Influence of the joint ultimate deformation in the behaviour of the timber-concrete composite beams

Alfredo. M. P. G. Dias
Assistant Professor, CIEC, Department of Civil Engineering, University of Coimbra
FCTUC – Polo II 3030-290 Coimbra– Portugal

Resume

The load carrying capacity and ultimate deformation of the timber-concrete composite beams, might be significantly influenced by the ultimate deformation of the joints. The failure of the joints might be the preliminary cause of failure of the global composite system. Such type of failure is highly dependent from the ultimate deformation of the joints, due namely, to the load redistribution between the fasteners, only possible if enough deformation is reached on them. The aim of the analysis presented here is to evaluate the deformation that is necessary to be reached in the joints to avoid their failure prior to timber or concrete and consequently maximize the load carrying capacity and the ultimate deformation of the composite structures. The study was made based on linear elastic models, considering always linear elastic behaviour for timber, concrete and joints. The study has shown that further analysis have to be done with the use of non linear models in order to fully address this topic. In spite of that it is clear from this study, that the ultimate deformation of most of the joints types is enough to allow redistribution of load between the fasteners. On the other hand, there are certain types of joints, such as for example, notched joints, with a stiff and very brittle behaviour for which the redistribution will hardly occur and consequently the failure of the composite structure might be significantly influenced by joint deformation/failure.

Introduction

The main objective of this study is to evaluate the deformations that have to be reached in timber-concrete joints to avoid their failure prior to timber or concrete. In order to do it, calculations were done to estimate the slip between timber and concrete at the beam end when timber reaches the failure stress.
Two different approaches were used to estimate the slip between timber and concrete: model with partial interaction given in Annex B from Eurocode 5 (2003), model considering two independent elastic elements. The first one was used to estimate the slip in the composite element with semi-rigid joint. The second one was used to estimate the slip in the composite element when the stiffness of the joints is infinitively low (no connection). Several configurations were used, covering most of the situations that can be found in the practice. In order to define the parameters necessary in the calculations the following assumptions were made:
-the composite element was considered as simple supported,
-the maximum strain on timber was considered as 0.35% ($f_{m,k}/E_{0,mean}$ – (CEN, 1999)) or 0.70% ($f_{m,mean}/ E_{0,mean}$ for spruce (FPL, 1999)),
-the cross section of the composite elements was obtained considering a maximum mid span deflection of L/500 assuming a full rigid joint and a distributed load of 4 kN/m^2,
-the relation between concrete and timber width is given by $C_p = E_C / E_t \times b_C / b_t$, with C_p equal to 3, 6, 12, 18, 24 30,

-the cross section properties were defined in order to have a ratio between the maximum and minimum stiffness equal to 4, the maximum that is possible to reach,
- the stiffness of the joints was considered as $K_u = 2/3K_{ser}$,
-the fasteners spacing was considering as 5 times the minimum spacing, which was defined based in Eurocode indications and fastener geometry.
In the analysis five different joint types were selected in order to have stiff and flexible joints, and joints with low and high ultimate deformations (Table 1).

Table 1- Mechanical properties of the joints used

Joint	K_{ser} (kN/mm)	F_{max} (N)	δ_{ult}^{*} (mm)	S_{min} (mm)
NP	49	48	10	Continuous
DTF	15	23	>15	50
D+N	80	51	>15	161
SM	1385	372	4	Continuous
NOT	305	139	<1	200

*-Indicative values obtained from the load slip curves

Test results and discussion

The results obtained considering the joint stiffness infinitively low are given in Figure 1, for a maximum timber strain of 0.35% and 0.70%. In the same Figure are also given horizontal lines corresponding to the ultimate slip measured in shear tests, for each one of the joint types considered in this analysis. The values presented were obtained for a geometry corresponding to Cp= 3, the one leading to the highest slip as it is clear from Figure 2.

