ABSTRACT: Timber-concrete-systems have been increasingly used in recent decades. This increased interest is due to various reasons, but particularly to the use of timber in new types of buildings, such as for example, multistory buildings or motorway bridges, where the timber-concrete composites play an important role. In spite of this higher interest, such development, was not supported by an adequate regulatory framework. The composite timber-concrete systems are, usually, analyzed and designed in accordance with Eurocode 5, which does not address many important issues that are specific for the design of this type of structure. To close this gap, CEN/TC 250/SC 5, the standardization committee responsible for drafting Eurocode 5, decided to establish a Working Group (WG2) on this issue. This Working Group will be supported by a Project Team, mandated to draft the new Eurocode 5 part on timber-concrete composites. This paper presents the main objectives and methodologies used in this task, as well as, the current status of the work and the schedule for the incoming years.

KEYWORDS: Timber-Concrete, Composite Systems, Design of Structures, Eurocodes, Standardization, CEN, Project Team

1 INTRODUCTION

Timber-Concrete Composite (TCC) systems have been used for a long time, all over the world. The first reports on their use are from a patent of a composite system on which nails and braces were used as the connectors [1]. On the same period, in the US, various research works were reported on the use of TCC systems for bridge applications. Conde McCullough mentioned that more than 180 structures had been built with this system by 1943 [2]. The first TCC bridge built originally as so, is usually referenced as early as 1924, based on experimental research from the City of Seattle and the University of Washington [3].

The reasons for this interest were at the time closely connected with the shortage of resources between the world wars, namely the steel.

At these early times, in many situations the concrete was added without design, neglecting the composite action, once the main purpose was to protect timber from the environmental actions. In spite of this, the composite action was clearly recognized to have, a significant potential, contribution to the structural performance. Already at that time ratios between composite and non-composite solutions were mentioned to be up to 2 and 4 for the load carrying capacity and stiffness respectively [2]. When the design was performed considering the composite effects, the ordinary transformed section formulae was suggested, as the analysis design model [2].

The use of TCC systems tended to decrease after the 1960’s decade from the last century. In the 1980’s early 1990’s a new interest appeared, namely due to its use in the renovation of existing timber floors [4]. This motivated the appearance of new connection systems, and analysis approaches, mostly as consequence of the various research projects undertaken [1, 5].

In the late 1990’s and 2000’s, a new incentive was motivated by appearance of new applications that became possible using wood based products. These are closely related to the development of new products and techniques as for example the Cross Laminated Timber (CLT), which significantly widened the potential application for timber in construction, namely in larger building typologies as the multi-storey buildings. Such demand brought new issues as the thermal, dynamic, acoustic, or fire requirements, where TCC systems can play a significant role [6].

This development evidenced the need for new design approaches for the analysis and design of TCC systems. These reasons motivated the creation of a specific group within CEN/TC250/SC5 to deal with the composite timber structures. Such initiative supported the inclusion of this issue in the first stage of the CEN Mandate M/515 [7].

This paper presents the main objectives and approaches towards the development of this work. Additionally, it describes the work undertaken up to now in close coordination with the other the revision work being done,
within the aim of the new generation of Eurocodes, particularly Eurocode 5 [8].

2 DESIGN OF TIMBER-CONCRETE STRUCTURES

2.1 EUROCODE 5

The design of TCC based on the transformed section might be acceptable in some cases, however, due to the limited stiffness of the connections other approaches, that take the connection slip into account, need to be used. Additionally, there are other topics such as the connection properties that need to be known even if very simple approaches are used [9].

