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Experimental stiffness verification of composite beams

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ABSTRACT

During their lifetime bridge structures are exposed to various weather conditions and load factors. Load applied to a construction is short-term or long-term, and some load factors act permanently during the whole construction life. The aim of this paper is to analyse the action of short-term and long-term static load on an experimental composite steel and concrete beam. The model composite structure simulates a deck bridge loaded by constant and random static load. The loaded beam consists of a pair of hollow steel sections encased in a concrete slab. Continuous long-term load is exerted using rubber air pillows inserted between two specimens in a prepared metal rack. A change in pressure in the rubber pillow causes a change in continuous load on the composite beam.

1. INTRODUCTION

The design solution and arrangement of structural members in deck bridges with encased filler beams have not changed dramatically since the beginnings of their utilisation. Nowadays, *Eurocodes* insist on structural design and verification using the limit states method. Standard requirements regarding composite bridges are stipulated in *Eurocode 4: Design of Composite Steel and Concrete Structures, Part 2: General Rules and Rules for Bridges* [9]. This standard allows for plastic design at the ultimate limit state. At the same time, however, it only allows the utilisation of H- or I-sections for deck bridges. Verifications have shown very ineffective utilisation of steel in such bridges: the upper flange of a beam is situated very close to the neutral axis; hence its contribution to the bending resistance is minimal. It only provides composite action/shear connection with the concrete element. The Civil Engineering Faculty at the Technical University in Košice is involved in a research programme studying deck bridges with encased filler beams of various sections with the aim of bringing

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considerable savings in steel consumption while maintaining the same bending resistance and flexural stiffness of structures. Static tests performed in the laboratories of the Faculty have indicated that beams made from T-sections are able to meet these requirements. The results have shown that special attention should be paid to the method of securing composite action, which seems to be essential in the utilisation of alternative beams [4].

2. ALTERNATIVE DESIGN SOLUTIONS FOR DECK BRIDGES

Most filler-beam deck bridges designed and constructed in Slovakia up to date have used rolled or welded I–sections (Fig. 1).

The first series of specimens using modified steel sections has been already tested in the laboratories of the Institute of Structural Engineering at the Civil Engineering Faculty of the Technical University in Košice. The main goal was to design and experimentally verify deck bridges with encased filler beams made of modified sections and achieve major economies in steel consumption. Steel beams using an inverted T-section in a variety of modifications, with smooth and comb-like web edges were compared with the traditionally used I-section (Fig. 1).

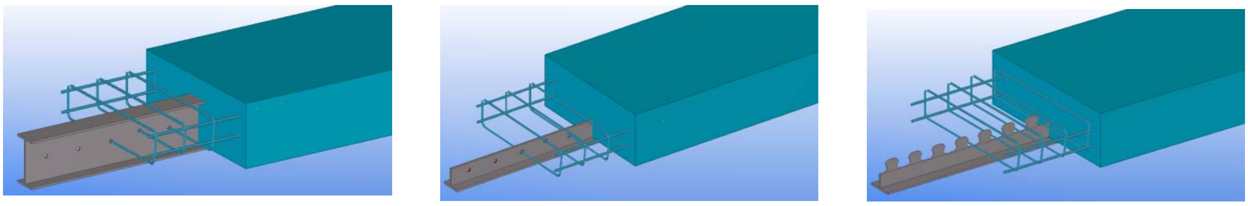

Figure 1: Modified steel beams in a composite steel-concrete member

Variables were measured and recorded continually and the average values displayed and evaluated graphically. The correlation between the overall mid-span deflection and load applied is shown in Figure 3 [17].

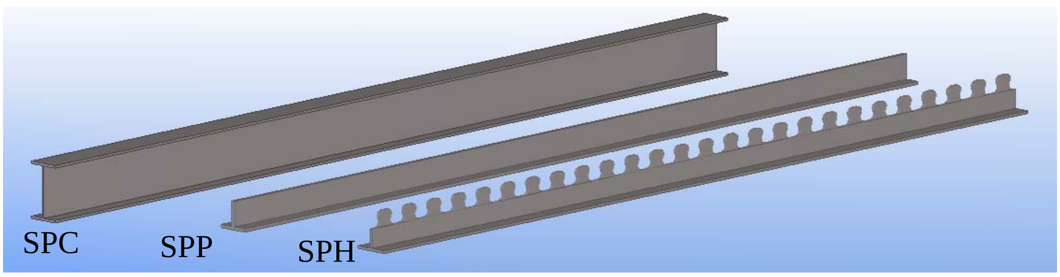

Figure 2: Designation of modified sections

The following graph indicates that the resistance of modified beams is sufficient; however, the composite action between the steel and concrete elements in the section must be perfected. T-sections do not have sufficient resistance in the construction phase, i.e. during the concreting work. Hence, the main advantage of this type of deck bridge – quick and direct in-situ construction – gets lost. On the other hand, these sections may be used well in prefabricated structural members.

