by referring to normal floor-loads at SLS. The efficiencies of both the specimens A and C, were η= 0; 82 and η = 0; 77, respectively.

-It was done a comparison of the outcomes obtained by theoretical and FEM models calculations and the ones registered from the two bending tests on specimen A and C. According to the comparison between the three approaches, it can be remarked:

1. Comparison amongst the mid-span deflections

Approach	Mid-span deflection	Mid-span deflection
FEM model	77 mm	5 mm
Theoretical calculation	82 mm	5 mm
Results from Specimen A	65 mm	4 mm
Results from Specimen C	67 mm	3 mm

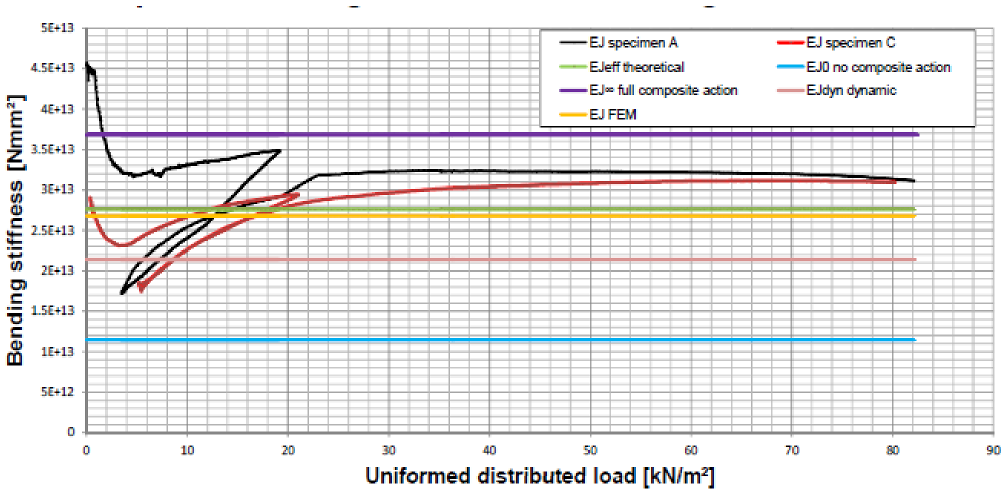
It can be concluded that the mid-span deflections predicted for the ultimate load from the *γ-method* is greater than the one which results from the FEM model. Therefore, the use of *γ-method* during the design phase allows to get results on the safe side.

2. Comparison amongst the fundamental frequency

Approach	Frequency [Hz]
FEM model	14,80
Theoretical calculation	15,21
Results from specimen B	12,89

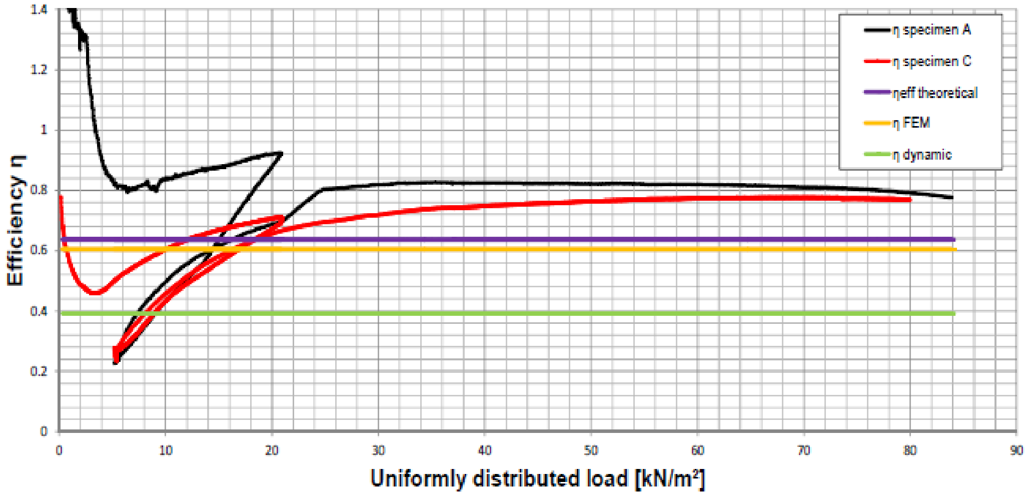
it can be concluded that the fundamental frequency calculated by FEM model and theoretical calculation give results fairly and a higher value than the frequency measured by the dynamic test performed on the specimen B. It is common that FEM programs give higher frequencies than in the real, and it means that the FEM models are usually stiffer.

