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ANALYSIS OF COMPOSITE ACTION OF VARIOUS MASS TIMBER STRUCTURAL PANELS WITH CONCRETE LAYER

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ABSTRACT

In the presented paper composite actions of various mass timber panels with concrete layer are compared. The composite action of timber and concrete by grooves in wood and by adhesive was realized. In the frame of experimental investigation bending test of real scale composite panels with cross-laminated and nailed/glued vertical planks mass timber was performed. In the analysis, vertical mid-span deflection of tested panels was compared and also some technological aspects of their production were taken into account

KEYWORDS: Timber-concrete composite, timber panels, grooves, adhesive, vertically laminated timber, cross-laminated timber, short-term bending test.

INTRODUCTION

Nowadays massive wooden panels are increasingly used in the timber industry and especially in the case of family houses as well as of multi-story wooden buildings or tall buildings. These types of massive structural panels are mostly produced from cross-laminated timber (CLT) and also from nailed/glued vertical planks (NLT/GLT). In structural bearing systems, they are mainly used for bearing walls structures and ceiling slabs. The use of timber has some limitation, especially in the field of fire regulation. Combination of two or more materials in the hybrid structures can overcome these limitations and take advantage of the positive properties of the bonded materials (Kaushik et al. 2018). In the case of ceiling slabs structures, the bearing properties of the massive panels can be favorably adjusted by coupling them to a concrete layer placed on their top, thereby creating a composite timber-concrete ceiling structure. The composite action of wood and concrete beside better static parameters also brings better structural behaviors to the ceiling structure, such as acoustic performance or fire protection (Riola-Parada et al. 2018).

The highest stiffness of composite connection between the wood and concrete can be achieved by grooves in wooden part (Kanócz et al. 2014, Dias et al. 2018, Yuchen and Crocetti 2019), or by adhesive (Brunner et al. 2007, Negrão et al. 2010, Eisenhut et al. 2016, Schmid et al. 2016). Epoxy adhesives allow bonding not only hardened concrete slab with the timber elements but also to bond fresh concrete with an epoxy bonding agent. The advantage of gluing the wet concrete and timber is in the savings concrete reinforcement comparing to glued composite beam created with prefab concrete slab.

The concrete layer of a composite member requires a reinforcement to avoid cracks due to shrinkage. The fiber reinforcement of the concrete layer seems to be very effective (Heiduschke and Kasal 2003, Kanócz and Kuliková 2006). The lower construction weight and positive thermal insulation and acoustic properties of timber-concrete composite members can be achieved using the lightweight concrete (Kanócz and Bajzecerová 2015, Schmid et al. 2016). The lightweight concrete has a minor displacement from creep, but increased displacement from shrinkage, which has a significant impact on the long-term behavior of timber-concrete composite members (Jorge et al. (2010).

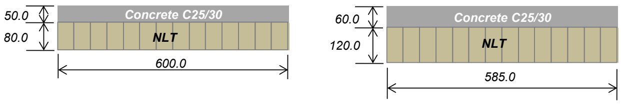
The aim of the article is to compare the effect of composite action of timber-concrete panels with various massive wood (NLT, GLT, CLT), with the rigid type of composite connections (grooves and adhesive) and with the different type of concrete (fiber-reinforced concrete, lightweight concrete). The compared timber-concrete panels were subjected to short-term bending test within two research projects.

MATERIAL AND METHODS

Characteristic of the specimens and material

Three types of timber-concrete composite panels with different mass timber part were investigated in experimental short-term bending tests. The first type of specimen from the nailed vertically laminated (NLT), the second type from glued vertically laminated (GLT) and the third type from the cross-laminated (CLT) mass timber part were created. The composite connection between the timber and concrete part in the first type of specimens by the grooves in timber was realized and in second and third type the adhesive was used.

The longitudinal dimensions of the specimens were 4.5 m and 6.0 m and the width of almost all beams was 600.0 mm (Figs. 1-3).



a *b*

Fig. 1: Cross-section of DBP2 panels with the length of a) 4.5 m and b) 6.0 m.

