Bulletin of the *Transilvania* University of Braşov • Vol. 10 (59) Special Issue No. 1 - 2017
Series I: Engineering Sciences

VIBRATIONS OF COMPOSITE WOOD-LIGHTWEIGHT CONCRETE FLOOR STRUCTURES

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Abstract: *This paper deals with vibrations of composite wood-lightweight concrete floor structures caused by human action, so that it could be theoretically and practically processed and ensured that these actions do not cause vibrations that can reduce functionality or cause unacceptable discomfort to the user. Lightweight concrete reduces the actual weight of the structure, so that greater spans can be achieved, in comparison to the regular concrete structures. However, greater spans of floor structures reduce its resonance frequency. The structure becomes more sensitive to dynamic stress, thus knowing the dynamic response of these light floor structures represents an important prerequisite for accurate planning. The basis of numerical procedure for solving the system of differential equations will be Finite element method (FEM). Serviceability requirements for vibrations of lightweight floors are also discussed.*

Key words: *timber floors, renovation, vibration, serviceability, FEM.*

1. Introduction

Composite wood-concrete structures have been studied for over 70 years. For the needs of the Oregon State Highway Department in the USA, McCullough [1] has tested 22 composite wood-concrete beams. He researched the possibility of applying these beams in short-span bridges on highways. At the same time at the University of Illinois, Richart and Williams [2] tested 32 composite beams with different types of of mechanical dowels.

In Europe, the composite wood-concrete beams are used mostly for the reparation of old wooden floor structures. Weight reduction can be achieved by application of high-strength lightweight concrete such as described by Kekanovic et al. [3]. This keeps the favorable effects of the composite action and emphasizes the advantage of the reduced weight.

The vibrations of composite wood-concrete floor structures caused by human action have been experimentally researched by Chien & Richie [4], Bachmann & Ammann [5], Allen & Murray [6], Williams & Waldron [7] i Nor Hayati, Deam & Fragiacomo [8]. The Finite

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element method in the calculation of floor structure's response to human action has first been introduced by Linden [9], Fragiacomo et al. [10], Hicks [11] i Ebrahimpour & Sack [12].

Multiple directives have been suggested for design of composite wood-concrete floor structures: Wyatt [13], Murray [14], Murray, Allen & Ungar [15] and Eurocode 5 [16]. Suggested empirical methods give guidelines to determine the first natural frequency. There is limited knowledge on natural frequencies of the higher order.

By testing over a hundred problematic floors, Murray [17] has concluded that their frequency is mostly between 5 to 8 Hz. It was recommended to avoid frequencies below 8 Hz because these cause discomfort to people, while human walk induces great displacements of floor structures with natural frequencies below 3 Hz. Also, Eurocode 5 [16] recommends that special research has to be carried out for floor structures with natural frequency below 8 Hz.

However, the vibrations of wooden floor structures repaired with lightweight concrete have not been researched enough. Based on the research carried out in the world and in our country, some of them already being applied in everyday engineering practice for reparation of numerous structures, it is apparent that available knowledge makes it possible for composite wood-concrete floor structures to be properly designed and constructed for static loads. On the other hand, special research of dynamic stresses, vibrations caused by human live loads in particular, which can significantly influence the exploitation reliability of the structure, have not been discussed enough and their design is insufficiently numerically verified although this type of structure could be more sensitive to vibrations due to its reduced weight when compared to structures with normal weight concrete.

This paper will numerically analyze dynamic behaviour of wooden floors repaired with lightweight concrete of different thickness, classes of lightweight aggregate density and spans. Advantages and possible shortcomings will be pointed out when lightweight concrete is used for strengthening timber floor structures that are subjected to dynamic loads i.e. human live loads.