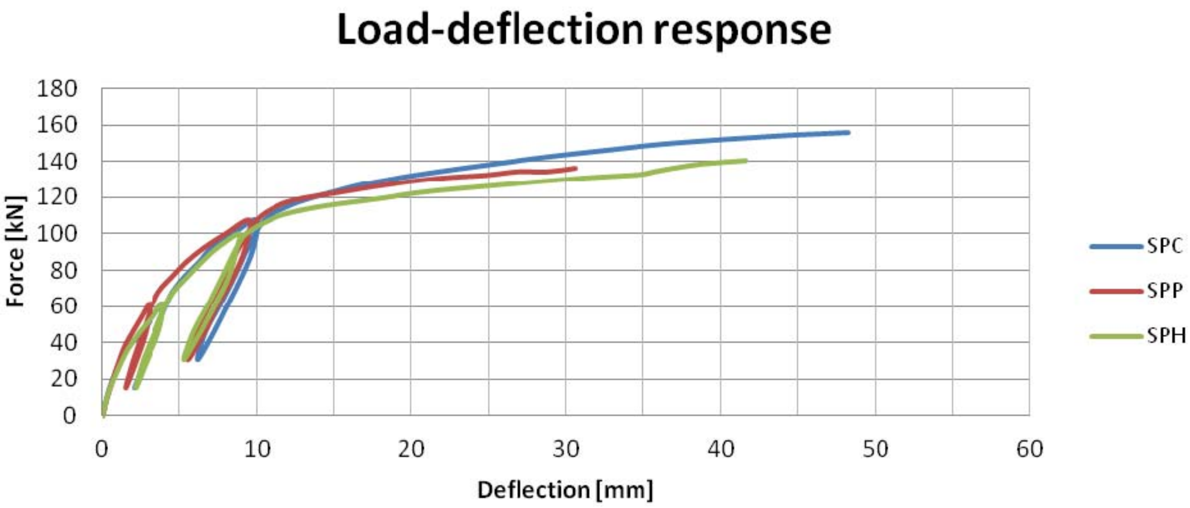

Figure 3: Correlation between deflection and load (force) applied

A new modified shape of steel section was designed in the Institute of Structural Engineering of the Civil Engineering Faculty at the Technical University in Košice which is able to take into account all the knowledge acquired in the previous research. The specimen in question can transmit the self-weight of fresh concrete in the construction phase without any falsework. The method of interconnection to transfer shear between the steel element and concrete element was improved as well so that there is no slip at the steel-concrete interface in the loading stage. Rigid load-bearing reinforcement in the experimental specimen N1 was designed as a welded hollow section. The hollow section was made by welding a 6 mm thick U-shaped steel sheet creating the upper flange and the webs of a section to another 6 mm thick steel sheet creating the lower flange with overhanging ends. Holes 50 mm in diameter were cut by flame in the webs at an axial distance of 100 mm. Reinforcement bars 12 mm in diameter were passed through every third hole in the beam. In addition, the upper flange was perforated by holes 50 mm in diameter at an axial distance of 100 mm. All the holes were arranged in such a way that there were holes either in the web or flange of each section. A cross-section and longitudinal section of Beam N1 are given in Figure 1.

The overall width of the specimens is 900 mm, the height 270 mm and the length 6000 mm. The theoretical span is 5800 mm. Every specimen contains two beams. In the longitudinal direction, the edges of the beam were fixed with reinforcement bars 12 mm in diameter to provide stability and ensure co-action with transverse reinforcement.

