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Experimental Program on Composite Steel and Concrete Beams

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Abstract

Plate bridges with encased beams are suitable for building bridges of short and medium range. The paper presented focuses on the research into progressive bridges with encased filler beams of modified steel sections designed to minimize steel consumption without affecting essentially the overall structure resistance. This type of construction is suitable for bridges over short and middle spans as it offers a number of advantages, such as little headroom, quite clear static action of forces and a short construction period with no falsework required. Among some disadvantages is the economic inefficiency of steel I-sections, which are employed in the majority of bridges of this type. Therefore, there is an urgent need for the development of more economical design approaches and more purposeful arrangement and employment of steel beams. The paper presented brings some results from experimental tests on elements with encased steel filler-beams acting compositely under both short-term static and dynamic loads, and long-term load.

Key words: composite beam, static loading tests, fatigue loading tests, long term tests

1 Introduction

Composite structures are more and more frequently used both in theory and practice. They make it possible to take advantage of good mechanical properties of concrete in compression and steel in tension [5]. One of the commonest types of composite structures is deck bridges with encased filler beams. These types of construction have been employed in Slovakia and all over Europe without any major change since the beginning of the 20th century. Among their advantages is their quite clear static action, simple structural design, a short period of construction and low maintenance costs. Their main disadvantage is their economical inefficiency. The design of filler-beam deck bridges is currently based on STN EN 1994-2, which allows only the utilization of rolled or welded sections of constant cross-sections. The verification and calculation of the filler-beam deck bridges with modified sections is not specified in the standards currently in force. Some detailed design and construction methodology for the filler-beam deck bridge is virtually absent from the current standards. Therefore, new research into the filler-beam deck bridges with various steel sections and methods of composite action is particularly desirable, particularly the one experimentally focused. The appropriate design of rigid reinforcing members in the filler-beam deck bridges (their appropriate type, shape, number and arrangement) as well as the appropriate method of composite action can bring great savings in steel consumption [1,3].

2 Experimental program

Experimental tests were performed on composite steel-concrete beams with rigid steel reinforcement. N1 beams are made up of concreted steel sections with closed shape [2]. The closed section was created by 6 mm thick welding sheet bent into a U shape that creates the top flange and the wall section to the lower flange of the overhanging ends. In the walls there are burned holes with a diameter of 50 mm in spacing of 100 mm. Every third hole is dressed by concrete reinforcing bars with a diameter of 12 mm. The top flange is just made of burned holes with a diameter of 50 mm in the axial length of 100 mm. The holes are arranged so that in each section there are only holes in the walls or just in the flange. The cross and longitudinal section of the beam is N1 in Fig.1.

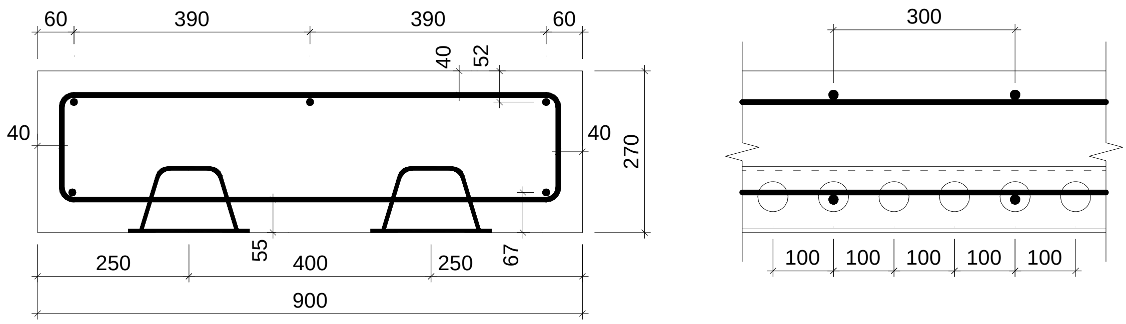


Figure 1: Size and shape of beam N1

Samples were concreted in the laboratory of the Institute of Civil Engineering Faculty of the Technical University in Kosice. Steel formwork placed on a support beam ensured a coupled deflection during casting. Concrete reinforcement and steel beams in the desired shape and size were supplied by specialized companies. The actual values of material characteristics of the steel and concrete were tested in the laboratory.

