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COMPOSITE TRUSS BEAMS BEHAVIOUR

Summary: *The design specifications of composite trusses are only partially included in the European standards. However this construction system can be considered as one of the most economical for building and bridge structures. In general, the composite trusses can be used for greater spans up to the 30 m, which allows better use of internal space without restricting columns. To create the interaction between steel and concrete, it is necessary to prevent the relative slip at the steel and concrete interface using the shear connectors. But the local effects of a concentrated longitudinal force and the distribution of the shear force between steel section and concrete slab, as special task, should be appropriately examined. The finite element analyses can be used to investigate numerically this structural system. But also the static, dynamic and nondestructive experimental research has examined real structural behaviour. The outputs of this study are presented in the paper.*

Key words: *Composite truss, shear connection, numerical and experimental study*

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1. INTRODUCTION

Composite steel-concrete trusses can be considered as one of the most economical systems for building, especially for greater spans allowing better use of internal space without restricting columns. The trusses are appropriate also to meet the requirements for building height limitation as well as the need to run complex electrical, heating, ventilation, and communication systems. Also composite steel bridges, whose carriageway deck is supported on a filigree steel truss structure and slim piers, are particularly preferable especially to ordinary concrete superstructures.

To create an interaction between steel parts and concrete, it is necessary to prevent the relative slip at the steel-concrete interface using shear connectors. But the local effects of a concentrated longitudinal forces and the distribution of the shear stresses between steel section and concrete slab, as special task, should be appropriately examined. There is no particular recommendation for the design of composite truss, except the formulas in EC 4 [2], clause 6.6.2.3 for the local effect of a concentrated longitudinal force and the distribution of the longitudinal shear flow between steel section and concrete slab.

In the case of a composite truss, the longitudinal forces are introduced into the concrete slab only locally in the nodes, where the web members are connected to the compressed chord. The finite element analyses can be used to investigate numerically this structural system behaviour, exploiting several computer procedures. Nowadays, different types of shear connectors are used. In our investigation, shear connection is developed using the welded headed studs. The outputs of this research are presented in the paper.

2. COMPOSITE TRUSS BEAM TESTS

2.1. General arrangement and initial experimental data

To analyse the global behaviour of steel-concrete composite trusses, experimental program was implemented. Four similar steel-concrete composite truss beams of span 3.75 m were prepared (Fig.1). Steel truss components were made from the steel S235. Upper chord of the beam was prepared from ½ IPE 160, bottom chord from two welded UPE 120 in box component. The web members at lateral parts consisted of square hollow section SHS 70x70x6.3 and the middle diagonals of the square hollow section SHS 40x40x3. Concrete slab of size 800x100 mm was made with demand on concrete grade C25/30. Transversal and longitudinal reinforcement was formed from the bars $\phi 10$. Shear connection was provided by headed stud of diameter 10 mm and height 50 mm located only above the nodes as shown in Fig. 1. For this configuration, the hypothesis, that the longitudinal forces are introduced into the concrete slab only locally, was followed. Loading was applied in the thirds of span above nodes.

Primarily, experimental testing using progressively static loading can be illustrated on the first two truss specimens (Fig.1). Strains were recorded in both chords and web members of the girders as well as concrete slab by system of sixteen strain gauges. The details positions of the devices in cross sections are labelled as T1 to T16. During the testing, the end slips of concrete slab have been measured using displacement sensors as P17 to P21. The deflection transducers P22 and P24 were situated at the girders ends as well as in the middle P23 and near the quarter part of span. Data received from the strain gauge package were digitized and sent to the notebook. This computer was used to communicate with the measurement system for commands regarding data acquisition, calibration, initialization, downloading and display.

