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PARAMETRICAL ANALYSIS OF LONG-TERM BEHAVIOUR OF TIMBER – CONCRETE COMPOSITE BENDED ELEMENTS

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ABSTRACT

The article presents results of the parametric study in which influence of several properties of wood-concrete beams changes to their final resistance under long-term loading was investigated. Influence of concrete and wood strength changes, concrete shrinkage and effect of various environmental conditions was analysed. The changed parameters on two types of timber - concrete elements with different structural systems, on beam-type and plate-type element were studied. For the analysis mathematical model derived in analytical terms was used, which takes into account viscous-elastic creep of concrete and wood, mechano-sorptive creep of wood, creep of shear connection, concrete shrinkage and the changes of environment under the long term loading.

KEYWORDS: Timber-concrete composite, long term behaviour, parametrical analysis.

INTRODUCTION

Long-term behaviour of composite wood - concrete beams is affected by numbers of different parameters. For theoretical analysis of timber-concrete composite elements number of calculation methods was developed by different authors, Schänzlin (2003), Glazer (2005), Fragiacomo and Cecotti (2006), Fragiacomo (2006). In practice selection of the useful calculation model depends on the type of connection between the timber and concrete and from the required accuracy of calculation results.

The intention of the article is to present the influence of time- dependent parameters for the overall resistance of the timber - concrete composite members with different structural arrangement under long-term loading. For the analysis, mathematical model derived in analytical terms, which takes into account the different characteristics of these beams and characteristics of the environment, was used. This model has been experimentally verified and the results were published in Kanócz at al. (2013, 2014).

In the analysis two reference timber-concrete elements was used, the beam type and the plate type, which were designed for the load bearing capacity of standard ceiling structure of apartment buildings. The composite connection for the beam-type elements have been designed by a pair of screws which have compared to grooved connection used for the plate-type elements smaller rigidity. This difference was expressed by differences in their response to changes of their parameters. Therefore, in the article both types of reference beams is presented side by side.

MATERIAL AND METHODS

Characteristic of reference elements

The beam-type reference element (Type 1) is a part of a composite wood-concrete floor system, consisting from timber beam which is joined with concrete layer by the pair of screws oriented 45°/-45°. The strength class of the used concrete is C25/30 and strength class of the timber is C24.

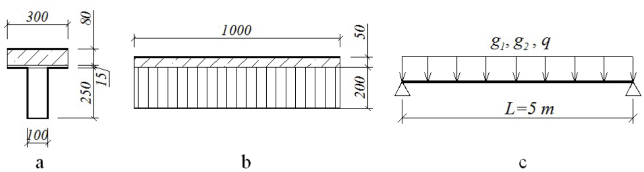

Fig. 1: Cross-section of the reference beams, a) Type 1, b) Type 2, c) calculation model.

The plate-type reference element (Type 2) representing the 1 m with part of composite wood-concrete ceiling structure consisting of timber vertical lamella plate fastened with concrete layer through grooves gouged to timber plate. The concrete strength class is C25/30 and C24 is the strength class of timber. Geometric, material characteristics and the load characteristics are shown in Tab. 1. Parameters of composite connections were considered from experimental tests (Kanócz and Bajzecerová 2013).

Tab. 1: Parameters of reference elements.

REFERENCE ELEMENT:			Type 1	Type 2	
LOAD PARAMETERS					
	Self weight	g_1	2.23	1.85	kN.m^{-2}
	Removal of temporary support	tg_1	14		days
	Permanent load	g_2	3.13		kN.m^{-2}
	Age of concrete	tg_2	28		days
	Quasi permanent part of variable load	$\psi_2 q$	0.69		kN.m^{-2}
	Short time part of variable load	$(1-\psi_2)q$	1.61		kN.m^{-2}
	Age of concrete	t_q	175		days
	Concrete curing duration	t_s	3		days
GEOMETRY	Beam span	L	5000	5000	mm
	Depth of the concrete part	h_c	80	50	mm
	Width of the concrete part	b_c	300	1000	mm
	Depth of the OSB layer	t	15	-	mm

	Depth of the timber part	h_t	250	200	mm
	Width of the timber part	b_t	100	1000	mm
MATERIAL PARAMETERS					
CONCRETE	Density	ρ_c	2300		$kg.m^{-3}$
	Characteristic value of compressive strength	f_{ck}	25		MPa
	Middle value of compressive strength	f_{cm}	33		MPa
	Modulus of elasticity	E_{cm}	31 000		MPa
	Thermal expansion coefficient	$\alpha_{c,T}$	1.00E-05		$°C^{-1}$
	Cement class		N		
WOOD	Middle value of modulus of elasticity	E_t	11 000		MPa
	Humidity expansion coefficient	$\alpha_{t,u}$	3.00E-03		-
	Thermal expansion coefficient	$\alpha_{t,T}$	5.00E-06		$°C^{-1}$
	Density	ρ_k	350		$kg.m^{-3}$
CONNECTION	Slip modulus	K_{ser}	11 500	593 000	$N.mm^{-2}$
	Spacing between connectors	s	150	500	mm
	Load carrying capacity of connectors	F_{su}	14	575	kN