2.1 Static loading tests

While casting the samples were placed on a support beam, because the zero state corresponded to the dead load. Bending moment from the self-weight was Mg = 27,33 kNm. A load test of the sample was by two vertical forces distant from the edge of 2000 mm, the axial distance between the forces was 1800 mm and the free end was extended for support of 100 mm. Samples were symmetrically loaded by spaced hydraulic loads so that the section between presses created a pure bending. Zero load condition corresponded to self-weight of beams. Another loading procedure was carried out stepwise with increasing pressure in hydraulic loads of 10 bars, corresponding to about 15 kN. Samples were twice unloaded.

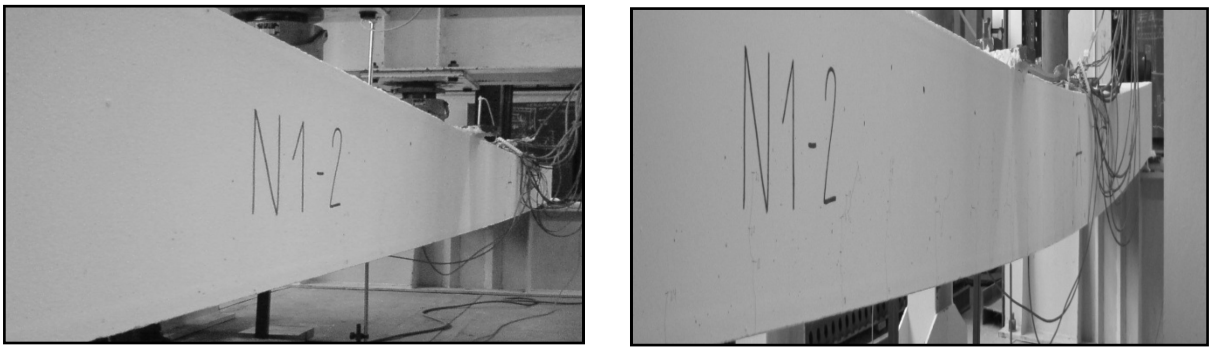


Figure 2: Samples at the beginning and end of the test

When loading above the tensile strength of the concrete, crack branching began to emerge in the tension concrete. These cracks were propagated and increased their magnification to reach a length of about 200 mm, which is the estimated position of plastic neutral axis. The tests were completed when it was not possible to increase the load transmitted by the samples. There was a significant growth of deflection without increasing the load. Dependence of longitudinal concrete strains on the size of load in the middle of the beam is plotted in the graph in Fig.3. On this chart there is a readable break in which a limit of state crack was exceeded and also the culmination of the load at its maximum value and the subsequent lightweight.