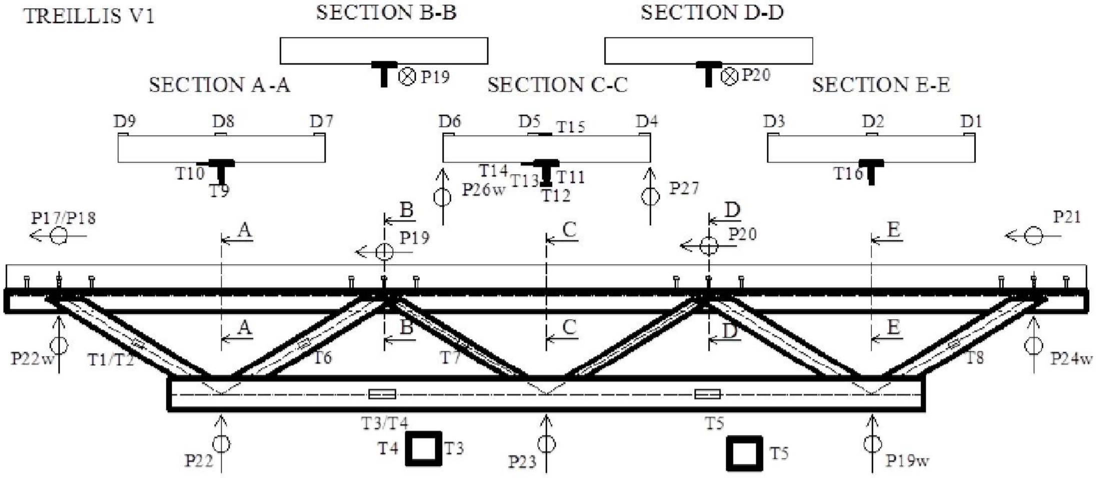


Figure 1. Components of composite truss specimen

The recorded deflections have been initially developing proportionally till the loading level of 325 kN. This maximum value of elastic load carrying capacity is in appropriate correlation with the result of the analyses according to EC4 [2]. The whole truss deflections under supplementary loading have been growing slightly nonlinearly and produced the ultimate permanent vertical deflection of 33 mm at the end of test.

Figure 2. Loading and measurement system

Even the stress distribution in strut sections has been initially rather uniform and progress proportionally. However, with increasing loading, the resulting stress patterns have proved different faster development. Especially the upper chord yielded rapidly in the mid-span sections due to combination of bending and compression as a result of significant beam deflections. Finally the chord failed by local instability. The comparison of stresses could be assumed also as good if the extremely complex character of composite truss is considered. The experimental limit load carrying capacity of the specimen was 530 kN. This value is good agreement with the numerical result.