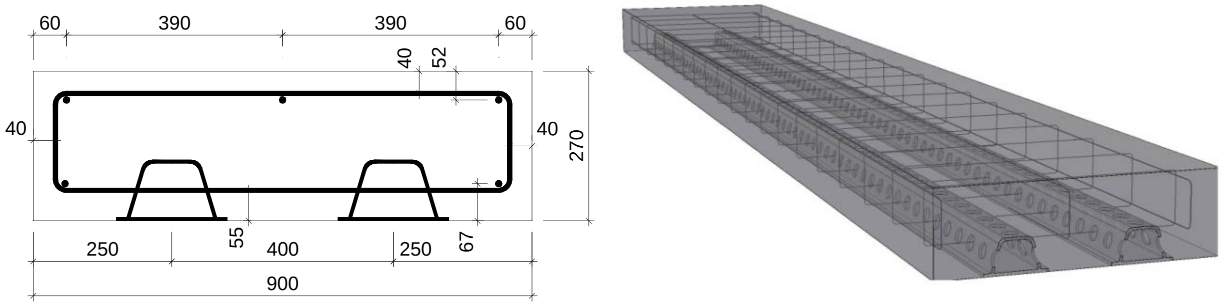

Figure 4: Composite Beam N1

3. STATIC LOADING TESTS

During the concreting phase the specimens were placed on a solid base, so the zero loading state corresponded to the dead weight of the beams. The moment caused by the self-weight was M_g = 27.33 kNm. The specimen was loaded by vertical forces applied at a distance of 2000 mm from both edges; the axial distance between the forces being 1800 mm and a free end overhanging the support 100 mm.

All the laboratory tests were carried out and the specimens manufactured in the laboratories of the Institute of Structural Engineering. The specimens were loaded by two symmetrically arranged hydraulic presses so that in the section between the presses simple bending occurred. The zero loading state was identical with the self-weight of the beam. The following loading procedure was gradual, incremental, while the compression in the hydraulic presses was increased by 10 bars at a time, this corresponding to approximately 15 kN. The specimens were unloaded twice, the first time from 60 kN per cylinder to 15 kN, and the second time from 75 kN to 30 kN. Hairline cracking occurred in the concrete on the stretched side of the beam under a load of 20 kN when the concrete tensile strength was exceeded. These cracks opened out later and developed until they reached a length of approximately 230 mm, which was the anticipated position of the neutral axis. The tests finished when it was impossible to increase the load transmitted by the specimens any more. Deflections in the specimens started do rise considerably without any increase in loading.

Based on the equation (1) it was possible to calculate the moment of resistance of the deck bridge specimens reached in the laboratory conditions under static short-term load:

$$M_{\exp} = F_{\exp}.2{,}0.r_a + M_g \tag{1}$$

Table 1 shows the maximum forces obtained from the hydraulic presses, $F_{\exp}$, by which the specimens were loaded just before the completion of the test, the moments $M_{\exp}$ corresponding to the maximum load, and the resulting average moment of resistance at the point of ultimate strength $M_{\exp,ave}$. Besides, the resulting moment was compared with the numerical calculations and the difference expressed in percentages.

Table 1: Test results

Specimen	F_{exp} (kN)	M_{exp} (kNm)		Difference %	$M_{exp,ave}$ (kNm)	M_{theor} (kNm)	Difference %
N1-1	154.0	335.33	317.48	+5.62 %			
N1-2	155.5	338.33	318.71	+6.16 %	339.37	318.69	+6.48%
N1-3	158.5	344.44	319.88	+7.68%			

Strain (relative deformation) was measured and recorded by means of strain gauges situated at the points most subjected to bending and those in the areas around holes. Inductive sensors detected the mid-span deflection and the sinking in the supports. The correlation between the maximum deflection and load (force) applied is shown in Figure 5.