Calculation model of the long term loading

The developed calculation model for the timber-concrete composite beams under long term loading considers the most significant rheological phenomena such as: Viscous-elastic creep of concrete and wood, mechano-sorptive creep of wood, creep of shear connection, concrete shrinkage and strains due to thermal and relative humidity changes of environment. This model is based on the linear elastic solution, is applicable for simple beam with linear material properties and allows determining the final deflection in the middle span and stressing distribution in the middle cross- section of the composite beam.

The visco-elastic creep of concrete according to the Eurocode 2 (2006) is inserted to the calculation of the effective bending stiffness. The visco-elastic and mechano-sorptive creep of wood is also involved in the form of rheological model developed by Toratti (1992).

For the shear connections with mechanical fasteners the following expression of creep coefficient is proposed:

$$\varphi_s = 2\sqrt{\varphi_c . \varphi_t} \tag{1}$$

where: φ_c – the creep coefficient of concrete,
φ_t – the creep coefficient of wood,
φ_s – the creep coefficient of shear connection.

Eq. (1) considers creep of both connected materials and can be used for the calculation of creep coefficient in case of different shearing fasteners.

Connecting the concrete layer to timber element the shrinkage of concrete is prevented by the timber, which leads to increase of deflection of timber-concrete composite beam. In cross-section the concrete shrinkage causes the eccentric force. The influence of this force on the stress distribution in the cross- section depends on the stiffness of fastening which is characterized by γ coefficient of fastening stiffness. The deflection affected by concrete shrinkage in the beam middle span δ_{cs} can be calculated from the Eq 2:

$$\delta_{cs} = \frac{\gamma\, \varepsilon_{cs}\, E_c A_c a_c}{(EI)_{eff}} \cdot \frac{L^2}{8} \tag{2}$$

where: γ – the stiffness factor according to Eurocode 5 (2008),
ε_{cs} – the strain of concrete affected by shrinkage according to the Eurocode 2 (2006),
E_c – Young's modulus of elasticity of concrete in bending,
A_c – the cross-section area of concrete part,
a_c – the distance between the centre of gravity of the concrete part and the centre of gravity of the effective cross section,
L – the span of the beam,
$(EI)_{ef}$ – effective bending stiffness Eurocode 5 (2008).

The different physical properties of timber and concrete concerning the heat and moisture diffusion processes lead to diverse responses of these materials with the environmental thermo-hygrometric variations. Relative humidity increase and temperature decrease of environment cause rising of middle span deflection value, which can be obtained according to:

$$\delta_u = \frac{\alpha_{t,u} \Delta u\, E_t A_t a_t}{(EI)_{eff}} \cdot \frac{L^2}{8}, \qquad \delta_T = \frac{\gamma(\alpha_{c,T} - \alpha_{t,T})\Delta T E_c A_c a_c}{(EI)_{eff}} \frac{L^2}{8} \tag{3), (4}$$

where: δ_u – the deflection in the beam middle span affected by moisture content changes Δu,
$\alpha_{t,u}$ – the moisture expansion coefficient of timber,
δ_T – the deflection in the beam middle span affected by temperature changes ΔT,
$\alpha_{t,T}$ – is the thermal expansion coefficient of timber,
$\alpha_{c,T}$ – the thermal expansion coefficient of concrete,
E_t – Young's modulus of elasticity of timber,
A_t – the cross-section area of timber part,
a_t – the distance between the centre of gravity of the timber part and the center of gravity of the effective cross section.

The formulas detail calculation model was presented in Kanócz at al. (2013).

RESULTS AND DISCUSION

Resistance of reference elements

The action of self-weight load starts after the removal of boarding supports at the time of 14 days after casting. The permanent loading is applied after 28 days and the live load starting act at the time 175 days after casting. Curing of concrete is predicted for 3 days. The size of the loading on elements was determined in accordance with the standard Eurocode 1 (2009) for residential buildings. Ψ2 coefficient was assumed to be 0.3. Environmental conditions for interiors were assumed. The waveform for temperature T and relative humidity RH by the following relationship was determined:

$$T = 23° + 5°.\sin\left(2\pi \frac{t+270}{365}\right), \; RH = 45\,\% + 15\,\%.\sin\left(2\pi \frac{t+210}{365}\right) \tag{5}$$

where: t - time in days.