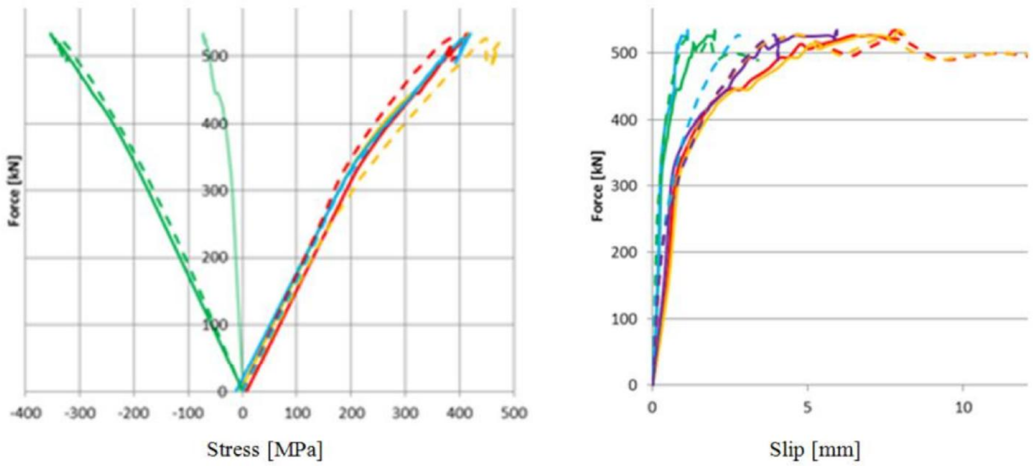


Figure 3. Load - stress in web members and load - slip development

In the beginning, also longitudinal slips in shear connection have been unimportant along the entire composite beam span with a symmetrical distribution to the mid - span. The slip shapes progressively became more irregular and finally fully irreversible. The maximum slip at the truss end was 8,1 mm and at the opposite beam edge only 5,9 mm. The limit state has been achieved at the load value under which the connectors in the support zone happening to fail by shearing. In this stage, the connectors in span were only somewhat distorted by bending thanks to favourable loading.

Figure 4. Shear failure of connectors at the edge zone and in less stressed interior span area.

2.2. Vibration analysis of the truss beam specimens

Consecutive investigation in several stages may permit to recognize advanced propagation of damages in structural elements as a function of rising loading. Figure 5 represents increasing and dropping loading steps. They started from the theoretically initial untouched first state without loading and going to the final stage of beam resistance exhausting. As it can be seen, time dependent loading grow was slightly nonlinear from the third step, because loading started to be introduced by imposed deflection to avoid sudden truss failure.

Possible technique for identification of structural component damages can be based on dynamic properties modification [1]. In the frame of the research, this type of nondestructive procedure was applied. In every unloaded stage, the truss free vibrations have been excited using a steel hammer two kilograms weight. Generated vertical accelerations have been recorded by four sensors, situated according figure 5. Knock was applied at the upper concrete deck side and in the vicinity of accelerometers. Each of measurements was reiterated three times.

Figure 5. Subsequent stages of measurements, acceleration sensor locations

Accelerograms processing by Fourier's transformation can provide proper frequencies of free vibrations and eliminate extreme amplitudes of waves from recorded signals [5]. Supposing that low damping of trusses can influence only marginally frequencies of ideal free vibrations.

