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Investigation of non-autoclaved foam-concrete beams reinforced with bamboo

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ABSTRACT

Purpose: of this paper presents the experimental results of a study of strength and flexural behaviour of non-autoclaved foam-concrete beams reinforced with bamboo

Design/methodology/approach: Six experimental samples of reinforced lightweight foamed concrete beams with hardened density D800 and D1200 with the same bamboo reinforcement were tested on lateral bending.

Findings: A low level of anchoring of bamboo reinforcement in foam-concrete beams can provide their premature destruction.

Research limitations/implications: Next experiments should be provided for improving the anchoring of bamboo reinforcement such as the bad adhesion between the bamboo and foam-concrete caused premature destruction of experimental samples.

Practical implications: Replacement of steel reinforcement on the bamboo one in foam-concrete structures can be economical benefit.

Originality/value: Increasing of experimental base leads to developing and creating new building standards in the nearest future.

Keywords: Lateral bending, Reinforced concrete beams, Lightweight foam-concrete, Bamboo reinforcement

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PROPERTIES

1. Introduction

The advantages of foam-concrete structures compared with common reinforced concrete structures are their low weight and good thermal and physical characteristics.

Foam-concrete structures should be used as substrate plates for road pavement, slab bases, monolithic floor slabs and insulated wall panels. Taking into account that the foam-concrete of non-autoclave hardening can be prepared directly on the construction site the range of its use may be much wider.

Since foam-concrete has a significantly lower strength comparing to heavy concrete the use of steel reinforcement is not feasible for manufacturing of foam-concrete supporting structures. A cheap substitute for the steel reinforcement can be bamboo. The mechanical characteristics of bamboo are much higher than those of softwood [1,5], especially the tensile strength along the grains. In some cases [16,18] the tensile strength of bamboo can be closer to the low carbon steel strength.

Foam-concrete constructions of non-autoclave hardening and concrete structures reinforced with bamboo are poorly investigated and therefore they need to be more thoroughly studied.

2. Material and methods

Researches of foam-concrete beams reinforced with bamboo truss and their effects on a bending moment and transverse force were carried out in the laboratory of Department of Building Constructions and Bridges of Institute of Building and Environmental Engineering of Lviv Polytechnic National University.

2.1. Testing program

The research program provided the manufacturing of six experimental samples of reinforced lightweight foamed concrete beams with hardened density D800 and D1200 (800 kg/m^3 and 1200 kg/m^3) with geometric parameters according to Figure 1.

All beams were reinforced with the same flat bamboo frames. Bamboo strips with the cross-section of 7×27 mm were used to make a reinforcing frame (see Figure 1). Great attention was paid to the absence of visible defects and bamboo colour for selecting bamboo strips. Brown colour meant that the bamboo was more than 3 years old and it was of better and more stable mechanical quality [21].

2.2. Title method of testing

Experimental foam-concrete beams were tested according to the scheme of a single-span beam, one of its supports was hinged immovable and the other one was hinged-movable (see Fig. 2). The distance between the beam supports corresponded to the estimated length of a span and it was 200 cm while the total length of the beam was 210 cm. The testing scheme is according to the requirements [2].

Staged loading of the experimental samples with a pitch of 50 kg was carried out using a traverse and a jack (Q_{max} = 3000 kg.). The concentrated loads were applied in the thirds of the beam span. Sample loading was carried out in stages with a curing period of 7-10 minutes at each level, then all sides of beams were thoroughly visually inspected in order to determine cracks and to take readings from all devices as well.