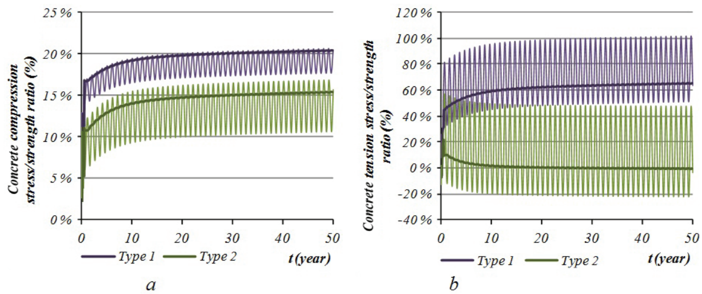

Fig. 2: Stress / strength ration of concrete in a) compression, b) tension.

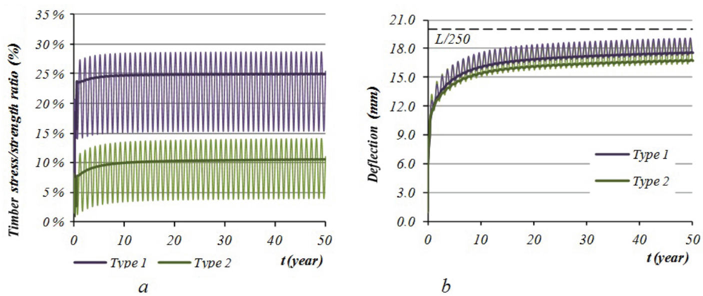

Fig. 3: a) Stress / strength ration of timber, b) the resulting deflection of beams.

On the Fig. 2 and Fig. 3 stress-strength ratio in the concrete and timber part of reference element in time is presented. In the diagrams the thick lines shows the stress-strength ratio without considering the impact of changes of environmental conditions. The thin lines indicate the stress-strength ratio with use of regular annual changes in temperature and relative humidity of the environment according to the formulas (5).

From the diagram is possible to see, that the determining stress for strength condition is the tension stress in concrete part of cross-sections of reference elements (Fig. 2 and Fig. 3a). If taking into account the regular changes of environmental conditions the element Type 1 reaches in concrete ultimate tensile stress and compression stress reach max. 21 % (Fig. 2). In the wood part of element Type 1 the tension stress reaches 29 % (Fig. 3). In case of serviceability limit state, when the ultimate value for deflection is L/250, the stress-strength ratio for the element Type 1 is 96 % and for Type 2 is 94 %.

Effect of strength classis

The following graphs show the effect of the strength class to deflection of the reference elements Type 1 and Type 2 under constant climatic conditions (temperature 20°C, relative humidity 65 %). In terms of comparison deflection is essentially the impact of changes of modulus of elasticity of concrete in the range of 29 GPa (concrete grade C16/20) to 35 GPa (concrete grade C40/50).

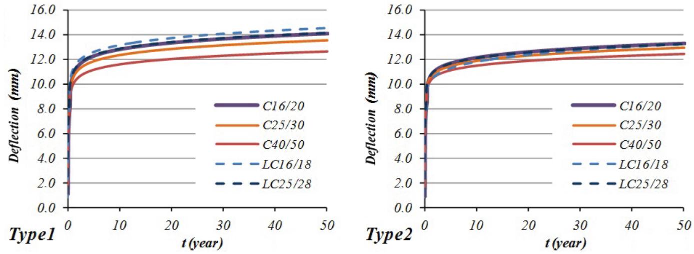

Fig. 4: Effect of concrete strength class to referent elements deflection.

As is evident from Fig. 4, the effect of concrete strength class is more pronounced in the case of element Type 1, but basically for both type these effect is negligible. Reduction of deflection of elements by use concrete with strength class C40/50 against the elements with concrete grade C16/20 presented 10 % for Type 1 and 6 % in case of Type 2. At lower classes of concrete the values are negligible. In terms of stress the reduction is max. 6 %. Therefore it can be assumed that the strength class of concrete does not affect significantly the design of composite timber - concrete beams and for their production concrete with lower strength class can be used.

Effect of strength class of wood is presented on Fig. 5, comparing the reference element deflection under constant climatic conditions (temperature 20°C, relative humidity 65 %) using different strength classes of wood. Change in the modulus of elasticity of wood ranges from 8 (Class C16) to 12 GPa (Class C30). The comparison showed that the change of timber strength class has similar influence for both types of elements. Difference between deflections of the reference elements using a strength class C16 and C30 is approximately 2.5 mm, which is reduction of deflection by 16 %. In terms of stress the reduction is 8 %.