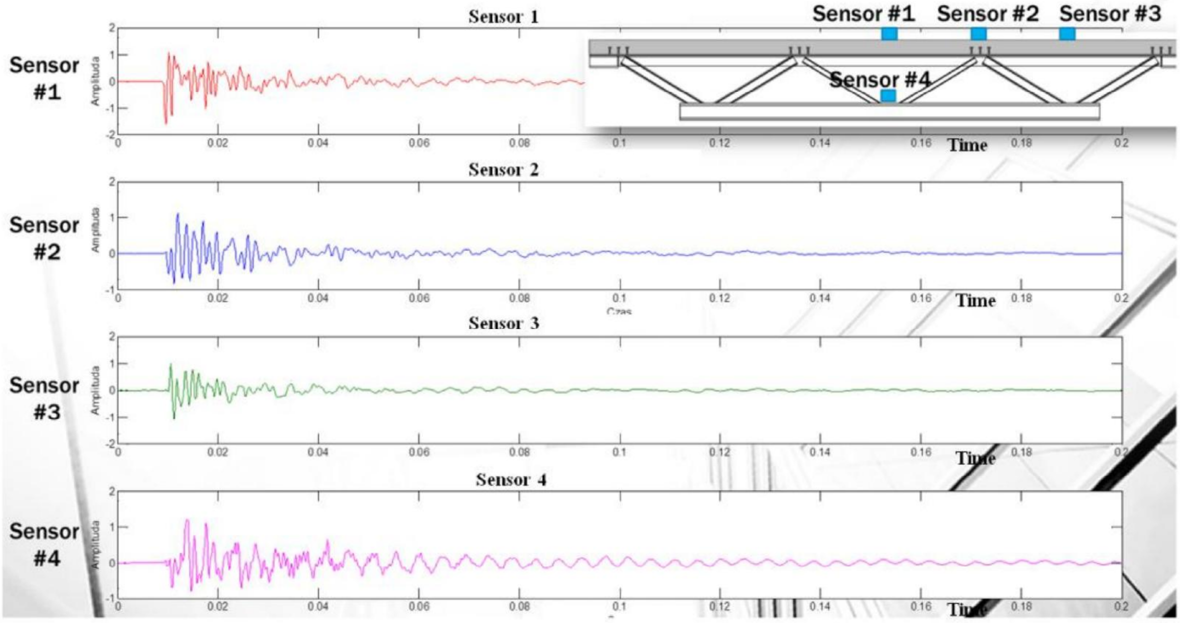


Figure 6. Exemplary accelerograms of the free vibrations of truss

Forms of natural vibration and corresponding frequency values were determined. The dynamic analysis was executed using Autodesk finite numerical model. As example, the first five bending shapes of the structure are shown in figure 7. The corresponding numerical values are listed in table. 1. Primarily theoretical frequencies in this table correspond to the infinitely stiff connection at the steel concrete interface. Then, the more realistic values relate to the experimentally determined actual rigidity, specified by a factor k = 54 MN/m are given in the second column. Also, it can be concluded that frequencies are decreasing progressively due to gradual damage propagation in the truss concrete deck.

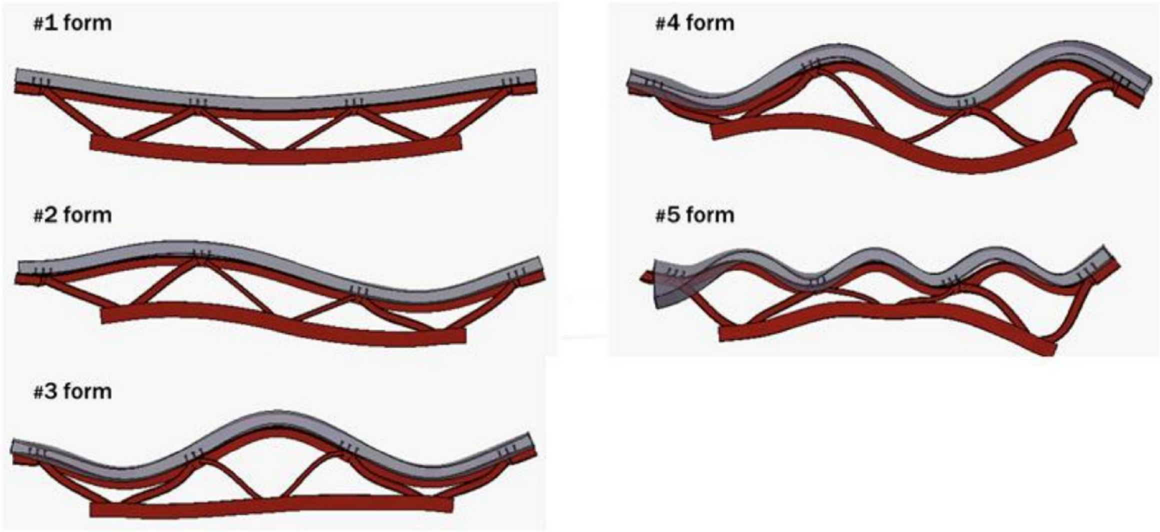


Figure 7. Forms of free flexural vibrations in the vertical direction

At the end of loading, this frequency depletion varies from 8 to 20 %. Evidentially, the decrease ratio to the initial values for higher free vibrations is greater, probably due to damping and boundary effects.