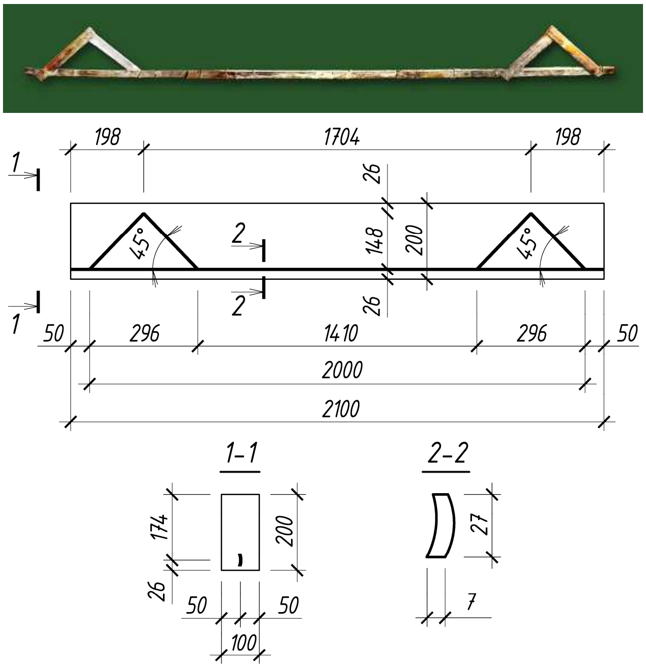

Fig. 1. General view of the bamboo frame (see above); Geometric sizes and scheme of the reinforcement of the experimental samples (see below)

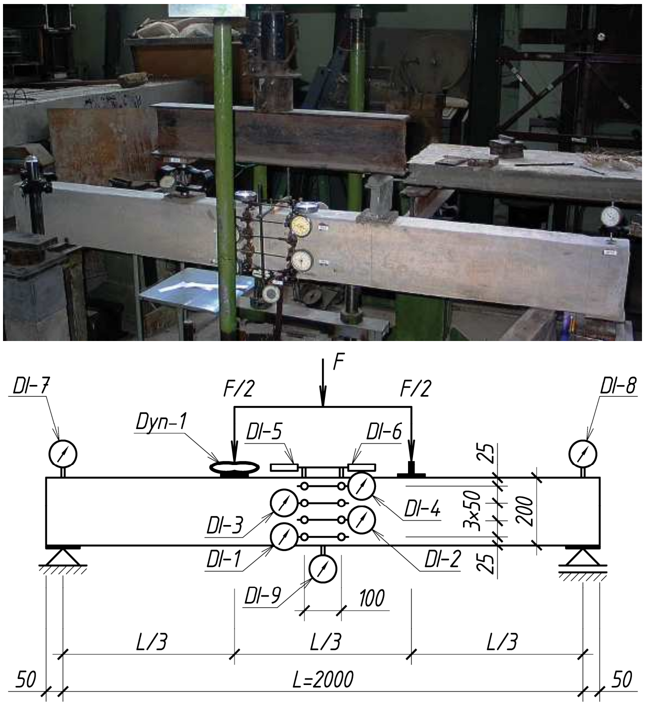

Fig. 2. General view (see above) and scheme of the experimental testing samples (see below)

Deflection of the beams in the middle of the span and the supports depression were measured by using clock type indicators with a value of 0.01 mm (see Fig. 2). The beam deflection was determined as the difference between the beam displacement, read in the middle of the span, and the average arithmetic means of the depression of supports.

The process of cracks forming and their disclosure width was visually fixed by using a 4-power magnifying glass and a 24-power microscope of type MP-2.

The typical view of the experimental samples after testing is shown in Figures 3-5.

Fig. 3. Process of the experimental samples destruction of type B-1 (see above) and type B 5 (see below)

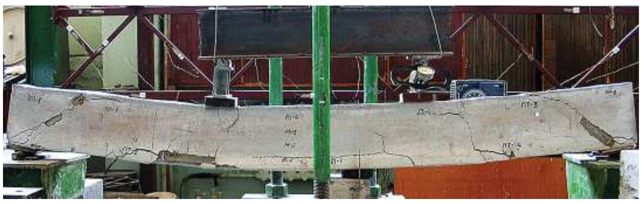

Fig. 4. General view of the experimental sample of type B-5 after destroying

2.3. Foam-concrete

The experimental samples were made of the sand from Yasnyskyi sand quarry in Lviv region and Polish Portland cement, type SEMI-32.5R. Also, there were used foam forming admixtures provided by the company "Handmar" (Poland) which are responded to [7] and [8]. Components formulation for the foam-concrete manufacturing was taken in accordance with its design types with paying attention to the recommendations given by the company "Handmar".