3. Comparison amongst the bending stiffness



The figure shows the different bending stiffness evaluated from the different approaches, from the short-time bending and dynamic tests. The real stiffness for both the specimens are higher than the effective one, evaluated on the basis of the stiffness of the shear connectors obtained from the results of the push-out tests performed. The bending stiffness evaluated from the FEM model is just a bit lower than the effective one but almost not appreciable. This is a good outcome since FEM model and theoretical calculations have the same assumptions of elastic and linear behavior of the structure up to the failure. The dynamic stiffness is a bit lower than the static one, and this could be due to the fact that the connections do not lead the system to a full-composite action.

4. Comparison amongst the efficiency



The efficiency evaluated by the FEM model and the theoretical calculations are very close to each other and besides, both lower than the real one obtained from the two bending tests. On the contrary, the dynamic efficiency is fairly lower. As a conclusion, it can be remarked that both systems show a resistant and rigid behavior, if related to normal floor-loads evaluated at SLS. The most important result concerns the huge real bending stiffness of the composite system, whose efficiency is very close to 1.

5. Comparison amongst the maximum shear force on the connector

Approach	Maximum shear force acting on the screw [kN]	
FEM model	51 kN	3,3 kN
Theoretical calculation	72 kN	4,8 kN

It can be concluded that for serviceability loads, the FEM model and the theoretical calculation provide a value of the maximum shear force acting on the screw at the supports lower than the real one, meanwhile for load close to the failure, the theoretical calculations provide a greater value than the real one registered on the two full-scale specimens, while instead in this case from the FEM model is obtained a lower value of the force.

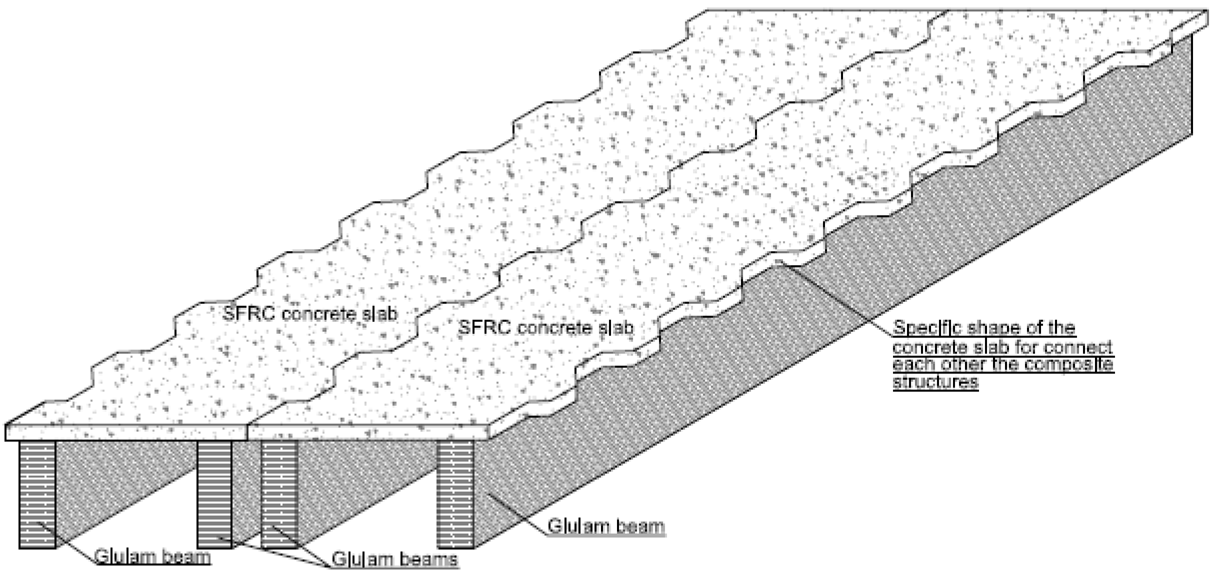
5. Future research_industrial implementation