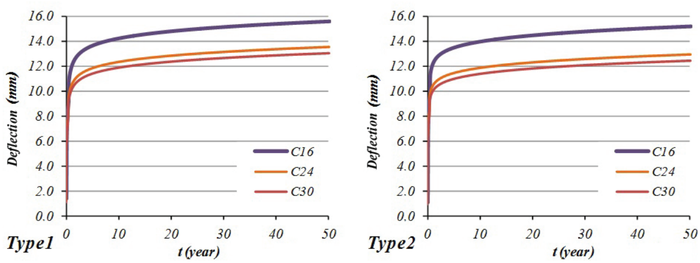

Fig. 5: Effect of timber strength class to referent elements deflection.

Strength class of timber has compared to concrete strength class more significant effect to the deflection of composite wood - concrete elements, which became evident in both types of investigated elements. However, for the beam-type of composite structures is preferable to use the higher quality of timber and for the plate-type structures is possible to use timber with lower strength class, because the planks formed part is less sensitive to errors in timber.

Effect of shrinkage of concrete

The composite timber - concrete structure is prevented to free shrinkage by means of shear connection which results increased value of deflection. Most significant effect to concrete shrinkage has the relative humidity of ambient environment. The shrinkage influence on the deflection of the reference elements at different levels of relative humidity and at the constant temperature of 20°C is shown in Fig. 6. A comparison of the relative deflection without and with considering shrinkage shows, that the deflection due to shrinkage of concrete cannot be neglected.

In the case of relative humidity of environment RH=40 % contribution due to shrinkage of concrete to the deflection of element Type 1 is 31 %. In case of Type 2 the effect of shrinkage is more significant, does 41 % from the final deflection. This can be caused by stiffer shear connection between timber and concrete.

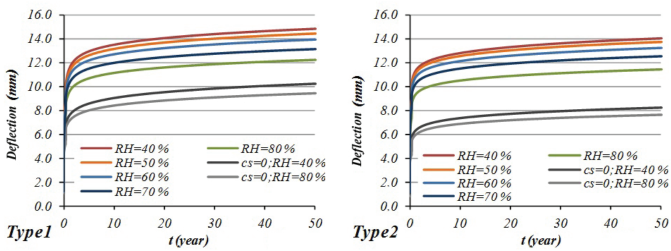

Fig. 6: Deflection of beams due to shrinkage at different humidity environment.

Lower relative humidity results the larger strain from shrinkage and there by increasing the deflection of composite timber concrete-concrete elements. In the interval of relative humidity from 40 to 80 %, the absolute deflection of the reference elements due to shrinkage decrease with 21 %. Therefore in the design of a composite timber-concrete structure is necessary to take into account the estimated relative humidity during its lifetime.

Analysis of the impact of changes environmental conditions

Because of different physical properties of wood and concrete with respect to temperature and humidity diffusion processes, due to changes in the environment different strain in wood and concrete parts occurs. This in formation of internal stress and the total deflection resulting.

Effect of changes in relative humidity and ambient temperature of the reference elements is shown in Fig. 7. The graphs represent a comparison of the reference elements deflection at constant and changing environmental conditions. Still environment have a constant humidity of 45 % and ambient temperature of 23°C. The changing environment is given by (5), the ambient temperature varies around an average air temperature 23°C with an amplitude of 5°C, humidity varies around a value of 45 % with an amplitude of 15 %.

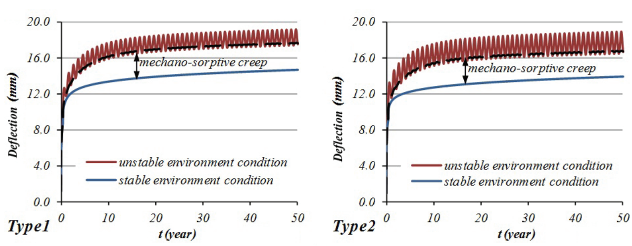

Fig. 7: Deflection of referent elements with unstable and stable environment condition.

Comparison of deflections of the reference elements indicates that the changes of relative humidity and ambient temperature have a significant impact for both types of elements. Deflection of beams in unstable environmental conditions by comparison to stable conditions increased to 31 % for element Type 1 and 36 % for element Type 2. Due to changes of relative humidity of wood under loading mechano-sorptive creep occurs. On Fig. 7 is highlighted effect of mechano-sorptive creep to deflection of the reference elements. For both types of beams, this effect is comparable. Deflection from long term loading, indicated by the dashed black line, due to of mechano-sorptive creep increased by 20 %.