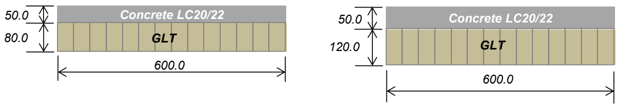


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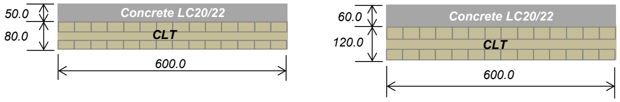
Fig. 2: Cross-section of TC1 panels with the length of a) 4.5 m and b) 6.0 m.



a *b*

Fig. 3: Cross-section of TC2 panels with the length of a) 4.5 m and b) 6.0 m.

The first type of specimens was signed as "DBP2". Three beam specimens of each length were prepared. Cross section of the 4.5 m long specimens DBP2-1 consisted from 50.0 mm thick concrete layer and 80.0 mm thick massive timber (NLT). In the case of 6.0 m long specimens DBP2-2, the cross-section consisted from 60.0 mm thick concrete layer and 120.0 mm thick massive timber panel (NLT). Timber panels were made from the timber planks with the cross-section dimensions of 30/80 or 45/120. The planks were nailed together using convex nails with a diameter of 5 mm according to the scheme in Fig. 4. To grooves with the depth of 20.0 mm or 25.0 mm were prepared before the nailing.

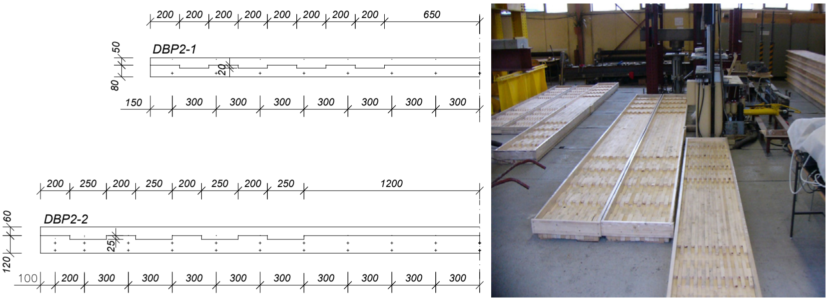


Fig. 4: Vertically nailed plank beams with grooves.

The second type of specimens signed as "TC1" consisted from glued vertically laminated timber (GLT) part and light-weight concrete layer bonded by adhesive. The depth of the timber part was 80.0 and 120.0 mm for beam TC1_4,5 and TC1_6,0. The depth of the concrete layer was 50.0 mm for both lengths of TC1 beams. Two specimens of both lengths were subjected to the short-term bending test.

The last type of composite beam was signed as "TC2". For the shorter beams TC2_4,5 with the length of 4.5 m, cross-laminated timber (CLT) slab with depth 80.0 mm was used. The thickness of the light-weight concrete layer was 50.0 mm. For the longer composite beams TC2_6.0 with the length of 6.0 m, 120.0 mm thick cross-laminated timber with 60.0 mm thick light-weight concrete was applied. The width of all tested beams was 600.0 mm. Three beam specimens were prepared.

The detailed information about the preparing the beams TC1 and TC2 can be found in (Kanócz and Bajzecerová 2015). In the Tabs. 1 and 2, geometrical and material parameters of all specimens are summarized.

Tab. 1: Geometrical parameters of beams.

