EVALUATION OF LONG-TERM BEHAVIOUR OF COMPOSITE TIMBER-CONCRETE STRUCTURES ACCORDING TO EC

Saulius Kavaliauskas[1], Audronis Kazimieras Kvedaras[2], Kęstutis Gurkšnys[3]

Departmen of Steel and Timber Structures, Vilnius Gediminas Technical University,
Saulėtekio al. 11, LT-10223 Vilnius-40, Lithuania
E-mail: [1]saul@st.vtu.lt; [2]akve@st.vtu.lt; [3]kestutis@st.vtu.lt

Abstract. The objective of this work is the investigation of long-term behaviour of composite timber-concrete beams. Both ultimate and serviceability limit states have to be satisfied according to modern design codes, such as Eurocode 5. Because of the rheological phenomena such as creep, time-dependent (viscoelastic) creep, mechano-sorptive (moisture change) creep and shrinkage/swelling that occur in the component materials, stress and strain distribution changes in time. The rheological phenomena have to be taken into account for long term verifications. This paper presents the review of the evaluation of long term behaviour of composite timber-concrete beams according to European design codes EC5 and EC2.

Keywords: timber-concrete composite, long-term behaviour, creep models, shrinkage, time-dependent modelling.

1. Introduction

The timber-concrete composite beams are a structural solution for both new constructions and reconstruction of existing buildings. The coupling of a concrete layer on the compression side and of timber on the tension side of cross section gives the best properties of these materials in terms of strength and stiffness. The third important part of such construction is a connection system between these two structural elements (timber and concrete). Its slenderness ratio influences the flexibility of cross-section and the whole structure. Since a relative slip between the two linked parts cannot be generally prevented, the connection should be regarded as flexible. Lots of different systems are investigated [1–7], and almost all of them are deformable. In order to analyse a timber-concrete composite beam and to determine internal forces and displacements, it is necessary to take into account the connection deformability. Because of its complication this problem can be solved in closed form only under simplified hypotheses. Current codes like DIN 1052 and Euro Code 5, adopt the Möhler's simplified formulation. The system of differential equilibrium equations of a timber-concrete composite beam is solved considering negligible shear deformations, connection elements smeared along the beam with linear-elastic behaviour, equal vertical displacements of single beams (timber and concrete), elastic behaviour of concrete and timber, and a sinusoidal vertical load along the beam.

The rheoligical phenomenon is very important for timber-concrete composite beams, which have to be taken into account for long-term verifications, also the simplified approaches to design a composite beam are necessary in order to promote the use of this technique.

All component materials of a composite beam (timber, concrete and connection) have important creep phenomena. Creep includes three distinct types of behaviour, which are difficult to separate because they can all operate simultaneously. These are time-dependent (viscoelastic) creep, mechano-sorptive (moisture change) creep, and recovery that is ascribed to differential swelling and shrinkage. The effect of moisture changes on creep in wood was first discovered and reported by Armstrong & Kingston [8], since then, much work has been done on this subject [9–15].

The main design parameter for composite timber-concrete beams is deflection, which is the addition of two types of behaviour, namely elastic deflection and creep one. These phenomena which increase the deflection and modify the

stress distribution in cross-section are considered in this paper and some calculations were made by using the Effective Modulus Method.

2. Description of the object

The calculations are made with 6 m length timber-concrete composite beam which cross-section is shown in Fig 1. The components of cross-section are a glued laminated timber beam (strength class GL24) and a horizontal concrete plate (strength class C20/25). As a connection system between timber beam and a concrete plate timber screws M8-160 were chosen, which initial slip modulus was determined according to EC5 [16]. To obtain the instantaneous slip module of connection K_i the distance between the connection elements (screws) was taken equal to 200 mm along the beam.
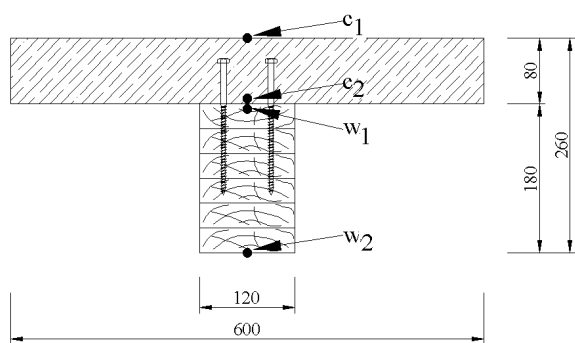