Periodic changes in relative humidity and ambient temperature oscillation cause deflection of composite timber - concrete composite beams during the year. Loads due to humidity and temperature changes are possible to consider as a short-term load. Fig. 8 shows regular oscillations of the reference elements deflection effected by temperature and humidity changes of environment during the year. In the case of element Type 1 deflection amplitude reaches the humidity changes 1.4 mm, which represents 37 % of the initial elastic deformation which value is 3.8 mm. In the case of Type 2 the moisture amplitude of the annual amplitude is 1.88 mm, which is 57 % of the initial elastic deformation with value 3.3 mm. Oscillations of the deflection due to environmental temperature changes have low values. In case of element Type 1 it is 0.55 mm, which represents 14 % of the initial elastic deflection. In case of Type 2 value of deflection amplitude is 0.74 mm, which is 22 % of the initial elastic deflection. Only a certain part of the amplitude of the annual hydrothermal deflection affects the increase of the overall deflection of elements. For reference elements Type 1 by 1.1 mm and for Type 2 by 1.5 mm is increased the resulting maximum value of deflection.

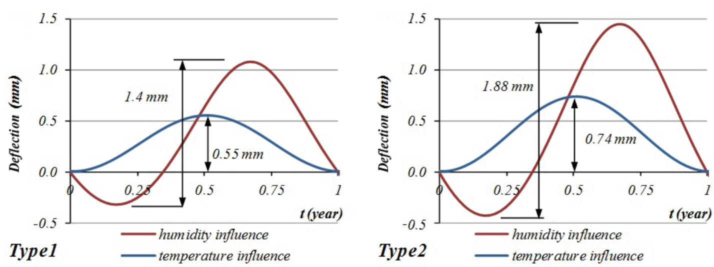

Fig. 8: Influence of annual hygrothermal environment on the reference beam deflection.

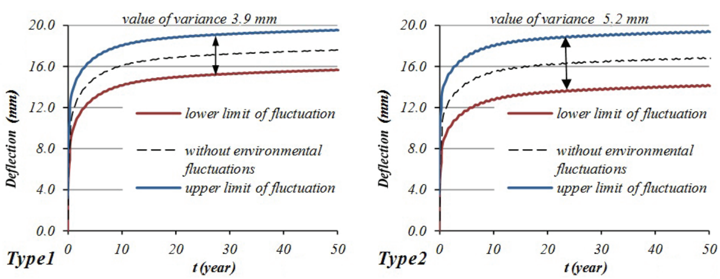

Fig. 9: Dispersion of possible values of the reference beam deflection due to hygrothermal changes of environment.

As is clear from the analysis of the reference elements, it is advantageous to start with loading of timber -concrete elements in the period with a maximum relative humidity when in the next period is assumed the decrease of deflection due to of desorption. Wooden element reaches equilibrium moisture with the environment, depending on size, with some delay. To calculate the moisture content of wood during the time it takes to solve the problem of diffusion, which for practical use in computational model is quite difficult. Thus, if the moisture content of wood in the cross section at time is not known, the effect of humidity changes of the wood to changes of deflection and stresses can be determined by possible variations in the lifetime of the structure. Fig. 9 shows the dispersion of maximum and minimum values of deflection due to hygrothermal changes of environment. Deviation is determined by the sum of the annual amplitude of deflection from moisture and deflection from temperature (Fig. 8).

CONCLUSIONS

From the above presented results of parametric analysis follows, that some of the investigated parameters have significant and some of them have less significant influence to the timber-concrete composite elements resistance under long term loading. Significant influence has the concrete shrinkage, because due to this phenomenon the final deflection may increase 40 % larger. Also significant is the influence of mechano-sorptive creep of wood which is depending from environmental humidity and may affect increase of deflection with 20 %. Analysis shows that less significant influence has the strength classis of applied concrete and wood. From the economical point of view the relatively low strength class of concrete is possible to use for the design of timber-concrete structural elements. Also is preferred to monitor humidity and temperature of environment in location where the structure will construct. It is advantageous to begin with load acting on timber-concrete elements in the period with a maximum relative humidity, because in next period the deflection decreases due to desorption.

In the case of timber-concrete composite beams with high stiffness of shear connection influence of concrete shrinkage and temperature and humidity changes of environment appears to be more significant. Currently bending tests of timber-concrete composite beams with adhesive shear connection under long-term loading are performed (Kanócz et al. 2014). The results of experimental and theoretical analysis will be published.

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