		DBP2-1	DBP2-2	TC1_4,5	TC1_6,0	TC2_4,5	TC2_6,0
Length (mm)		4500	6000	4500	6000	4500	6000
Span *L* (mm)		4350	5850	4400	5800	4400	5800
Distance of load from support c (mm)		1450	1950	1500	2000	1500	2000
Concrete part	Strength class	fiber reinforced C25/30	fiber reinforced C25/30	light weight LC20/22	light weight LC20/22	light weight LC20/22	light weight LC20/22
	Depth (mm)	50	60	50	50	50	60
	Width (mm)	600	585	600	600	600	600
Type of connection	grooves	grooves	adhesive	adhesive	adhesive	adhesive	
Timber part	Type of timber panel	nailed laminated timber	nailed laminated timber	glued laminated timber	glued laminated timber	cross-laminated timber	cross-laminated timber
	Depth (mm)	80	120	80	120	80	120
	Width (mm)	600	585	600	600	600	600
Weight (kg/m)		95.9	119.8	74.2	84.4	78.3	101.1

Tab. 2: Material parameters.

		DBP2-1 DBP2-2	TC1_4,5 TC1_6,0	TC2_4,5 TC2_6,0
Concrete	Cylinder compressive strength (MPa)	-	25.6	19.3
	Cube compressive strength (MPa)	32	29.1	24.1
	Modulus of elasticity (GPa)	30	17.7	20.8
	Density (kg·m^{-3})	2342	1792	1827
Timber	Strength class	C24	GL24	C24
	Bending strength (MPa)	25.3	54.79	26.4
	Modulus of elasticity (GPa)	8.44	13.93	11.6
	Tensile strength (MPa)	15.18	32.87	16.5
	Density (kg·m^{-3})	435	425	490

Beam bending test under short-term loading

Four points bending tests with short-term static load was carried out. The set-up of the specimens and the geometrical data can be found in Fig. 5 and Tab. 1. During the test, mid-span deflection and the deflection under the point load were gauged. In case of beams type DBK and TC2, horizontal slip between the concrete and timber part was measured (Fig. 6).

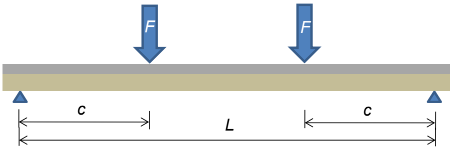


Fig. 5: Set-up of the short term bending test.

Fig. 6: DBP2 - bending test set-up.

Calculation models

Theoretical analysis of tested panels by analytical calculation models was carried out. For the specimens with grooved composite connections (DBP2), the rigid (Kanócz at. al. 2014) and semi-rigid (Kanócz at. al. 2013) calculation models were applied respectively. For the semi-rigid model, the slip modulus of grooved connection received from shear tests with grooves dimensions 30/150 mm by value 23 724 $N \cdot mm^{-1}$ was considered (Bajzecerová and Kanócz 2016).

In the case of panels TC1, the same rigid calculation model as for DBP2 was applied. For panels TC2 the calculation model taking to account the behaviors of transverse layers of CLT mass timber was used (Bajzecerová 2017, Kanócz and Bajzecerová 2015).

RESULTS AND DISCUSSION

In Figs. 7-9, measured and calculated mid-span deflection of each type of panels are presented. It can be seen, that the bending stiffness of the same type and length specimens is similar. The mode of failure of all mass panels was brittle. After the failure of some timber lamellas, the concrete part failed in the middle of the span. No failure of connection system occurred.

The calculated values (in Figs. 7-9 dotted line or dashed line) were calculated according to the above-mentioned models using appropriate geometrical and material characteristics. In the case of the panels DBP2 with the grooved connection, both rigid and semi-rigid models were used. It can be seen, that the semi-rigid model better reflect the behavior of specimens under the short-term load. On the other hand, the stiffness of grooved connection is very high, almost rigid. In case of the panel DBP2-21, an error on the measuring device occurred.

For the adhesively bonded panels TC1, the fully rigid connection was considered. The behavior of both specimens and the theoretical behavior are similar. The specific behavior at the beginning of the loading may be caused by the positioning of the supports during the unloading process.

In case of TC2 panels for CLT mass timber semi-rigid action of transverse layers was considered. The measured data shows the largest variance comparing to the other types of panels, but the calculation model properly reflects the real response of panels.