	FEM		Experiment					
			Load capacity utilization [P_{MAX}]					
Form	Virgin state		Virgin state	10% [55kN]	20% [100kN]	40% [200kN]	60% [400kN]	80% [500kN]
	$k_v \to \infty$	k_v=54MN/m						
1	53,4	39,31	39	37,56	37,56	36,12	36,12	36,12
2	79,4	71,02	72	66,45	65	62,12	62,12	62
3	108,2	114,77	111,2	108,4	107	102,6	102,6	101,1
4	148,2	152,05	158,9	153,1	144,5	143	141,6	132
5	180,7	182,13	195	193,6	193,6	189,3	186,4	177,7
6	223,3	225,47	216,7	216,7	216,7	212,4	206,6	204
7	336,8	346,44	302	300,5	300	294,7	283,2	273
8	429,3	406,13	388	387,2	385,7	375,6	355,4	335,2
9	518,6	537,4	502,7	501,3	501,3	494,1	485,4	466,6
10	630,2	653	585	573,5	573,5	567,8	524,4	505

Table 1. Comparison of free vibration frequencies from finite numerical model and test

2.3. Ultrasonic investigation of concrete plate

Propagation time and velocity of waves are reliable parameters in ultrasonic diagnostic of structural materials, especially by means of longitudinal type of waves with highest transmission velocity [3]. An average value of velocity can be obtained by measuring wave time propagation between sending and receiving points. Usually sender and receiver are located perpendicularly at opposite side of a tested specimen providing a shortest and quickest running route.

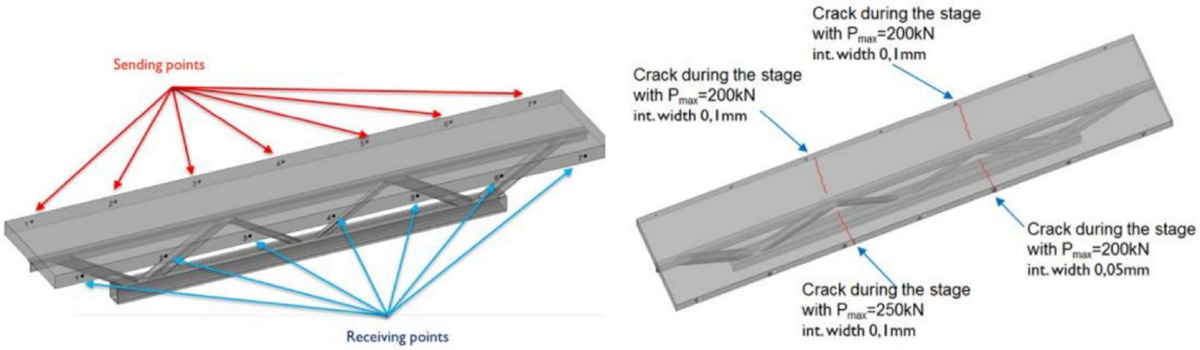
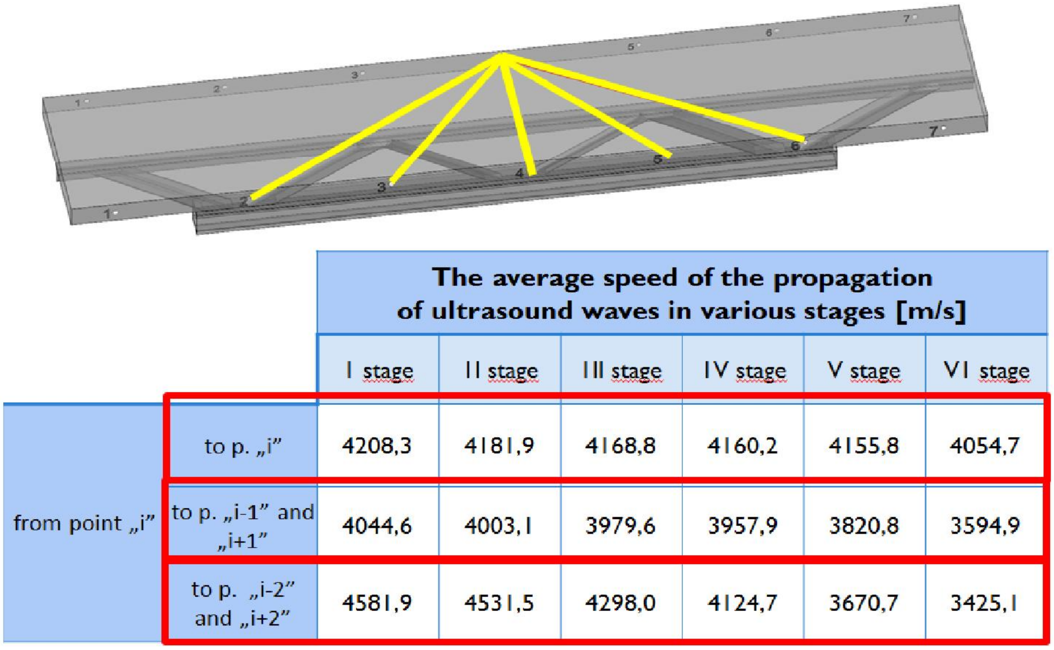