The current version of the Eurocode 5 does provide some indications on a number of these aspects. In part 1-1 [10] only one clause can be found, explicitly and specifically meant for the design of TCC systems:
- Clause 7.1 (3) Joint slip for concrete-to-timber connections

On the other hand, in part 2 [11] there are a number of clauses specific for the design of TCC bridges:
- Clause 2.4.1 – Table 2.1 – Recommended partial factors for material properties;
- Clause 5.1.3 – Simplified analysis - Effective cross-section of the beam;
- Clause 5.2 – Influence of the joint slip in composite action deck plate systems;
- Clause 5.3 (1) – The concrete part should be designed according to EN 1992-2;
- Clause 5.3 (2) – Design of steel fasteners and grooved connections;
- Clause 5.3 (3) – Effective width of the concrete plate composite timber beam/concrete deck structures, SLS;
- Clause 5.3 (4) – Consideration of cracks in concrete plate, SLS;
- Clause 5.3 (5) – Consideration of tension stiffening. Simple approach to determine the stiffness of a cracked concrete cross section;
- Clause 6.1.2 – Table 6.1 Design coefficients of friction for timber-concrete.
- Clause 8.2 – Timber-concrete connections in composite beams

Despite these indications, many relevant aspects are not explicitly covered in the Codes. In such cases, relevant clauses, originally not meant for composite design, available from other Codes, such as for example Eurocode 5 [10] and Eurocode 2 [12] are adapted and adopted. A good illustration of that approach, is the worked example from STEP 2 [13], which is often followed and used as a reference.

A clear example from such adaptation is the $\gamma$ method given in Eurocode 5 for timber structures, that in spite of not having been specifically derived for TCC systems, is probably the most used approach to analyse this type of structure, and has shown to deliver good results for most of the engineering applications [14].

There are however many issues such as for example the long term analysis of TCC system for which the adoption of the Eurocode 5 models do not lead, in most of cases, to appropriate solutions [15].

2.2 AUSTRALIA AND NEW ZEALAND DESIGN GUIDELINES AND TIMBER BRIDGE MANUAL

The Australian and New Zealand design guidelines [16] follow the EC5 approach as the underlying basis for the design procedures. The procedures and clauses have, however, been modified to comply with the Australian and New Zealand codes [17].

Some limitations apply to this procedure due to the recognised uncertainty about some aspects of long term deflection of TCC floors. The analysis and design are based on the $\gamma$-method given in Eurocode 5.

Elastic properties of the connections are assumed for the both limit states and analysis, but the procedure limits its aim to two notched connection configurations described in the document. For these connection types, mechanical properties are indicated based on data available from empirical test data [17].

In Australia it is also available a Timber Bridge Manual [18] which has one chapter focused on Timber bridges with concrete overlay, and another on timber-concrete composite bridges. Comprehensive execution and detailing indications are given in this manual.

2.3 CANADIAN DESIGN CODE FOR BRIDGES

Canadian Highway Bridge Design Code [19] gives specific indications for the design of TCC bridges. These include analysis, connection systems, detailing and execution. Nevertheless, the aim of the code guidelines is restricted to TCC with timber deck floors.

The method to determine the resistance assumes linear elastic behaviour of the materials and the use of the transformed sections method.

Two connection configurations are allowed, both based on notches obtained through different depths of the laminations, combined with steel fasteners.

Minimum requirements are indicated for both concrete thickness and concrete strength. Additionally, minimum reinforcement steel requirements as well as the corresponding detailing are also indicated.

2.4 BRASILIAN MANUAL FOR TIMBER CONCRETE BRIDGES

Likewise in Brazil, indications for the analysis and design of TCC systems for bridge applications are also given in a Manual for the project and execution of timber bridges [20].

The design approach is meant for TCC bridges with timber deck systems, made with round wood members.

The analytical approach is based on the shell theory. Also in this manual, connection mechanical properties are given for two configurations with X glued in bars, varying in the rebar’s diameter.

The procedure indicates in an explicitly way the design of the TCC system with fresh concrete and with hardened
concrete. Brief and general recommendations are given on the execution and detailing.

3 SOME KEY ASPECTS IN THE DESIGN OF TIMBER-CONCRETE

The definition of the aspects to be addressed in the code is based on a number of principles which, were defined in advance.