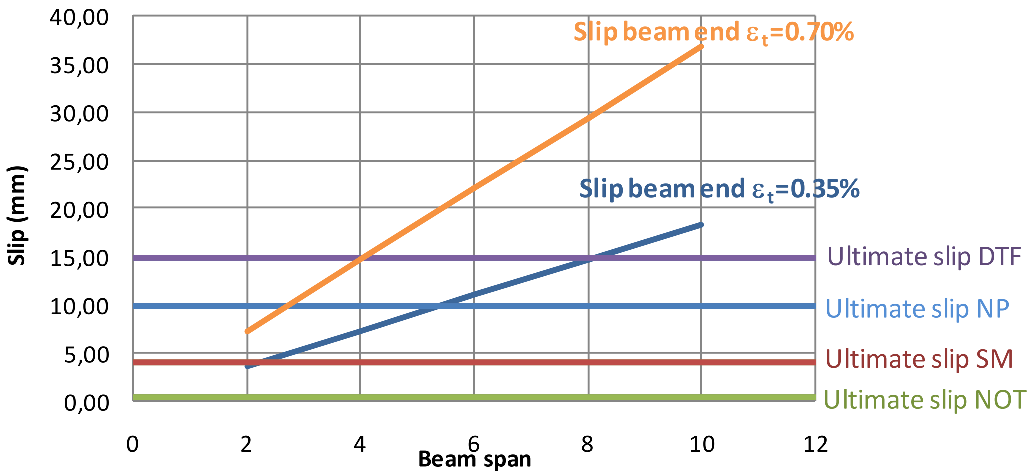

Figure 1- Slip at the beam end for a joint with zero stiffness

These results show that the increase of the slip between timber and concrete is proportional to the increase of the composite element span. It is also clear from the Figure that the ultimate slip in the joints might, at least theoretically, interfere with the failure loads and deformations of the composite elements.

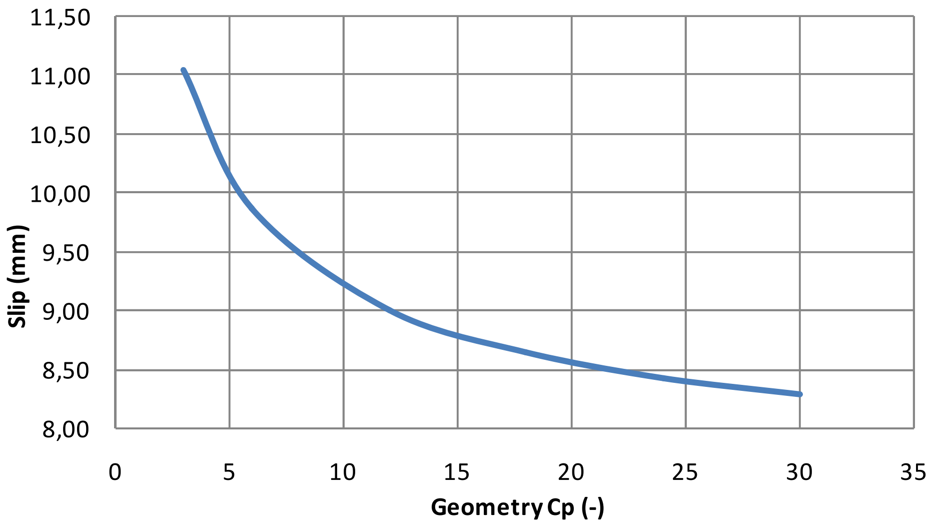

Figure 2-Variation of the slip at the beam end with the geometry of the cross section

As it was shown before Dias (2005), even a very flexible joint will lead to a significant composite action. Therefore, a more precise analysis has to take this aspect into consideration. In order to do it, the linear elastic model presented in EC5 was used. Using the model together with the geometry defined above and the timber-concrete joints properties given in Table 1, values of the slip at the beam end were computed for a maximum failure strain of 0.35% and 0.70%. In Figure 3 are presented the slip values at the beam end, obtained for all the joint types considered, including a joint with infinitely low stiffness, assuming a 10 meter span and failure strain equal to 0.35%.

