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Time-dependent behaviour of timber lightweight concrete composite floors

L.F. Jorge [a], J. Schänzlin [b,1], S.M.R. Lopes [c,*], H. Cruz [d], U. Kuhlmann [e,2]

[a] *Polytechnic Institute of Castelo Branco, Portugal*
[b] *Konstruktionsgruppe Bauen AG, Kempten, Germany*
[c] *FCTUC, University of Coimbra, Portugal*
[d] *National Laboratory of Civil Engineering (LNEC), Portugal*
[e] *Institute of Structural Design, University of Stuttgart, Germany*

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ABSTRACT

This article presents a study on the time-dependent behaviour of timber lightweight concrete composite floors. The option of using lightweight aggregates in concrete (LWAC), instead of normal weight aggregates, is the focus of this document.

The load-slip behaviour of SFS-screwed joints in timber-LWAC structures is analysed both for the short term and the long term cases. The study takes advantage of an experimental programme carried out at the University of Coimbra where several timber-LWAC specimens were tested for 600 days.

The load-slip behaviour of the connections is very important for the behaviour of the whole structure. The last aspect that is developed in this article concerns the time-dependent behaviour of LWAC composite floors. The calculated results obtained through the computer programme proHBV, developed at the University of Stuttgart, proved to be very close to those obtained from tests carried out at the University of Coimbra. As explained in this article, the direct application of the design rules for creep in concrete and timber, as presented in Eurocodes 2 and 5, results in great deviations from the actual behaviour of structures composed of two materials, timber and concrete. To overcome this difficulty, the authors also present a simplified procedure that can be taken as an extension of the Eurocode design philosophy. This simplified procedure does not need the use of computer programme proHBV, and is much more accurate than the current Eurocode proposals. The deviation of the simple design procedure from the test (even if a bit higher than that of proHBV) is in the order of usually accepted values for practical design, however, the advantage of this approach for the practice is decisive.

1. Introduction

The load-slip behaviour of timber–concrete connections has been studied in the past years but most studies were focused on short term behaviour of timber–concrete composite floors [1–6].

As far as long term behaviour is concerned, the different rheological behaviour of timber and concrete influences the performance of the composite floor: stresses are redistributed and the deflection increases with time due to the different creep and shrinkage behaviour of these materials. Therefore, the design of such structures is often conditioned by the standard rules related with the maximum deflection in service. As the span increases, deflection is more important in the design outcome.

The time-dependent deflection is caused by the creep of the connection (not only the creep of the connection device, but also the creep in the neighbouring area, both in timber and concrete, due to the local stress concentration) and by the creep and shrinkage of the timber and concrete along the whole beam. For the consideration of the time dependent behaviour of all components a global creep coefficient would be the easiest way. For the final deformation the elastic deformation of the composite floor can be multiplied with this global creep coefficient in order to get the increase of the deformation after 50 years. In [7] a first attempt was made in order to determine the global creep coefficient for the range of parameters given in Table 1.

As seen in Fig. 1, the typical global creep coefficients of a timber–concrete composite (TCC) floor evaluated with proHBV lays somewhere between 1.5 and 4.5 [7]. These global creep coefficients consider the deflection caused by creep as well as that caused by shrinkage. In fact, shrinkage should not be neglected, because it may cause a deflection of about 70% of the elastic

* Corresponding author. Tel.: +351 239797253, +351 239797252; fax: +351 239797123.
E-mail addresses: schaenzlin@kb-ke.de (J. Schänzlin), sergio@dec.uc.pt (S.M.R. Lopes), sekretariat@ke.uni-stuttgart.de (U. Kuhlmann).
1 Tel.: +49 831 52156 0; fax: +49 831 52156 60.
2 Tel.: +49 711 685 66245; fax: +49 711 685 66236.

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Table 1
Range of parameter for the determination of the global creep coefficients f.