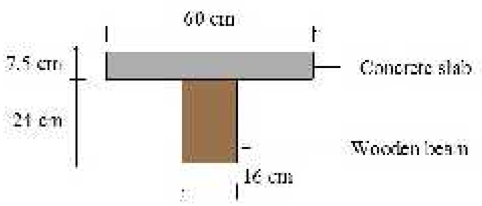
2. Material and Methods

Four composite floor structures have been analyzed. The structures have identical cross sections and dowels, but are made from different types of lightweight concrete. Beams are 6 m long while the distance between supports is 5,8 m. The distance between each timber beam is 60 cm. The cross section of the beam is a composite T-section. The rib is a monolithic wood, while the top concrete slab is made of lightweight concrete, Fig. 1.

The concrete slab 7.5 cm high and 60 cm wide is casted over the wooden beams that are 24 cm high and 16 cm wide. Concrete is poured directly onto the existing structure. Four types of beams have been analyzed, that have concrete slabs made of lightweight concrete of the same strength class but with different density. Short overview of the physical-mechanical properties (density and elastic modulus) according to Eurocode 2 [18] of the lightweight concrete from which slabs were made is given in Table 1.

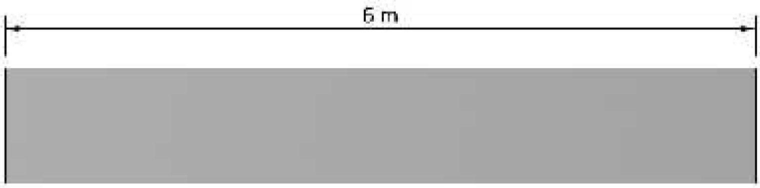
According to Eurocode 2 [18] the value of Poisson's ration for concrete without cracks is 0.2.

The analysed composite floor structure is constructed from monolithic wooden beams made out of a fir tree (*Abies alba*) strength class C16.



(a) Cross section

(b) Top view



(c) Boundary conditions of the model

Fig. 1. *Geometrical characteristics of the beam*

The finite element method (FEM) is applied by using Ansys (2011) computer software. The beam is designed as a 2D model made out of 2 layers, an upper concrete slab from lightweight concrete and a lower layer which is a monolithic wooden beam. The concrete slab is designed to receive compressive stress, so the presence of minimum reinforcement is neglected in its numerical modelling. Similar was done by Davison [19] and Rijal [20].

Beam design is done by using elements from the Ansys library. The concrete slab and the wooden beam are modelled using 4-node two-dimensional element PLANE42. It is used as a 2D element with biaxial stress and thickness. The element is defined by 4 nodes having 2 degrees of freedom at each node, translations in the nodal x and y directions. Basic input data for this element are: elastic modulus, Poisson’s ratio and the density of the wooden beam and the concrete slab.

The contact surface between the wooden beam and the concrete slab is modelled using contact elements CONTA171 and TARGE169. CONTA171 element is used for the lower edge of the concrete slab and TARGE169 is used for the upper edge of the wooden beam. Applied contact elements are one-dimensional and set between the nodes of 2D elements, in this case element PLANE42. In this model, contact elements are first allowed to slide during deflection, but separation is prevented. After that, the same model is analysed but this time with prevented sliding and separation of the contact elements during deflection. The first analysis corresponds to repaired wooden-concrete ceiling without dowels at contact surface, while the second corresponds with a ceiling with full composite action between the lightweight concrete and wooden beams at the contact surface.

The physical-mechanical properties of concrete slabs according to Eurocode 2 [17] Table 1

Beam	ρ (kg/m^3)	$\eta_E=(\rho/2200)^2$	E_{cm} (GPa)	$E_{lcm}=E_{cm}\cdot\eta_E$ (GPa)
G1	1150	0.27324	31	8,47
G2	1350	0.37655	31	11,67
G3	1550	0.49638	31	15,38
G4	1750	0.63275	31	19,61

3. Results and discussion

First three natural frequencies of the model and corresponding characteristic vibration mode shapes are calculated with modal analysis in Ansys software. The results are shown in Table 2.

Composite floor structures with a concrete slab 10 cm and 12.5 cm high have also been analyzed. The calculated values of natural freq. of those beams are shown in Table 3.