A first critical criteria, for this definition, is certainly, the identification of the gaps existing in the rules/codes. Such gaps need, in addition, to be relevant regarding the state-of-the-art in terms of practical application, which in many cases deviates significantly from the state-of-the-art in terms of research. In order to be included in the code it is necessary that sound scientific knowledge is, also, available regarding that specific issue. Additionally, due to the nature of the normative work, such knowledge needs to be appropriately consolidated.

3.1 SHORT TERM ANALYSIS

A basic and critical phase of any design process is the system analysis. In case of TCC systems both short and long term analysis have to be performed.

In terms of short terms analysis, usually, a linear elastic analysis is adopted for which various models were developed, for different conditions such as for example different load cases [21]. More advanced models have been proposed for specific situations such as for example when the second order effects can not be neglected [5]. In spite of this fact, in most of the situations the design is performed using the so-called $\gamma$ method, based the previous work from Möhler [22], which is base the calculation on an effective bending stiffness. In this method, composite action is quantified through the parameter $\gamma$, where $\gamma = 1$ means a fully rigid connection and $\gamma = 0$ means no composite action. By providing $\gamma$ values for typical connectors, the method enables practitioners to design TCC systems.

It is known that other approaches are possible as the material non-linear elastic [14] or non-linear plastic analysis [23]. In some situations the possibility to use such approaches can be rather important due to specific conditions, as it has been clearly demonstrated [14]. The use of such approaches is nowadays difficult or even impossible due to inexistence of an adequate normative framework.

3.2 LONG TERM PERFORMANCE AND ANALYSIS

Timber and concrete have rather different mechanosorptive, and rheological behaviours. At long term such circumstance can raise significant issues regarding both stress distribution and deformations. Additionally, the long term behaviour of the connection is also quite nonlinear, adding extra difficulty to the analysis.

The methodology, usually, followed in the design, is the use of the model available in Eurocode 5 part 1-1 for timber structures. Research has shown that this model can be acceptable in some conditions but can, also, lead to significant deviation from the actual behaviour of the structures, in other situations [1, 15, 24].

In order to address such issues more accurate models have been proposed [24, 25]. The use of such models require however a set of material and environmental variables that need to be provided.

3.3 COMPOSITE ACTION - CONNECTIONS

The composite action in TCC systems relies on the connection between the two materials. Such connection shall have an appropriate load carrying capacity to transmit the shear loads, and simultaneously be stiff enough to allow a limited slip deformations between the two materials.

Contrarily to what occurs in most timber structural systems, the connection stiffness will, directly, influence the stress distribution and the deformations. Consequently it affects both the Ultimate Limit States and Serviceability Limit States verifications. This influence might be significant, and is directly reflected in the effective bending stiffness of the composite system, which increases with the connection stiffness as it is shown in Figure 1.

![Figure 1. Relation between connection stiffness and TCC effective bending stiffness](image)

In spite of this influence scarce information can be found in the standards related to either the analytical or experimental determination of the TCC connections. This fact is certainly closely connected to the large variability that can be found in terms of connections typology for TCC systems.

In literature a large number of researches leading with the connections is available. Its analysis shows that the approaches and methodologies followed vary significantly making it difficult to compare results, and consequently use them in a different context.

3.4 EXECUTION

The execution of TCC systems has relevant specificities, namely due to the characteristics of concrete. The combination of these two materials bring some execution challenges that need to be addressed.

One of the most relevant challenges is the presence of water when the TCC systems are cast-in-place, the large majority of the situations, nowadays. The contact of the concrete water with timber can be an issue for both materials, once it is necessary for an appropriate cure of
concrete and at the same time can lead to significant concerns if absorbed by timber.
A “dry” construction is also possible in TCC systems, if precast concrete is used. Nevertheless, specific execution issues have to be taken into account. One of the most relevant, to this end, is the connection between the two materials, once most of the systems available were developed and optimized for cast-in-place. Additionally, the connection between concrete members also need to be properly addressed.