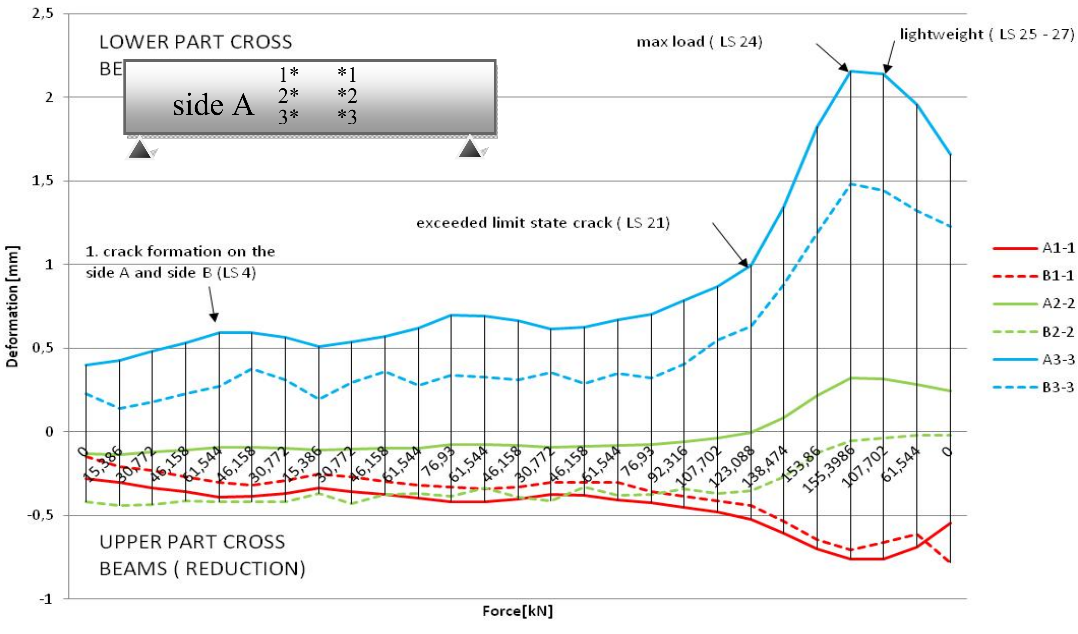


Figure 3: Graph of longitudinal deformation and strength during loading on side A and B

Tab.1 shows the maximum power of cells F_{exp} in which the samples were loaded on completion of the tests, and also bending moment M_{exp} corresponding to the maximum load and the resulting average of bending moment resistance $M_{exp,priem}$ detected by the experimental test. The resulting of bending moment is the percentage compared with numerical calculation based on Eurocode EN 1994-2.

Table 1: The test result

Sample	F_{exp} (kN)	M_{exp} (kNm)	$M_{teoret.}$ (kNm)	difference %	$M_{exp,priem}$ (kNm)	$M_{teoret,priem.}$ (kNm)	difference %
N1-1	154,0	335,33	317,48	+5,62 %	339,37	318,69	+6,48%
N1-2	155,5	338,33	318,71	+6,16 %			
N1-3	158,5	344,44	319,88	+7,68%			

During the tests relative deformations of steel were measured and recorded by strain gauges. Strain gauges were placed at the locations of highest stress bending and around openings. Inductive sensors captured the deflection at a mid-span and decrease of the supports. Dependence of strain of composite beams on the size of the load is plotted in the graph in Fig.4.

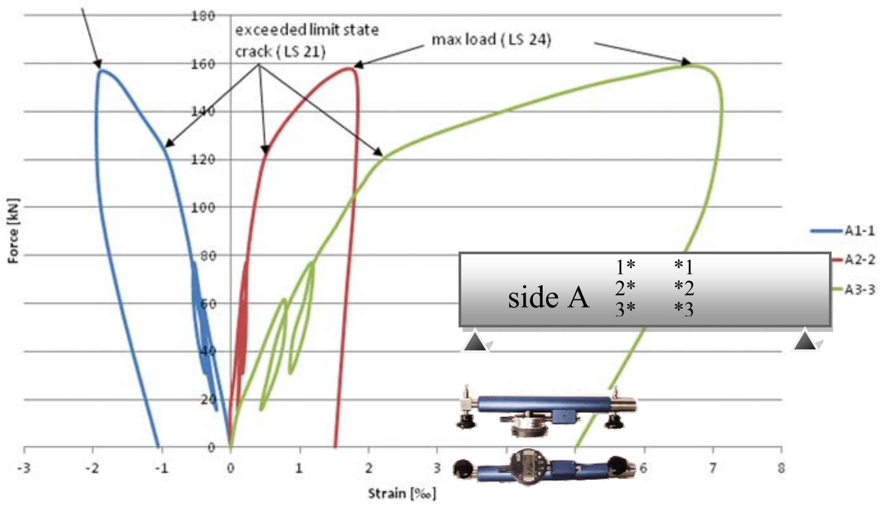


Figure 4: Graphical dependence of strain and force during loading

When loaded with 60kN and 80kN the beam was lightweight, and even without any external beam load, a significant permanent deformation remained on the beam. The break, when exceeding a limit state of cracking in the concrete section, is clearly shown on the chart.

2.2 Fatigue Loading Tests

Fatigue tests on the experimental beams took place on breaking equipment, the same equipment which was used for short-term tests with static loads. The specimens were symmetrically loaded by means of hydraulic loads so that pure bending occurred in the section between the presses. The axial distance between the two hydraulic cylinders was 1800 mm and the distance from the supports 2000 mm. All test arrangements are given in Fig.5.