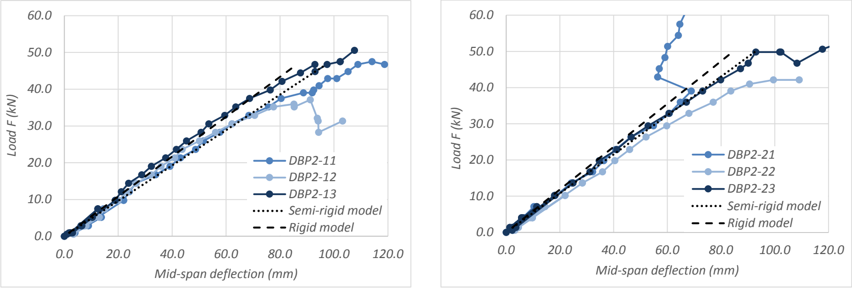


Fig. 7: Load – mid-span deflection relationship of DBP2 panels.

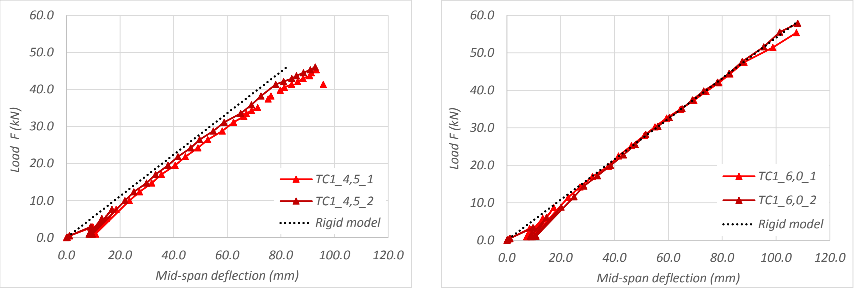


Fig. 8: Load – mid-span deflection relationship of TC1 panels.

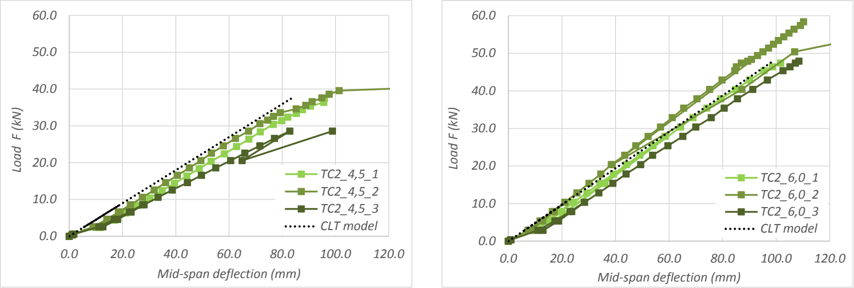


Fig. 9: Load – mid-span deflection relationship of TC2 panels.

Despite the small differences in the geometrical and material parameters of the investigated panel types, comparison of their effects from the short-term load is possible. In the Fig. 10, measured mid-span deflection of all panels with the length of 4.5 m and the length of 6.0 m are compared. It shows that panels DBP2 have similar bending stiffness as the panels TC1 – in the DBP2 the strength of concrete, in the TC1 the strength of the timber is higher. There is also seen, that bending stiffness of panels TC2 are lower comparing to the other two types. It is caused by the relatively small stiffness of transverse layers in CLT mass timber.

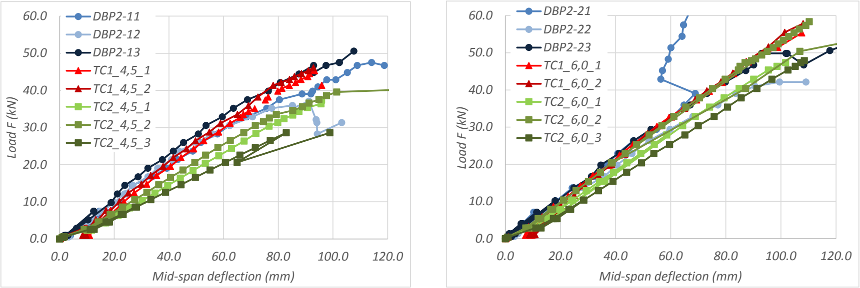


Fig. 10: Load – mid-span deflection relationship of investigated panels.