The relatively high dead weight of concrete in comparison to timber will certainly influence the short and long term deformations. This is particularly relevant in cast-in-place systems during the curing period, when the systems relies only on the timber bending stiffness. In these cases the adoption of appropriate constructive strategies as for example propping might be very effective, and in many cases a requirement for a good execution.

4 CEN MANDATE

4.1 PROJECT TEAM SC5.T2 AND COORDINATION WITH OTHER PROJECT TEAMS AND WORKING GROUPS

The CEN mandate M/515 “Towards a second generation of EN Eurocodes” aims, among other objectives to: i) assure that the Eurocodes evolve in an appropriate manner aiming the maintenance of the users confidence, ii) ensure that the standards remain fully up to date through embracing new methods, new materials, and new regulatory and market requirements,. iii) enable further harmonisation and a major effort to improve the ease of use of the suite of standards for practical Users [7].

The work is organized in four phases, which started in 2015 and are expected to be finished in 2020. Within Subcommittee 5 the answer to the Mandate was organized around 6 Project Teams (PT):

- SC5.T1 – Cross Laminated Timber (CLT) and Reinforcement of timber structures; Eurocode 5, new and revised clauses for Eurocode 5 part 1-1;
- SC5.T2 – Timber Concrete Composites; New Eurocode 5 Part;
- SC5.T3 – New and revised clauses; Eurocode 5 part 1-1;
- SC5.T4, Fire design, new and revised clauses for Eurocode 5 part 1-2;
- SC5.T5 – Connections, new and revised clauses for Eurocode 5, part 1-1;
- SC5.T6 – Bridges, new and revised clauses Eurocode 5, part 2.

SC5.T1 and SC5.T2 were included in the first phase, and the development of the corresponding work is being held now [26]. The remain Project Teams are expected for later Phases, namely SC5.T3 in Phase 2, SC5.T4 and SC5.T5 in Phase 3 and finally SC5.T6 in Phase 4.

In accordance with the answer to the mandate, the Project Team SC5.T2 is expected to yield a new Eurocode part for the design of Timber Composites. Its scope is defined as the simplification of the part 1 where a number of clauses are given for this type of structures. This shall be done in close coordination with other related Eurocodes namely Eurocode 2 and, up to less extend, Eurocode 4. Additionally, a special effort is expected in drafting the new work, in order to be as clear as possible, to use simple routes throughout the document, and to avoid additional and/or empirical rules for particular structure or structural-element types, all to the extent that is reasonably in practice [7].

A general coordination will be required with the other 5 Project Teams from Subcommittee 5 as well as with other from other related subcommittees. Nevertheless, a closer relation is expected with three Project Teams: SC5.T4, SC5.T5 and SC5.T6.

The fire performance of TCC systems is a major motivation for its use, whilst their design has important specificities that will be addressed in the revised part 1-2 of Eurocode 5 (SC5.T4).

One of the most relevant applications of TCC systems are the bridge decks, once it is well known that they can provide significant advantages when compared to traditional timber solutions [27]. The design of these structures will be dealt in the revised part 2 of Eurocode 5 (SC5.T6).

For both, SC5.T4 and SC5.T6 it is already agreed that the base principles will be given in the new part whilst the specific design clauses will be given in part 1-2 and part 2, respectively.

On the other hand, the performance and design of TCC systems is to a large extend dependent from the performance and design of the connection systems. Traditionally, the approach used for the TCC connections has been, to the possible extent, based on the approach defined in part 1-1 for timber-timber connections. It is desirable and useful that a similar tendency is followed in the next generation of Eurocode 5. To this end a close coordination with Project Team SC5.T4 is required.

4.2 COORDINATION WITH OTHER SUBCOMMITTEES

Similarly to most of the other material codes, composite part from Eurocode 5 will be closely related to most of the other non-material Codes (Figure 2).