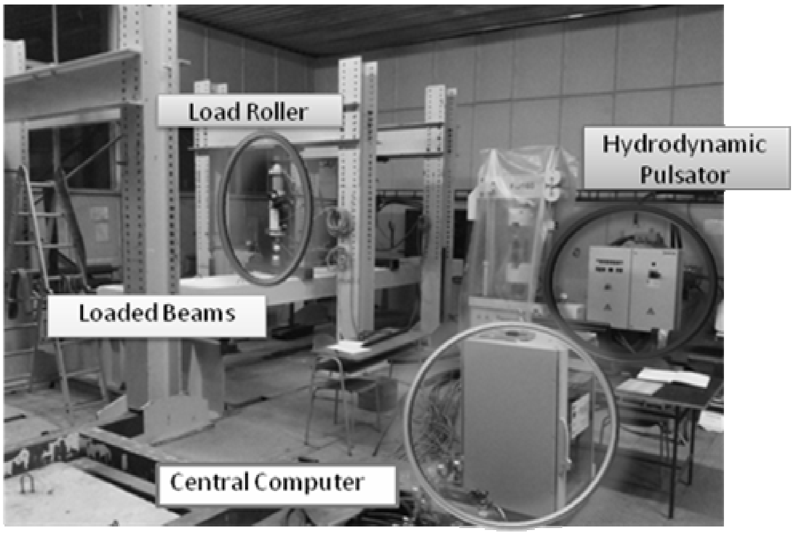


Figure 5: Tests arrangements

Fatigue tests were carried out on 3 beams. First beams was subjected to variable loads ranging from 10 kN to 90 kN per one cylinder corresponding to approximately 66% of his theoretical load-carrying capacity and a stress range $\Delta\sigma_1 = 350 MPa$.

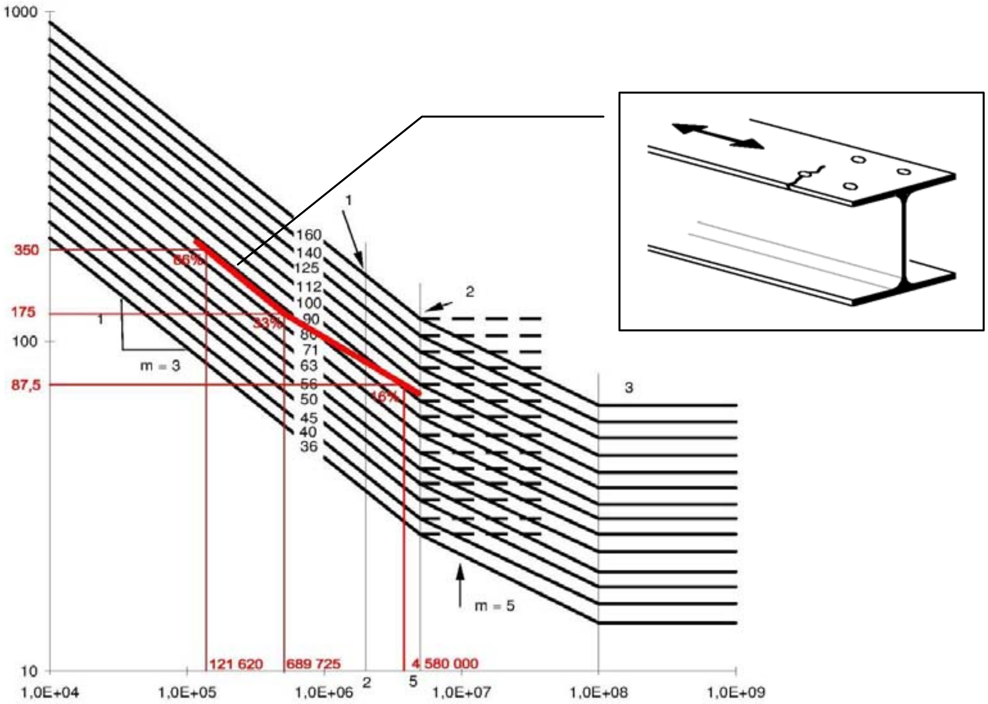


Figure 6: Fatique strength of composite beam

Another beams was loaded within the range of stress from 10 kN to 50 kN corresponding to approximately 33% of his load-carrying capacity and a stress range $\Delta\sigma_2 = 175 MPa$. The last one was subjected to long-term loads corresponding to 16% of his loading capacity and a stress range $\Delta\sigma_3 = 87.5 MPa$. They have been loaded by variable loads, the stress range per one hydraulic cylinder oscillating between 10 kN and 30 kN. The failure of the beams was owing to a fatigue crack in the encased steel section approximately at the point of loading. The stress dependence on number of cycles are shown in Figure 6. According to EN 1993-1-9 could be obtained curve to include details of the construction element with holes exhibited bending and axial forces of the weakened section.