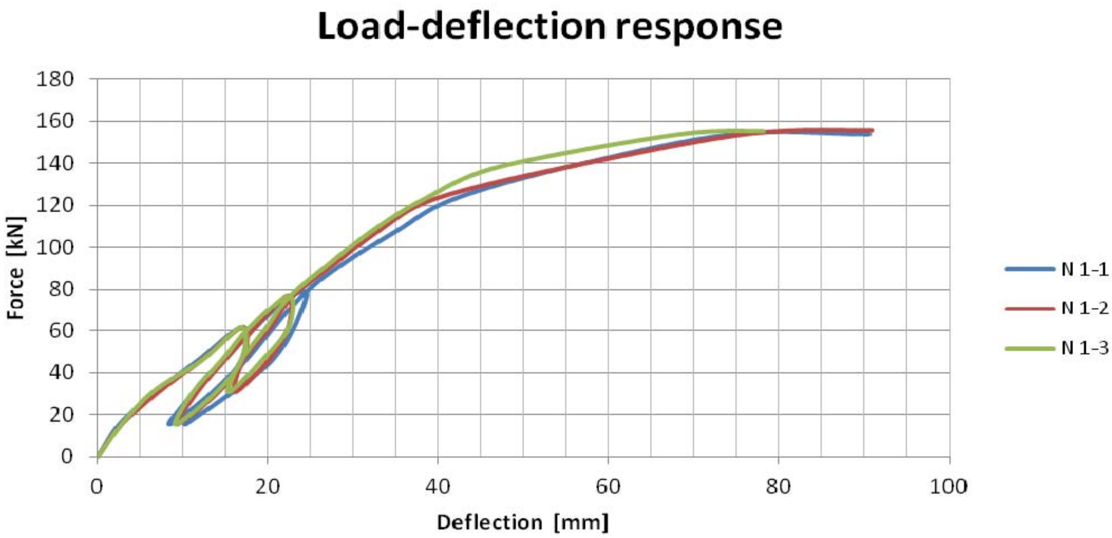

Figure 5: Correlation between deflection and load (force) applied

The graph above represents the correlation between the deflection and loading force in the specimen of a composite beam. The beam was unloaded at the loads of 60kN and 80kN and even though there was no further external load applied, severe permanent deformation in the beam remained. There was sufficient composite action/shear connection between the steel and concrete elements of the section, which is illustrated by the graph itself. There is no substantial increase in deflection that would otherwise have occurred if the composite action between the elements had failed.

4. LONG-TERM LOADING TESTS

During the long-term loading tests the specimens are placed on their sides. There are always two specimens making a pair of beams supported and loaded simultaneously. The beams are turned with the upper flanges facing each other at a distance of 50 mm. The support structure consists of frames which compress the beams against each other at their theoretical supports. Compression load is exerted using air pillows located in the gap between the beams. The load activated in such a manner is continuously uniform all over the top surface of the beam. The constant pressure in the pillow is maintained with an air compressor connected through valves to air pressure gauges. It is possible to set a specific pressure for each pillow.

Figure 6: Loaded beams in the steel frame

The specimens have been loaded by small incremental advances of 5 kPa up to a pressure of 30 kPa in N1 beams and up to 25 kPa in other beams. The long-term pressure that will be applied to the specimens corresponds to as much as 40% of their bending resistance. Deflection is measured separately in the beams stored on the right-hand rack (P) and the left-hand rack (L) (Fig. 7).

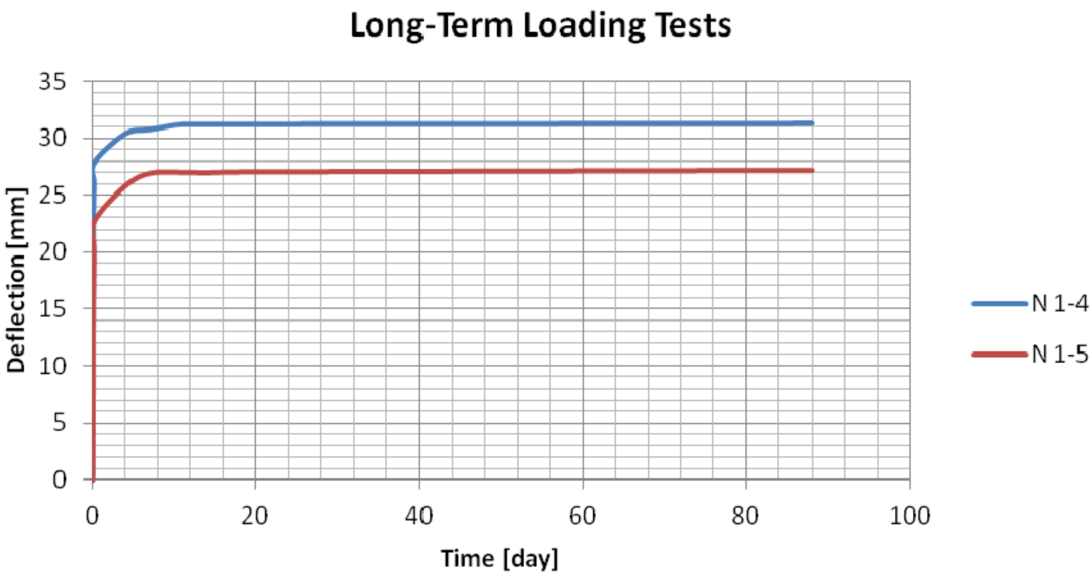

Figure 7: Time-dependent deflection of the beam

The graph in Figure 7 shows the relationship between deflection and time. It represents the gradually increasing permanent deformation of the beam under continuous load (i.e. creep) exerted by the rubber pillow. Deflection increased sharply at the initial stage of loading. When the beam stabilised over time, the increase in deflection became very modest. The test will continue by adding more load to the beams and, after the consolidation, the load will be increased for the third time. It is possible to observe time-and-load-dependent rheological changes in the beam.