Fig 1. Cross-section of timber-concrete composite beam

The composite structure was assigned to the 1st service class by EC5 [16], which is characterized by moisture content in the materials corresponding to the temperature of 20 °C and the relative humidity of the surrounding air only exceeding 65 % for a few weeks per year. As described in EC5, in service class 1 the average moisture content in most softwood will not exceed 12 %. In this paper the swelling and shrinkage of neither wood nor concrete were considered.

3. Design according to EC5

The elastic solution for simple beams under uniformly distributed load can be obtained using a simplified method, the so called „gamma-method". Calculating timber-concrete composite structural members by EC5 the final mean value of stiffness property should be taken as:

$$E_{mean,fin} = E_{mean} / (1 + \psi_2 \cdot k_{def}), \qquad (1)$$

where:

E_{mean} – is the mean value of the stiffness property of timber determined by standardized tests;

ψ_2 – is a factor for the quasi-permanent value of a variable action;

k_{def} – is a deformation factor taking in to account the effect on the stiffness parameters of the load and the moisture content in the structure.

To evaluate the creep deformation of concrete plate and connection elements, the value of deformation factor k_{def} should be doubled. According to EC5 computation the creep behaviour of timber, concrete and connectors separately is impossible. The slip module of connection is possible to evaluate only if connectors are evenly arranged through the whole length of the beam.

The stresses and deformations in composite cross-section at time $t = 0$ can be obtained by the following expressions:

$$\sigma_i = \gamma_i \cdot E_i \cdot a_i \cdot M / E_{mean} \cdot I_{ef}, \qquad (2)$$

$$\sigma_{m,i} = 0,5 \cdot E_i \cdot h_i \cdot M / E_{mean} \cdot I_{ef}, \qquad (3)$$

$$f = 5 \cdot q_k \cdot l^4 / 384 \cdot E_{mean} \cdot I_{ef}, \qquad (4)$$

where: γ_i – is a coefficient which evaluates the slenderness of the connecting system between timber and concrete, and which can be found by the formula:

$$\gamma_i = 1 / (1 + \pi^2 \cdot E_i \cdot A_i \cdot s / K_i \cdot l^2), \qquad (5)$$

where:

E_i – the stiffness property of component material of composite cross-section;

A_i – is a cross-sectional area of a component material of composite cross-section;

K_i – the initial slip modulus of connectors;

l – is a span of composite beam;

s – is a distance between connectors.

The effective moment of inertia of a composite cross-section should be taken as:

$$I_{ef} = n_1 \cdot I_1 + I_2 + n_1 \cdot \gamma_1 \cdot a_1 \cdot A_1 + a_2^2 \cdot A_2, \qquad (6)$$

where:

$n_1 = E_1 / E_2$ – is a ratio of stiffness properties of concrete and timber.