2.3 Long - Term Loading Tests

Long-term tests started at the laboratories of the Institute of the Civil Engineering Faculty in Košice in 2012 and they are planned to be completed in 2016. During these tests the specimens are placed on their sides. There are two specimens making a pair of beams supported and loaded simultaneously. The beams are turned with their top 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 remains 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.

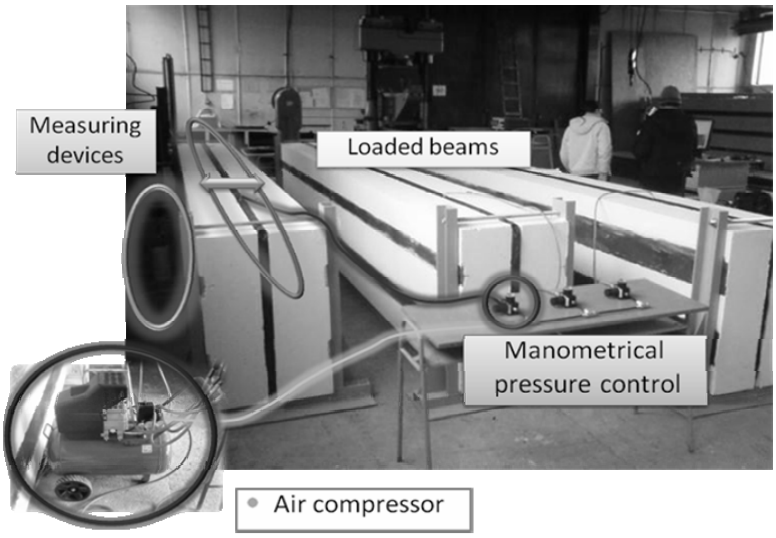


Figure 7: Loaded beams in a steel frame

The specimens were loaded by small incremental advances of 5 kPa to reach the final pressure of 30 kPa. The long-term pressure applied to the specimens corresponds to as much as 40% of their bending resistance. Deflection in the middle of the beam is measured separately in the composite beams stored on the right- hand rack (N1-4) and the left-hand rack (N1-5) (Fig. 8) Composite beams N1 have rigid steel beam with closed shape (Chapter 2).

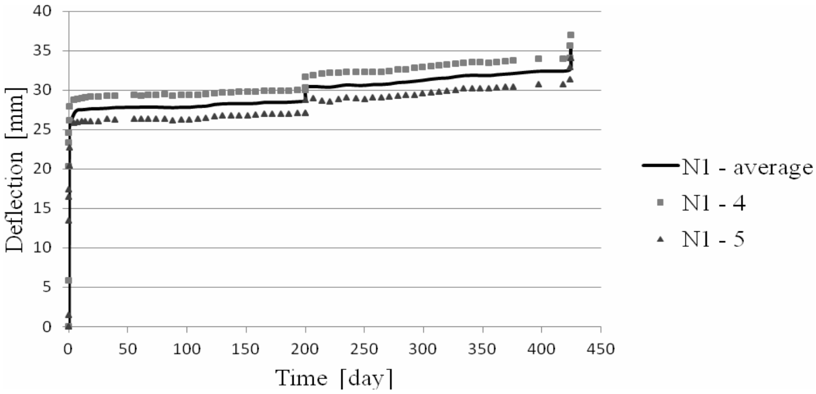
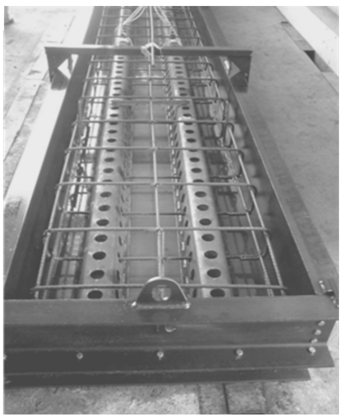


Figure 8: Time - dependent deflection of the beam

The graph in Fig.8 shows the relationship between deflection and time. It represents the gradually increasing permanent deformation of the beam under permanent load (i.e. creep) exerted by means of the air pillow. The deflections in the beam 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 second time. It will be possible to observe time-and-load-dependent rheological changes in the beam.