Fig. 5. Destruction features of the experimental samples: the slip of the bamboo at the end of the beam in type B-2 (see on the left) and the appearance of longitudinal cracks on the upper edges in type B-3 (see on the right)

According to the volume of experimental research the foam-concrete with the hardened density of 800 kg/m^3 (type D800) was used for beams manufacturing of types B-1, B-2, B-3, and foam-concrete with the hardened density of 1200 kg/m^3 (type D1200) was used for beams manufacturing of types B-4, B-5, B-6.

The cubic and prism strength of compression, the elastic modulus and tensile strength of foam-concrete of the experimental samples were determined in order to [3] and taking into account [9,10]. Foam-concrete cubes 150×150×150 mm in size and prisms 150×150×600 mm in size which were tested were made of the same kind of mortar as the beams. The results of obtained physical and mechanical characteristics of the foam-concrete are given in Table 1.

2.4. Bamboo reinforcement

Density and moisture content of the bamboo were determined according to [12] and [13]. Mechanical characteristics of the bamboo were determined using experimental samples (see Fig. 6), made of bamboo strips with the cross-section of 7×27 mm and the length of 300 mm, in accordance with [4] and [14]. The results of obtained physical and mechanical characteristics of the bamboo are given in Table 2.

Fig. 6. General view of the bamboo experimental samples to determine tensile strength

Table 1.
Average mechanical characteristics of the foam-concrete of experimental samples

Type of foam-concrete according to its density	Cubic strength MPa	Prism strength, MPa	Bending tensile strength, MPa	Modulus of elasticity, GPa
D800	1.62	1.32	0.14	0.52
D1200	2.38	2.26	0.21	1.86

Table 2.
Average mechanical characteristics of bamboo

Compression strength along the grains, MPa	Tensile strength along the grains, MPa	Bending strength, MPa	Modulus of elasticity, GPa
40.9	94.5	107.6	11.2

3. Results and discussion

Summarizing the results of the experimental researches, we can say that horizontal and inclined cracks began to appear at the supports in all the experimental beams at the first or the second stage of loading. As a rule, the process of cracks forming was accompanied by a distinctive sound. While the loading was increased the cracks were instantly spread to the entire depth of the beams cross-section.

3.1. Strain of the cross-section fibres

During the research, the foam-concrete fibre strain distribution was measured in the middle of the span by using microindicators DI-1-DI-6 (see Fig. 2) with the accuracy of the measure 0.001 mm on the basis of 100 mm. Figures 7 and 8 present diagrams of strain distribution of the cross-section of foam-concrete beams B-3 and B-6.

The nature of strain of the cross-section fibres (see Figures 7 and 8) shows the following:

- the longitudinal bamboo reinforcement was in the stretched area of the beams cross-section;
- the compressed area of foam-concrete was triangular in the shape;
- the neutral axis of the cross section was below the beam geometric axis.

3.2. Deflection of the beams

The graphs of the development of deflections for the beams of types B-3 and B-6 are presented in Figure 9.

Analysing the given graphs, we can state the following:

- the type of foam-concrete significantly influenced the beams load-bearing capacity: grade increasing of foam-concrete from D800 to D1200 increased the load bearing capacity from $F_{u,6} / F_{u,3}$ = 270 kg/105 kg = 2.57 times (point A);
- the type of the foam-concrete affects substantially the beams stiffness: grade increasing of the foam-concrete (from D800 to D1200) decreases deflections at the same load-bearing capacity by 2.55 mm/0.87 mm = 2.93 times (point B).