From the organization point of view, the new part is expected, for obvious reasons, to follow the only code available for composites, Steel and Concrete Composite Structures, Eurocode 4 [28]. Likewise from the approach point of view many similarities are expected between these two documents, once many of the issues share a common nature.

In spite of this, the closest coordination is expected with the material codes Eurocode 2 and Eurocode 5, for concrete and timber design, respectively. The purpose it is not to replicate the contents of these two codes but instead to define proper references for an easy and accurate gathering of the information available in them. Such approach was considered to be critical for matters of simplification and ease of use, from the practitioners. Informally such methodology is nowadays used in the design of these systems. The design is usually based on some basic indications, given or adapted from Eurocode 5, and all the parameters from concrete are obtained in Eurocode 2, whilst the timber parameters will be obtained.
in Eurocode 5 or related standards. During the preliminary work it was concluded that in the present situation the relation to concrete code and particularly the information available to determine some parameters was not clear and subjected to multiple interpretations. Naturally, due to the nature of this type of composite system, much higher references are expected to the timber code Eurocode 5 part 1-1.

At the moment Cost Action FP1402 is close to its half duration, up to now WG4 has been busy with the collection of background information connected to the mechanical performance and mechanical assessment of TCC connections and the Short Term Analysis of TCC systems. In the second half of the Cost action WG4 will address issues related to the long term performance and the input values for the design of TCC systems. Due to the multinational character from Cost and to the wide European and Pan-European interest that FP1402 has motivated, it can give a significant support to the standardization work held within CEN\TC250\SC5, namely by providing results and knowledge from multiple countries, often difficult to obtain through the conventional databases, as well as boosting the discussion at national level.

6 STRUCTURE AND ORGANIZATION OF THE WORK

The preparation of the work related to the composite timber structures was initiated in 2012 through an Evolution Group established within CEN\TC250\SC5. The main tasks of this group were: i) identify the aim of the contribution, ii) discuss the best options to include the design of timber-concrete in the new code generation. From that work resulted a Report [30] where the various possibilities were discussed. Following this work, the preparation of a new part was the preferable option, after discussion in subcommittee 5.

This evolution group was later formalised as a new Working Group from CEN\TC250\SC5, now working in close cooperation with PT SC5.T2.

6.1 STRUCTURE AND CONTENTS

In accordance with the CEN Mandate the deliverables expected from this revision are:

- New CEN Technical Specification
- Background document

The Technical specification will have the proposals that, eventually, will later be adopted through a new Eurocode part. Additionally, draft versions of this document will be also prepared and distributed aiming for a wide discussion.

As described in the tender specification [31] the background documents shall serve as a ‘technical audit trail’ to decisions taken in the process. These will also be available to national mirror committees to assist in the development of the corresponding National Annexes.

Clearly the most relevant delivery from the PT is the Technical Specification, which eventually will later be transformed into a standard. The content of the document is highly based on the previous work and it attempts to combine the needs from the code users with the knowledge available, having always in mind the state of the art in terms of practical application. The document structure follows closely the one from the other Eurocodes, especially Eurocode 4 as discussed before. In line with this approached it is proposed that the document comprises 9 sections and annexes, organized as follows:
As indicated before in these clauses is given the information specific for timber-concrete design, which can not be found in other documents. The exact content of each of these clauses it is not defined yet, nevertheless some indication on the main addressed issues can be already given.

Section 2 will give the framework to consider actions not given in part 1-1, but quite relevant in the design of TCC systems, such as for example long term and environmental actions. The document will include the three service classes, similarly to what is defined in part 1-1, but the use of TCC systems in service class 3 will not be encouraged.

Section 3 will make proper references to the related material codes, namely for the properties of timber based materials, concrete and steel. Some exclusions in terms of connection can also be given (e.g. systems with connections exclusively based on gluing).

Section 4 complement the indications given in part 1-1, namely through indications related to the contact between concrete water and the timber based materials.

Section 5 will give general principles for the analysis of TCC systems, namely the type of models, and stress strain relationship to be used, for both short and long term.