Figure 8. Localization of measuring points and visible cracks during testing

A micro-cracking in the concrete can modify the original velocity c_{L0} using scalar damage parameter ω at the reduced value c_L as follows

$$c_L = \sqrt{1-\omega}\, c_{L0}$$

In every unloaded stage, similarly as during dynamic testing, velocity propagation of ultrasonic waves with frequency of 54 kHz among selected concrete deck points was recorded (Fig. 8). This measurement was repeated three times. Beside two points at the opposite deck surfaces, the adjacent points and in addition also two postponed points were taken into consideration. The average velocity determined from registered times are listed in the table at the figure 9. The results indicate the velocity decrease about 30% especially for skew wave movement. For the shortest transversal wave paths between points on opposite sides, the average velocity variations were less significant. The main reason is that cracks started developing and then rising in the crosswise direction of the truss, so matching the wave paths (Fig. 8).



		The average speed of the propagation of ultrasound waves in various stages [m/s]					
		I stage	II stage	III stage	IV stage	V stage	VI stage
from point „i"	to p. „i"	4208,3	4181,9	4168,8	4160,2	4155,8	4054,7
	to p. „i-1" and „i+1"	4044,6	4003,1	3979,6	3957,9	3820,8	3594,9
	to p. „i-2" and „i+2"	4581,9	4531,5	4298,0	4124,7	3670,7	3425,1

Figure 9. Average wave velocity among selected points

The presented procedure may identify damaged concrete zones due to stress actions. Moreover, the obtained results allow predicting degree and cracking location in the truss deck before appearing at its surface. In the case of tested truss, the cracks became observable only after the third loading stage (Fig. 8).

3. CONCLUDING REMARKS

The experimental program of bending test of composite truss beam would go on to test and investigate real behaviour of the composite truss with connection only above the nodes. The promising finite element models are in progress using solid elements and local damage evolution of concrete. The aim is to take account of the local phenomena such as the plastic deformation between the connectors and the top chord on all the length including the panel points.

Dynamic and ultrasonic non-destructive investigation methods represent effective tools for identification of inner non-evident imperfection also in the case of composite trusses. Deck cracking could be predicted in selected concrete part from beginning of truss loading and started to be observable after the third stage.

4. REFERENCES

1. Berczyński S., Wróblewski T.: Experimental Verification of Natural Vibration Models of Steel-concrete Composite Beams. Journal of Vibration and Control 2010 16: 2057
2. Eurocode 4 “ Design of composite steel and concrete structures”. Part 2: General rules and rules for bridges. Brussels: CEN; 2005.
3. Kak A.C., Slaney M., Principles of Computerized Tomographic Imaging, IEEE Press, New York, 1999
4. Lam, D., El-Lobody, E., 2005. “Behavior of Headed Stud Shear Connectors in Composite Beam”. Journal of Structural Engineering, ASCE, January. p. 96-107.
5. Lemaitre J., A continuous damage mechanics model for ductile fracture, J. Egineering Materials and Technology, 107, 83-89, 1985