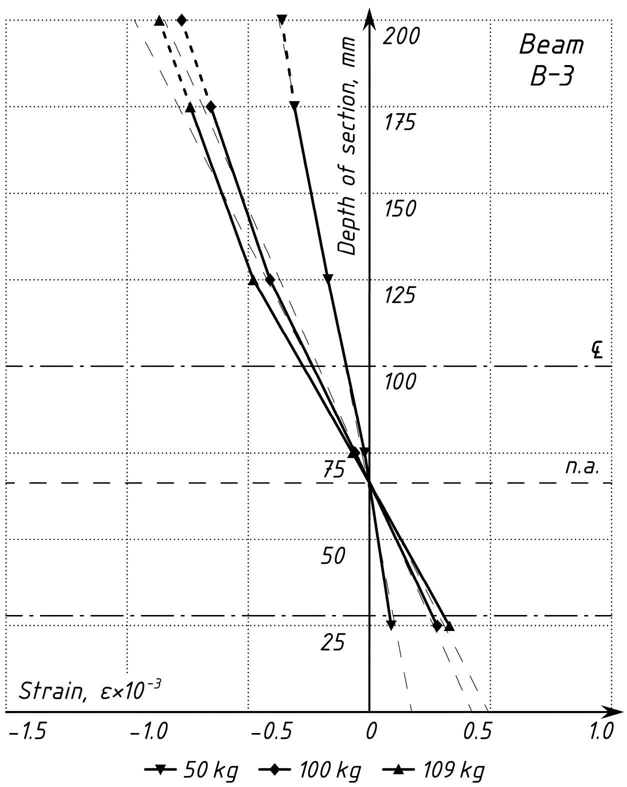

Fig. 7. Strain distribution of cross-section along beam depth (Beam B-3)

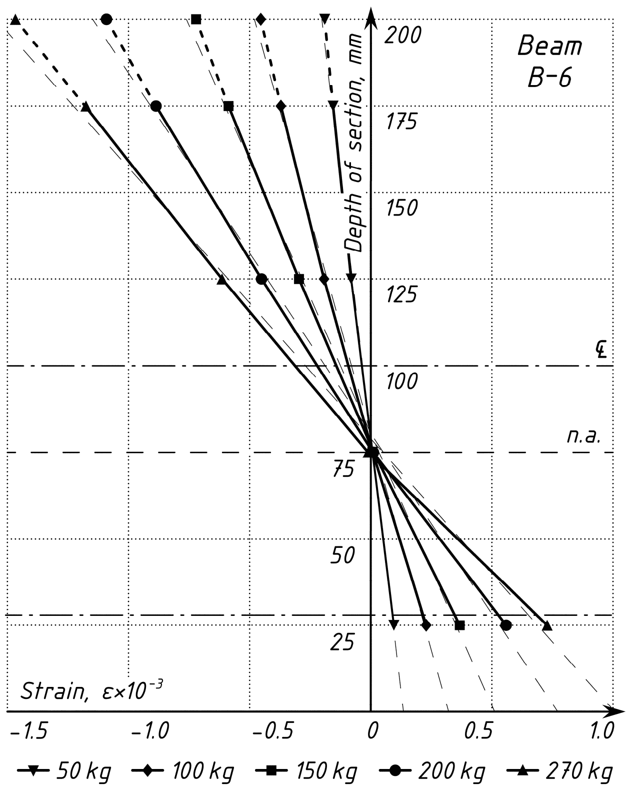

Fig. 8. Strain distribution of cross-section along beam depth (Beam B-6)