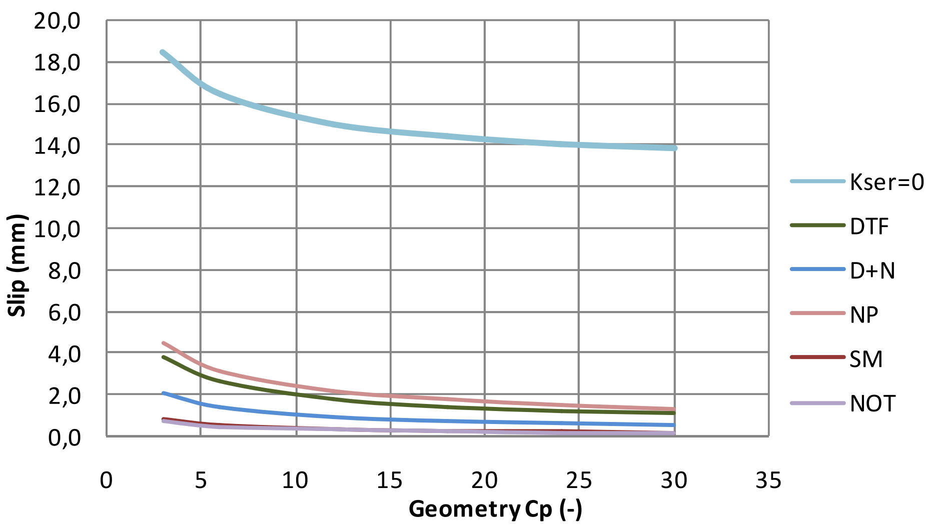

Figure 3- Slip at the beam end for the various joints types for a maximum strain on timber equal to 0.35%

It is clear from Figure 3 the large difference between the slip values obtained with a joint with zero stiffness and with the other joints. In Figure 4 and Figure 5 are given the slip at the beam end for the various joints, together with the ultimate deformations obtained in shear tests for each joint type.