The stresses and deformations at time $t = \infty$ can be found calculating them from expressions (2), (3) and (4), by changing the stiffness properties E_{mean} into $E_{mean,fin}$. Using such method of calculation of composite timber-concrete structures the stresses and deformations can be obtained only at time $t = 0$ and $t = \infty$. However experimental results show [17–20] that deflections of medium to large span composite beams within the first year often exceed final value estimated with EC5. It necessitates the different creep behaviour in time of components of composite element.
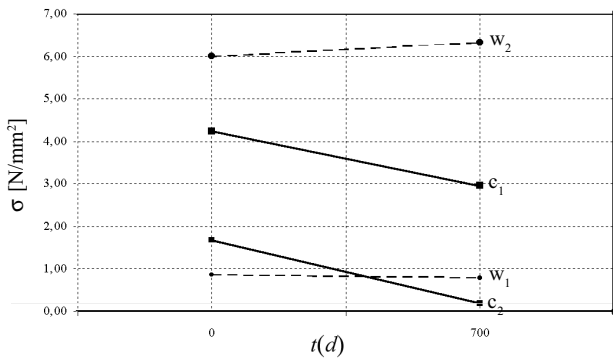
Fig 2. Stress changes during time in the components of a composite timber-concrete element cross-section according to EC5: c_1 – in lower point, and c_2 – in upper point of concrete slab; w_1 – in upper point and w_2 – in lower point of timber beam cross-section
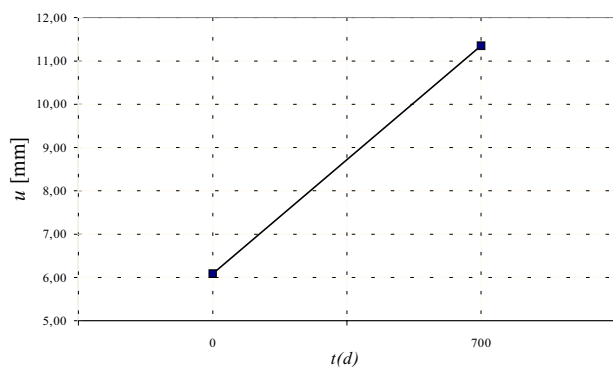
Fig 3. The mid-span deflection of a composite beam according to EC5

The calculation results corresponding to design codes [21] are shown in Fig 2 and Fig 3.

The stresses in a concrete part of composite element cross-section decrease in time significantly (from 1.4 to 5 times) when ones in a wooden part increase, but in a smaller degree (approximately only a 2 times).

The results of calculations show the most intensive stresses change at the first months, and this process continues approximately during two years. Afterwards their changes are marginal till eventually level off.

4. Design according to EC2 and EC5 evaluating the creep behaviour of timber and concrete in time separately

It is very difficult to simulate exactly long-term behaviour of composite timber-concrete elements including all creep, shrinkage and swelling effects of both elements. In Euro Code 2 proposed the method for determination of creep coefficient of concrete is reasoned by aging a creep model.

This model is constituted of two functions, one of them characterizes the influence of concrete age on the notional creep coefficient, and the second one evaluates the duration of loading. The method of EC2 to obtain creep in time of concrete can be used only if the stresses in concrete do not exceed 40 % of its strength (f_c), and relative humidity of environment should be 40–100 %. The modulus of elasticity at the time moment t can be obtained from the following expression:

$$E_c\left(t_0\right) = E_c \cdot \left(28\right) \cdot e^{\frac{s}{2}\left(1-\sqrt{\frac{28}{t}}\right)}, \qquad (7)$$

where: s – a coefficient which depends on the type of cement.

The creep model for timber material is not given in the design code EC5, however, to define the creep deformation of timber in time, the *Le Govic* [18] proposed exponential law can be used; for bending (8) and for compression (9):

$$\varepsilon\left(t-t_0\right) = \frac{\sigma}{E}\left[1+0,65\left(1+0,65\left(1-e^{-(t-t_0)}\right)\right)\right], \quad (8)$$

$$\varepsilon\left(t-t_0\right) = \frac{\sigma}{E}\left[1+0,3\left(1+0,3\left(1-e^{-(t-t_0)}\right)\right)\right]. \qquad (9)$$

According to these two concrete and timber creep models the stresses and deformations at time t can be found. The calculation results of stresses in composite timber-concrete cross-section are shown in Fig 4.

The stresses in a concrete part of cross-section are close to those obtained in Section 3, but the stresses in a timber part are higher than those from Section 3 approximately 1.3–3 times.