5. CONCLUSIONS

The first step in the experimental research was to perform static tests under short-term loading. The moments of resistance at the yield point of the steel in three specimens were determined by the experiments. The moment values measured exceeded the theoretical resistance in all specimens. The average margin in resistance was approximately 15.24%. Great deflection was observed at the state of reaching the plastic moment of resistance. Upon unloading, permanent deformation was detected due to the changed bending stiffness after cracking occurred in the concrete. Another series of experiments is long-term loading tests. Specimens of composite beams are subjected to continuous long-term load. Deflection and strain of the steel flange and concrete at mid-span of the beam are recorded in the conduct of the experiment. After the completion of the experiment these long-term measurements will be used for the evaluation of creep in the beams.

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REFERENCES

Bujňák J., Hubinska L.(2007), The Real Behaviour of the Bearing Plate Structures with Encased Beams. Metal, Composite and Wooden Structures and Bridges, XXXIII. Workshop of Steel Structures Specialists, Oščadnica, 3rd–5th October, 2007

Gramblička, Š.; Bujňák, J.; Kvočák, V.; Lapos, J.(2007), Zavádzanie Eurokódov do praxe: Navrhovanie spriahnutých oceľobetónových konštrukcií STN EN 1994 – 1 – 1, Bratislava, Inžinierske konzultačné stredisko Slovenskej komory stavebných inžinierov, ISBN 978-80-89113-36-1

Kožlejová, V.(2009), New and Traditionally-Used Manners for Shear Connection in the Composite Steel-Concrete Structures, Mladý vedec 2009, Podbanské, 15th–16th April, 2009

Kvočák V., Karmazinová M., Kožlejová V. (2012), Verification of the Behaviour of Deck Bridges with Encased Filler Beams. In: International Journal of Systems Applications, Engineering and Development. Vol. 6, No. 1, pp. 163-170. ISSN 2074-1308

Kvočák V., Kožlejová V.(2009), Filler-beam Deck Bridges with Encased Beams of Alternative Sections. In: Selected Scientific Papers: Journal of Civil Engineering. Vol. 4, No. 2 , pp. 7-14. ISSN 1336-9024

Kvočák V., Kožlejová V., Chupayeva K., (2013), State of Art in the Utilization of Deck Bridges with Encased Filler-Beams in the Standard Construction, In. Selected Scientific Papers - Journal of Civil Engineering. Volume 8, Issue 1, Pages 107 - 114, ISSN 1338-7278, May 2013

Rovňák, M.; Ďuricová, A.; Kundrát, K.; Naď, Ľ. (2006), Spriahnuté oceľovo – betónové mosty, Košice, Elfa s. r. o., ISBN 80-8073-485-2

Samec, J. – Studnička, J. (2003), Rozbor chování spřahovací lišty, Ocelové konstrukce a mosty , 20. česko – slovenská konference s mezinárodní účasti, Prague, 17th–20th September, 2003, pp. 379 – 384. ISBN 80-01-02747-3

Seidl G. (2009), Prefabricated Enduring Composite Beams Based on Innovative Shear Transmission, E. ViefhuesArcelor Profil Luxembourg S.A.; Rue du Luxembourg 66, 4009 Esch-sur Alzette, Luxembourg (ARCELOR), 1st July 2006 to 30th June, 2009.

STN EN 1994-2: Design of Composite Steel and Concrete Structures, Part 2: General Rules and Rules for Bridges

Vargová R., Beke P., Chupayeva K. (2013), Preparation of experimental bridges program with steel beams modified shape, In: Science and research activity UIS: Herľany, s 19-24 Košice: TUKE, SvF, UIS 2013 ISBN: 978-80-553-1300-9

Vičan, J. - Odrobiňák, J. - Gocál, J. - Hlinka, R. (2006), Železničné mosty so zabetónovanými oceľovými nosníkmi v prevádzke - diagnostika a prepočet; Uplatňovanie oceľových, oceľobetónových a drevených konštrukcií a mostov vo výstavbe, XXXII. celoštátny aktív pracovníkov odboru oceľových konštrukcií so zahraničnou účasťou, Slovenský raj, Čingov, 14th–16th November, 2006, pp. 147 - 152

Vičan, J. - Gocál, J. - Koteš, P. (2003) Loading capacity of steel railway bridges according with European in Reference: Steel structures and bridges 2003, 20. Czech - Slovak conference, 17. -20. 9. 2003 (pp. 269 - 274). Praha