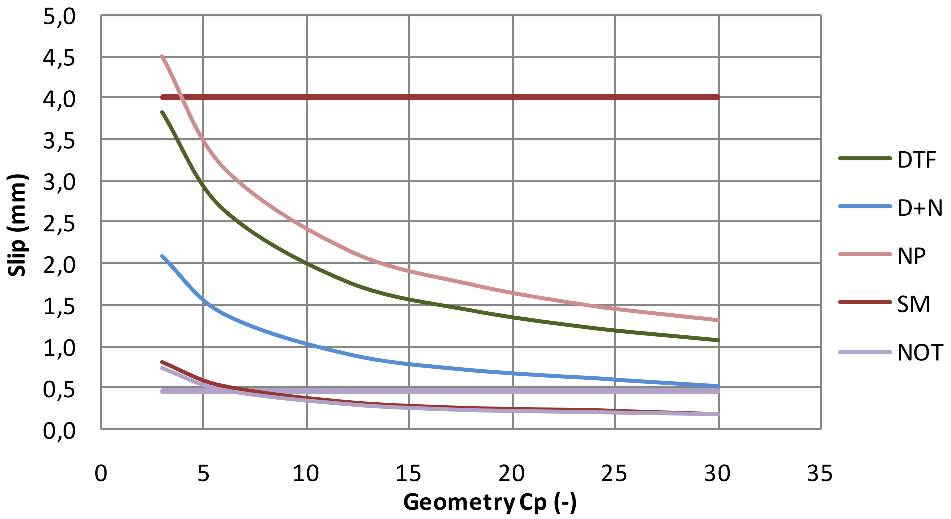

Figure 4-Slip at the beam end for a maximum strain on timber equal to 0.35%

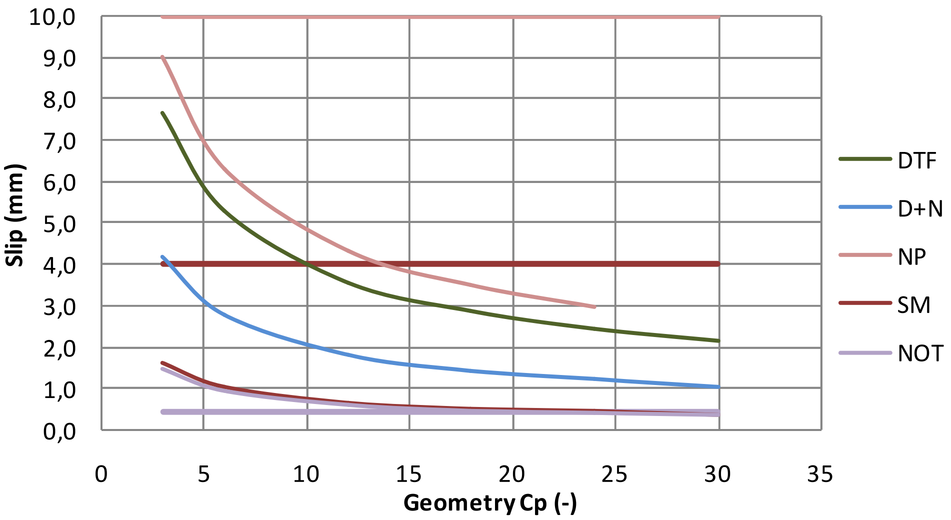

Figure 5- Slip at the beam end for a maximum strain on timber equal to 0.70%

For a maximum timber strain equal to 0.35% (Figure 4) it is clear that only in a restrict number of situations the ultimate deformation on the joints will influence the timber-concrete composite beam behaviour. Furthermore, this it is only likely to occur for the joint types with very high stiffness and at the same time brittle behaviour, such as the notched joints. The values obtained with a maximum timber strain of 0.70% are presented in Figure 5. These results confirm that the ultimate deformation of timber-concrete joints might influence significantly the failure load and deformation, however, in a restrict number of situations. In spite of the higher maximum strain on timber, the slip values obtained might not be completely realistic since some non linear phenomena such as material and joints stiffness degradation could only be taken into account by using a non linear model, not available at this time.

Conclusions

From the analysis presented here it is possible to conclude that:

-The slip at the beam end decreases with the increase of the timber height and width reduction.

-The slip at the beam end increases linearly with the beam span.

-Assuming a joint with zero stiffness and considering the maximum tension strain on timber to be 0.35% the slip at beam ends it is almost always smaller than the ultimate slip of most of the joints. On the other hand if the maximum tension strain is considered as 0.70% the slip at the beam ends will be often higher than the ultimate slip of the joints.
-When the stiffness of timber-concrete of the joints is considered with its actual values, the slip at the beam ends decreases by a factor higher than 4.
- Considering a maximum timber strain of 0.35% only in a very restrict number of situations (width timber members and joint with very stiff and brittle behaviour) the ultimate deformation of the joints will influence the composite beam load carrying capacity and ultimate deformation. On the other hand, if the maximum timber strain is considered as 0.70% situations where the failure is significantly influenced by the joints ultimate deformation are much more likely to occur.
-A non linear behaviour up to the failure it is not possible because of the model characteristics and assumptions made. For high loads (close to the failure loads) the stiffness of the joints could decrease significantly due to the large deformations reached on the fasteners. On that situation the analysis made here might not be completely valid. For that reason further calculations shall be performed using more powerful models that can take into account with the non-linear behaviour of the joints and of the materials.

Notation

NP - Timber-concrete joint with a nailplate

DTF – Timber-concrete joint with a 10mm dowel type fastener

D+N – Timber-concrete joint with a circular dowel with a notch

SM – Timber-concrete joint with steel mesh.

NOT – Timber-concrete joint with a notch.

F_{max} – Timber-concrete joint ultimate load carrying capacity.

K_{ser} – Slip modulus.

S_{min} – minimum spacing.

ε_t – Maximum timber strain

δ_{ult}– Timber-concrete joint ultimate deformation.

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