The natural frequencies (Hz) of analysed beams Table 2

Girder	Mod 1		Mod 2		Mod 3	
	no composite action	full composite action	no composite action	full composite action	no composite action	full composite action
G1	7.36	13.64	29.20	50.64	64.64	88.12
G2	7.05	13.46	27.96	49.62	61.97	85.88
G3	6.81	13.22	27.03	48.45	59.96	83.69
G4	6.63	12.95	26.33	47.26	58.45	81.57

The frequencies (Hz) of analysed beams with slab 10 cm and 12.5 cm high Table 3

Girder	Mod 1		Mod 2		Mod 3	
	no composite action	full composite action	no composite action	full composite action	no composite action	full composite action
$G1_{h=10}$	7.02	13.31	27.86	49.06	61.78	82.98
$G2_{h=10}$	6.80	13.14	26.97	48.12	59.86	81.00
$G3_{h=10}$	6.62	12.94	25.63	46.80	57.01	78.62
$G4_{h=10}$	6.40	12.67	25.02	45.68	55.82	76.39
$G1_{h=12.5}$	6.90	13.43	27.38	48.80	60.75	79.92
$G2_{h=12.5}$	6.68	13.23	26.42	47.91	58.76	78.00
$G3_{h=12.5}$	6.49	13.09	25.24	46.63	56.02	75.67
$G4_{h=12.5}$	6.23	12.81	24.52	45.47	54.84	73.50

Wooden beams of floor structures are usually at a distance of 60 cm, but during repair and reconstruction they can be found at a distance of up to 100 cm. Table 4 illustrates natural frequencies of composite floor structures with a lightweight concrete slab 7.5 cm high and wooden beams set at a distance from 80 cm to 100 cm.

Table 4

The natural freq.(Hz) of analysed beams with a conc. slab 80 and 100 cm wide

Beam	Mod 1		Mod 2		Mod 3	
	no composite action	full composite action	no composite action	full composite action	no composite action	full composite action
$G1_{b=80}$	6.75	12.47	26.78	46.30	59.38	80.61
$G2_{b=80}$	6.47	12.28	25.66	45.32	56.95	78.48
$G3_{b=80}$	6.26	12.07	24.54	44.11	54.81	71.64
$G4_{b=80}$	6.02	11.73	23.70	42.81	53.47	68.98
$G1_{b=100}$	6.22	11.76	24.69	43.46	54.82	75.31
$G2_{b=100}$	5.97	11.52	23.70	42.30	52.65	73.09
$G3_{b=100}$	5.70	11.20	22.20	41.36	50.39	66.35
$G4_{b=100}$	5.58	11.08	21.66	39.84	49.04	62.83

Performed testing shows the advantage of using lightweight concrete with low density from a dynamic aspect, considering how the fundamental frequency of composite beams increases as the density of the lightweight concrete becomes smaller. The wooden floor structure repaired by lightweight concrete of 1.2 (beam G1) density class, without mechanical dowels, has a fundamental frequency close to the minimal requirement of 8 Hz, Eurocode 5 [15]. By choosing and arranging mechanical dowels correctly, lightweight concrete slab can achieve full composite action with existing wooden beams and reach fundamental frequency of over 13 Hz which corresponds to the recommendations to avoid unwanted vibrations caused by human action. By increasing the density of the concrete, height of the concrete slab or the distance between wooden beams, the sensitivity of the floor structure to the vibrations is also increased.

4. Conclusions

Presented results of analysed floor structures made by joining existing wooden beams with a lightweight concrete slab, show that this way of joining wood and lightweight concrete can, among other things, be successfully used for reparation of wooden floor structures. The rigidity of the structure is increased by improving composite action of these two materials, that is, by an adequate choice of dowels for shear force transfer. Future research into vibration of composite floor structures made with wood and lightweight concrete will include the analysis of the effects that type, number and arrangement of mechanical dowels have on their dynamic behavior.

Acknowledgement

This research was partly funded by the funds of the Faculty of Civil Engineering in Subotica pursuant to Clause 23 in “Guidelines for transfer of knowledge and cooperation with the industry”.

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