Section 6 will follow closely the corresponding section from part 1-1, additionally clear indications will be given regarding the properties and specific parameters to be considered in each of the verifications.

Section 7 similarly, to the previous one will mirror the principles given in part 1-1. Specific models, or indications will be given to determine the deformations and dynamic properties in TCC systems.

Section 8 will address all the issues related to the connections systems, either those related with the strength or with the stiffness. It is expected that, whenever possible, indications will be given for the computation of the connection properties. When the direct computation it is not possible, indications will be given for the experimental determination.

Section 9 will deal with the detailing and execution of TCC systems particularly in aspects specific from the system, as for example the cast in situ or the propping requirements.

The annexes will complement the information given in the previous sections namely by providing information in following areas: inelastic strains as those due to shrinkage or temperature, environmental actions such as temperature and timber moisture.

6.2 WORK ORGANIZATION AND DISCUSSION

The PT work has been undertaken step by step in close cooperation with the WG2 on composite structures from subcommittee 5. The close cooperation and open discussion is critical to develop a strong solid base for the future document. It aims to clearly present what is being done, the rationale behind it and at the same time bring the wider expertise available in the WG into the work. The national representativeness nature of these committees is expected to allow a larger inclusion of the CEN countries on the work to be developed, which is impossible to achieve solely through the six PT members. In an effort to promote this inclusion, the documents in discussion will be circulated as early as possible to allow significant participation of the national mirror committees in the discussion.

6.3 STATE OF THE WORK AND SHORT-MEDIUM TERM PLANING

The planning of the Project Team work is detailed in a time schedule deliver by the PT. A simplified version of this schedule is presented in Figure 3. The official work started in September 2015 and the main part of the work is expected to be finalized by April 2018. This positions the work, at this moment, close to its half.

![Figure 3. Simplified Schedule for PTSC5.2](image-url)
At the moment the focus is concentrated in the preparation of the second draft that is expected to be delivered by April 2017. This second draft will, already, include an outline of the proposals that will be part of the final document.

7 CHALLENGES OF THE WORK

The preparation of a new code/code part raises always significant challenges. Often large amounts of information, spread in many ways (e.g. different documents, different regions, and different approaches) need to be collected and processed in order to be included in a new consolidated document. Such effort will only be successful if a varied set of members with different interests (e.g. construction, education, regulation) geographic origins (e.g. different countries) and technical and backgrounds (e.g. consultancy technicians, construction technicians) are involved in the work. The open and wide discussion expected during the development period, in different forums (e.g. CEN subcommittees and Work Groups, Cost actions, National mirror committees) is essential to this end, and will be strongly encouraged.

Another significant challenge is related to the simultaneous revision of standards and codes, closely related to this new part (Figure 2). Indeed, as stated before this document will be complementary to other existing parts, namely Eurocode 5 part 1-1 and Eurocode 2 part 1-1, making proper reference to them whenever possible. Due to simultaneous revision a very close and effective coordination, with both the Project teams in charge as well as the corresponding Committees and Work Groups, will be required in order to come to a final document consistent with the complementary documents.

Another challenge, more specific from this work, is related to the national experience and state of the art in terms of use. TCC systems have been used for a relatively long period. In spite of that, the applications, experiences and “legal” frameworks are quite diverse among the CEN countries. A good example are certain systems “largely” used in some locations but completely unknown in other. Indeed, the preliminary discussions, clearly showed that some of these systems are understood as traditional and well consolidated in some countries, while will hardly be accepted in other countries as suitable for practical application. Such type of issue can raise significant difficulties during the development phase, but will certainly raise much higher difficulties later, in the approval stage, when might be difficult to successful address them. To avoid such problems the involvement of the National mirror committees and national expertise is essential from an early stage.

It is clear, from these discussion that the desired final results will only be possible to be achieved through an effective coordination with other groups and wide open work discussion being held from an early stage.

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