Parameter	Minimum value	Maximum value
Span in m	4	10
Variation of shrinkage in concrete	0	-60×10^{-6}
RH_{mean} in %	50	800
h_{timber} in cm	12	20
$h_{concrete}$ in cm	4	12
Concrete grade	C20/25 and LC16/18	
Timber grade	C24	
Live load in kN/m^2	1.5	5
h_c/h_t	1/2	
b_c/b_t	1/1	

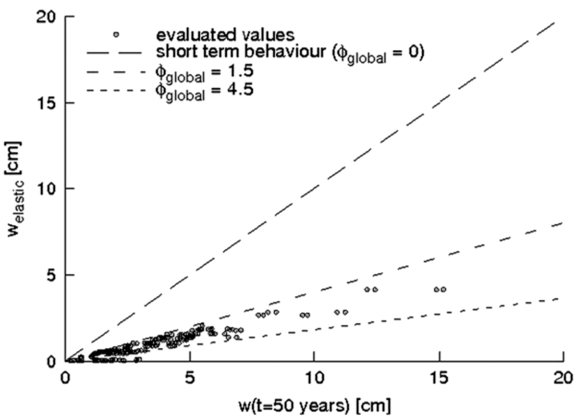

Fig. 1. Range of the effective creep coefficients.

deflection in the whole length. However, the most influencing factor is creep (for both materials and connection), and therefore it should deserve special attention.

Using lightweight aggregated concrete instead of normal weight concrete usually leads to smaller creep deformations, by reducing the creep coefficients and reducing the dead load. However, the stiffness of the concrete is also reduced, and this causes the deflections to increase. Therefore, the advantage of using LWAC is not obvious from this. In order to evaluate if the use of LWAC instead of normal weight concrete is actually advantageous some uncertainties have to be clarified, such us:

- load-slip-behaviour of the connection
- time-dependent behaviour of the global system.

The option of using LWAC in timber concrete composite floors instead of normal weight concrete is evaluated here. The behaviour of the connection is also covered (both for short and long term cases). The time-dependent behaviour of LWAC composite beams is explained and comparative analyses of experimental results with computational programme simulations and with a simplified numerical procedure predictions are also presented here.

2. On the option of LWAC in timber concrete composite floors

The advantages of the composite floors of normal concrete and board stacks in comparison to pure concrete are well known. Some of them are:

- reduced dead load
- increase of the amount of renewable materials
- faster construction due to less *in-situ* concrete casting
- reduction of the required number of props due to the bending stiffness and bending capacity of the board stacks.

In comparison to pure timber floors,

- the load capacity and the stiffness of the floor can be increased and
- the sound and fire insulation can be improved.

So the question is whether the replacement of the normal concrete by LWAC is reasonable? This question cannot be answered directly because two different effects concerning the often critical deflection are obtained by using LWAC instead of normal concrete. On one hand, the deflection is expected to increase if LWAC is used, due to

- the larger shrinkage strains of LWAC
- its lower Young Modulus.

On the other hand, the deflection should be reduced by the use of LWAC because of

- the nominal reduced creep coefficient of LWAC concrete and of
- the reduced dead load.

In order to determine the overall balance of these opposite influences on the deflection, a case study involving composite structures of board stacks and concrete for different spans is performed and the required depth of these spans is determined according the design method proposed by [8]. For this case study a single span girder with grooves as connection devices is chosen [9] (Fig. 2). It has to be mentioned that "only" the smeared stiffness and the smeared ultimate load is considered in the design. Therefore the results should be transferable to other connection devices, as long as the smeared properties are comparable. The live load is assumed to be 1.5 kN/m^2. The concrete as well as the timber depths are determined by iteration, so the following boundaries are fulfilled:

- The complete cross section is compressed.
- The design stresses in the composite floor are lower than the design resistance of the materials.
- The maximum deflection in the long term including creep and shrinkage is lower than L/200 and the increase of the deformation after un-propping due to live load, creep and shrinkage is lower than L/300. The first limit ensures functionality within the whole life time, whereas the second one avoids cracks in the partition walls, which are normally built after unpropping (see DIN 1052:2008 [10]).
- Creep behaviour of the normal and the lightweight concrete, respectively follow the equations given in Eurocode 2.
- The time dependent behaviour of timber can be described by Hanhijärvi's rheological model of timber [11].

As seen in Fig. 3 the required depth of the cross section members using LWAC are about 6% higher than the required depth using normal concrete.

Therefore, only from the point of view of a maximum slenderness of the cross section, LWAC penalises the timber–concrete-composite floors.

Concerning the total dead load of the structure, the use of timber-LWAC floors leads to a reduction of 25% of the dead load. Therefore, the application field of timber-LWAC floors will be mainly in the renovation and upgrading of existing timber floors, where the loading of the load bearing members of the structure limits the load capacity of the whole structure.

This type of system has been chosen in order to reduce the numbers of possible combinations of the input values. However it is expected that the tendency of the comparison between LWAC and NC is comparable.

3. Load-slip behaviour of SFS-screws in timber-LWAC structures

3.1. General

The use of screws as connection devices for timber–concrete composite structures is a common option because of their good