The research project presented answers many questions, about the way of production and the way to predict the behavior of the structure by means of theoretical calculations and development of FEM models, but it raises new questions about how these prefabricated timber-concrete composite structures can be used for various purposes.

The self-tapping screws used to join the concrete slab to the glulam beams well responded to their purpose. The composite structure shows high level of bending stiffness and degree of efficiency, and a high load-carrying capacity as well. As regards durability, the composite system is well working against wheatering, since the concrete on the top side protects the beams from precipitation. Only special attention must be taken when more of these types of system are placed close to each other in order to realize a horizontal floor by providing a waterproof joint. Last, since the fire resistance of timber-concrete composite elements is heavily dependent on the effects of fire on the timber and shear connectors, and composite beams will inevitably lose stiffness when subjected to fire, the fire-resistance of the full-prefabricated timber-concrete composite system should be investigated.

On the other hand, the choice of using self-tapping screws for connecting the two members turns out to be the cheapest and fastest. Further, considering the high degree of prefabrication here proposed, it allows to save money and time. Other ways to develop this type of system completely at the workshop should be investigated. One aspect of the system which is not discussed in the research project, but not least from a manufacturability point of view, is the connection detail between composite floors and vertical element. These aspects need to be considered to ensure that any developed composite floor structure is compatible also for seismic requirements, which need that the horizontal floors for new building must be not deformable in their plane in order to well distribute the horizontal forces.

A possible connection between composite systems, which can be considered for a high degree of prefabrication, is presented in the figure below. In this case, a specific shape of the formwork for the concrete slab is needed.



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3. Future collaboration

It must be pointed out that the work realized during the STSM in Trondheim University by the ESR María Bona Gallego was in collaboration with and complementary to the tasks developed during the STSM in Lund University (Sweden) by the ESR Edurne Bona Gallego. Therefore, those two STSMs could be a first step for a standing collaboration between the three working groups Spain-Norway-Sweden.

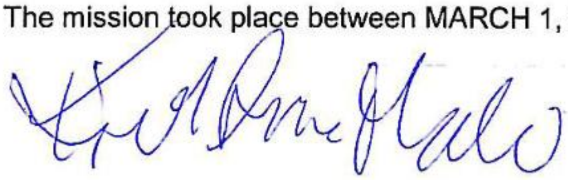
Both ESRs have recently joined a research group coordinated by Prof. Jose Luis Fernández Cabo in Universidad Politécnica de Madrid. One of the aims of the group is to write a **report**, at the end of 2012, containing a catalog of the existing connection systems linked with criteria for their rational ranking. This report will be used for parametrical studies (to be developed as a next step and inside this COST action). The work developed by the ESR María Bona (literature review focused on connections in TCB and analysis of results of a long-term test using self-tapping full-threaded inclined screws as shear connectors in full-prefabricated timber-concrete composite beams) would complement the already developed investigations in Universidad Politécnica de Madrid. This STSM could be also a first step for a possible standing collaboration with other member of the WG2 (Prof. Kjell Arne Malo) in order to write this report about rational criteria for selecting the connections.

Finally, this STSM offers possibilities to open Ph. D. thesis for the ESR around the field of new connectors in timber-concrete composite systems.

4. Confirmation of the successful execution of the STSM

In the name of the host institution, Norwegian University of Science and Technology, NTNU, Department of Structural Engineering, the undersigned Professor Kjell Arne Malo confirms the successful execution of the STSM by María Bona Gallego within the COST FP1004 action.

The mission took place between MARCH 1, 2012 and APRIL 15, 2012.



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