By applying the creep model for a timber element according to (7) and (8) expressions, mid-span deflection of composite beam at time $t = 0$ is twice as large as defined according to EC5. It increases mostly during the first 60 days and at this moment reaches almost its final value (Fig 5).
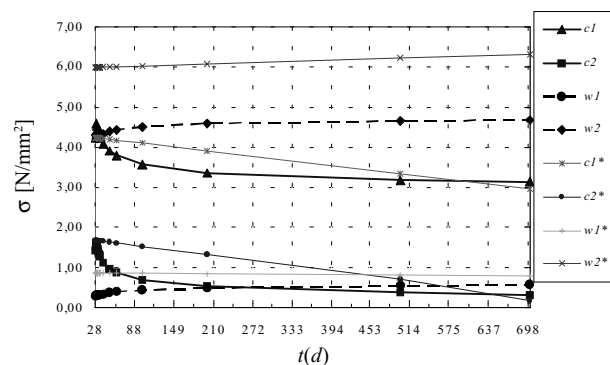
Fig 4. Stresses at different points of cross-section of a composite timber-concrete beam
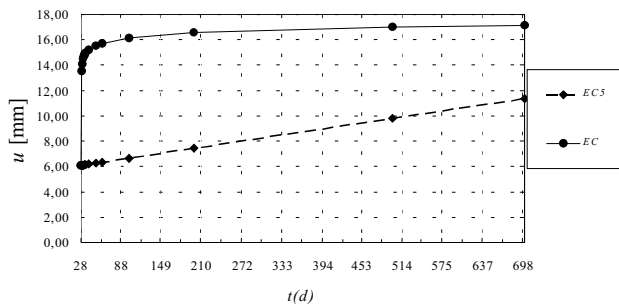
Fig 5. The mid-span deflection of composite beam by calculating creep deformation for timber and concrete separately and by EC5

5. Conclusions

The design code EC5 considers timber, concrete and the connection behaviour as linear-elastic. However, the real behaviour of composite structures does not comply with these hypotheses. Mechano-sorptive effect and shrinkage/swelling of timber and concrete have to be taken into account in the long-term analyses. This simplified method may be safely used when creep phenomena and the serviceability limit state are not decisive in the design of a structure (as in the case of short- and medium-span beams). Also creep behaviour of the connection system of composite beams should be evaluated. The calculations performed have shown that both stresses and mid-span deflections change significantly during the first 180 days, later these changes are very small. When (8) and (9) expressions were used to determine the creep deformations in timber, the initial mid-span deflections of a composite beam are received 2 and the final one – 1.5 times larger than the ones obtained according to EC5 recommendations.

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KOMPOZITINIŲ MEDIENOS-BETONO PERDANGŲ SIJŲ ILGALAIKĖS ELGSENOS VERTINIMAS PAGAL EURONORMAS

S. Kavaliauskas, A. K. Kvedaras, K. Gurkšnys

S a n t r a u k a

Straipsnyje atlikta kompozitinių medienos ir betono perdangų skaičiavimo pagal Euronormas analizė, pateikti jos ilgalaikės elgsenos vertinimo aspektai. Atlikti vienos tokio tipo perdangų skaičiavimai pagal EC5 pateiktas formules – efektyvaus modulio metodą (*Efective Modul Method*), taikant konkrečius medienos ir betono medžiagų valkšnumo modelius.

Raktažodžiai. Medienos-betono kompozitas, ilgalaikė elgsena, valkšnumo modeliai, traukumas, ilgalaikiškumo modeliavimas.

Saulius KAVALIAUSKAS. M.Sc. PhD student from 2003 in the Dept of Steel and Timber Structures of Vilnius Gediminas Technical University. Research interests: timber, timber-concrete composite structures.

Audronis Kazimieras KVEDARAS. Professor, Doctor Habil. Head of Department of Steel and Timber Structures of Vilnius Gediminas Technical University. Research interests: steel, composite steel-concrete and timber structures. Member of IABSE and ASCCS, invited NATO expert (1996, 2000)

Kęstutis GURKŠNYS. M.Sc. PhD student from 2001 in the Department of Steel and Timber Structures of Vilnius Gediminas Technical University. Research interests: timber, timber-concrete composite structures.