In order to perform the more accurate comparison of tested panels, the measured values of maximum load and corresponded deflection and the values of effective bending stiffness obtained from the measured values were summarized in Tabs. 3 and 4. These values were related to the self-weight per meter of respective panel.

Tab. 3: Summary of results for 4.5 m long panels.

	DBP2-11	DBP2-12	DBP2-13	TC1_4,5_1	TC1_4,5_2	TC2_4,5_1	TC2_4,5_2	TC2_4,5_3
Max load F (kN)	47.5	37.1	50.6	46.1	46.1	37.4	40.6	28.6
Mid-span deflection from *max F* (mm)	114.1	91.2	107.6	95.9	92.8	95.8	138.6	98.9
Measured stiffness $(EI)_{eff}$ (10^{12}MPa·mm^4)	1.41	1.46	1.63	1.52	1.58	1.20	1.30	1.05
$(EI)_{eff}$/ weight (10^{10} MPa·mm^4·m/kg)	1.47	1.52	1.70	2.04	2.13	1.53	1.66	1.34
Max *F* / weight (kN·m/kg)	0.50	0.39	0.53	0.62	0.62	0.48	0.52	0.36

Tab. 4: Summary of results for 6.0 m long panels.

	DBP2-21	DBP2-22	DBP2-23	TC1_6,0_1	TC1_6,0_2	TC2_6,0_1	TC2_6,0_2	TC2_6,0_3
Max load *F* (kN)	-	42.1	52.5	55.4	57.9	47.4	58.4	49.4
Mid-span deflection from *max F* (mm)	114.8	109.1	124.85	107.6	108.1	101.7	110.2	118.2
Measured stiffness $(EI)_{eff}$ (10^{12}MPa·mm^4)	3.92	3.43	3.86	3.81	3.80	3.37	3.75	3.13
$(EI)_{eff}$/ weight (10^{10} MPa·mm^4·m/kg)	3.27	2.87	3.22	4.52	4.50	3.33	3.71	3.10
Max *F* / weight (kN·m/kg)	-	0.35	0.44	0.66	0.69	0.47	0.58	0.49

From Tab. 3 is seen, that average values of maximum load, corresponding displacement and measured bending stiffness of panels DBP2-1 and TC1_4,5 are very similar and for panels TC2_4,5 the values are 20% lower. Average values of maximum load, corresponding deflection and measured bending stiffness from Tab. 4 for all three types of panels are comparable. It also can be seen in Fig. 10.

According to the ratio of bending stiffness/weight, the TC1 panels are most effective and panels TC1 with the length of 6.0 m are more effective as panels TC1 with the length of 4.5 m.

The effectiveness of panels TC2 from this point of view is comparable with the effectiveness of panels DBP2.

From the above comparison results, that the efficiency of the timber-concrete panels is increase using the light-weight concrete instead of standard concrete. The analyzed type of panels are characterized by a brittle failure without ductility, but the panels have a high resistance and therefore a high reserve of reliability.

CONCLUSIONS

The presented comparison study based on the experimental tests of three different type of timber-concrete panels with mass timber layer shows the following conclusions:

- For timber-concrete panels with grooved composite connection the semi-rigid calculation model is more accurate as the rigid model, but for practical application also by rigid model reliable results can be obtained.
- For timber-concrete panels with the adhesive composite connection, the rigid calculation model is suitable except for panels with CLT, where semi-rigidity of transverse layers is necessary to be taken in to account.
- Timber-concrete panels with grooved connection have comparable bending stiffness by panels with the adhesive connection but from the economical point of view are more effective, because of the high price of adhesive.
- From the wide variety of composite connection, the adhesive seems to be the more suitable for the timber-concrete panels with CLT.
- In terms of span dimension, the panels with larger span are most effective.

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