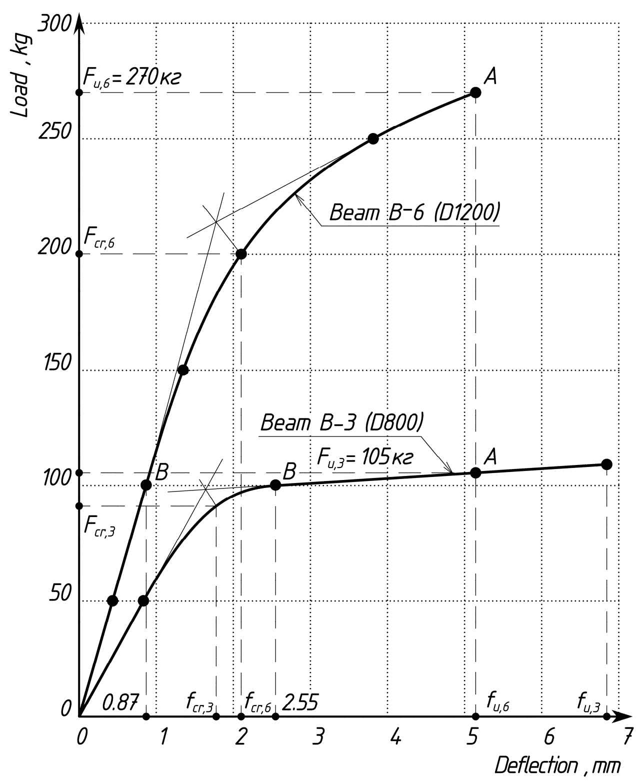

Fig. 9. Curves of load versus midspan deflection (Beams B-3, B-6)

Table 3.
Results of beams testing

Series	Beam type	Applied load, kg				Deflection, mm			
		Crack load		Ultimate load		Crack load		Ultimate load	
		Sample	Average in series	Sample	Average in series	Sample	Average in series	Sample	Average in series
I	B-1	76	86	89	101	1.36	1.58	5.02	6.10
	B-2	92		105		1.71		6.45	
	B-3	90		109		1.67		6.83	
II	B-4	167	185	224	248	1.74	1.92	4.16	4.63
	B-5	188		250		1.92		4.58	
	B-6	200		270		2.10		5.15	

It should be emphasized that all experimental samples were destroyed by the transverse force. The reasons for such behaviour of beams can be influenced by many factors such as:

- low adhesion between the bamboo and the foam-concrete, [15,20] and an improper anchoring of the bamboo truss in the foam-concrete (see Figs. 3 and 5);
- an insufficient area and step of the transverse reinforcement;
- a bad co-operation of the frame made of the bamboo stripes with the foam-concrete of the beam.

There were compared the prism strength of the foam-concrete beams of series I and II (see Table 1), which increased by $f_{c,3}/f_{c,6} = 2.26\ \text{MPa}/1.32\ \text{MPa} = 1.71$ times and these beams bearing capacity, which increased by 2.57 times. According to these results, it can be determined that such disproportional increasing of the beams load bearing capacity (series II) to the strength of the foam-concrete is not only due to the increasing of prism concrete strength but it is also connected with the improvement of adhesion bamboo reinforcement with the foam-concrete.

The results of the experimental researches of the foam-concrete beams reinforced with bamboo are presented in Table 3.

4. Conclusions

1. All the samples of the researched foam-concrete beams reinforced with bamboo were destroyed by an insufficient grip of bamboo reinforcement with the foam-concrete. The destruction type of the experimental samples and the diagrams of relative deformations are good examples.
2. Grade increasing of the foam-concrete from D800 to D1200 by density affects the cooperation of the concrete and bamboo reinforcement. The results are the beams load-bearing capacity increased by 2.57 times and the beams stiffness increased by 2.93 times.
3. Bamboo's high strength properties with a low thermal conductivity as well as bamboo price can make bamboo reinforcement competitive to the steel reinforcement. It refers to load-bearing structures made of porous and lightweight concrete. It is especially beneficial in the countries where steel reinforcement is in short supply and it is expensive, while bamboo grows in the natural environment and it is available.

Thanks to the co-authors

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