2.4 Numerical model

A calculation model was based using the beam specimens tested at the Civil Engineering Faculty laboratory [4]. For the modelling of load plate and support was used linear elastic isotropic material solid 185. For the modeling of concrete, it was used group of materials Solid concrete. Abaqus program simulate crack in concrete using plastic model of the concrete - concrete damage plasticity. Steel beam and structural reinforcement were medeling as Solid - 8node185. Measurement and dimension of the samples was the similar like in the experiment. A three-dimensional view of the analysed composite beam is given in Fig. 9b.



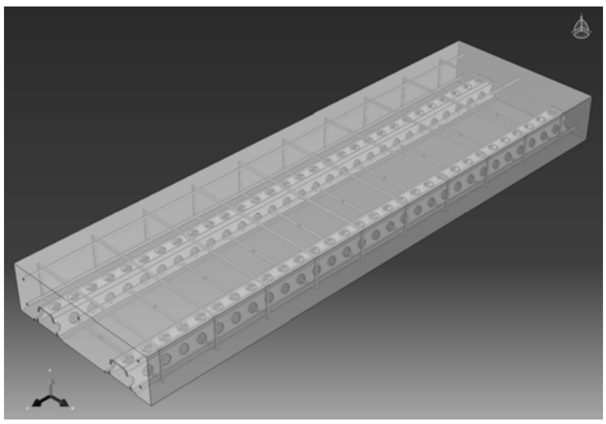


Figure 9: a) Test specimen b) Half-beam model created by Abaqus

To test the composite beam model, it was necessary to run simulations on a computer using Abaqus 6.11-2. The advantage of beam and load symmetry was taken of; therefore, it was perfectly enough to model only half the beam. The loading and placing arrangements complied with standard laboratory practice requirements. Concrete, steel beam and reinforcement elements were modelled by 3D finite elements. The computational model contained approximately 180,000 elements and 41,000 nodes. Plastic deformations of the individual elements were taken into consideration. The material properties were then used for the development of the Explicit Transient Dynamics computational model with a selected time step of 0.1s. The contact between the beam placing and loading plate was set as HARD. The computational procedure lasted 42 hours on XEON 820-2x 3.0GHz, 64GB RAM while 12 system cores were utilised. The simulation outputs were then compared to the outcomes of all experimental measurements. In reality, there is no material in a crack. This software package works with a model where there is infinitely elastic plasticised material in such a crack. Therefore, a crack in concrete will manifest itself in plastic yield and plastic deformations in a beam model developed (Fig. 10).

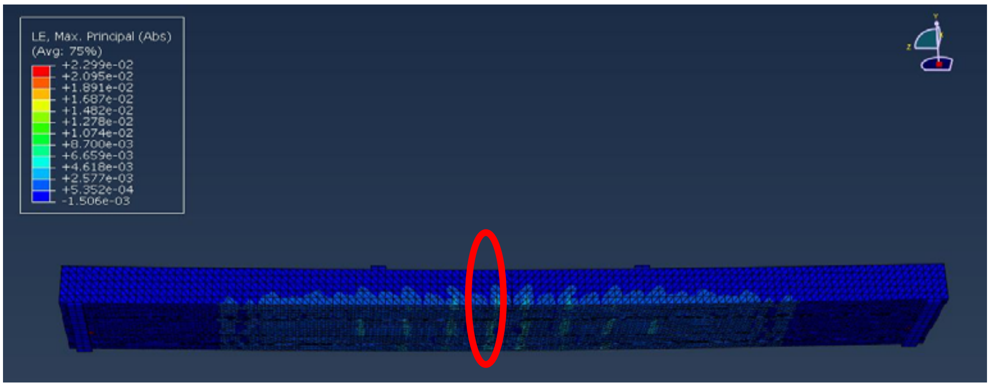


Figure 10: Development of plastic deformations in concrete

At the location of crack initiation towards the mid-span of the beam with the highest stress levels, consequent plastic flow in the steel takes place. Stress levels decrease towards the ends of the beam at its supports (Fig. 11).

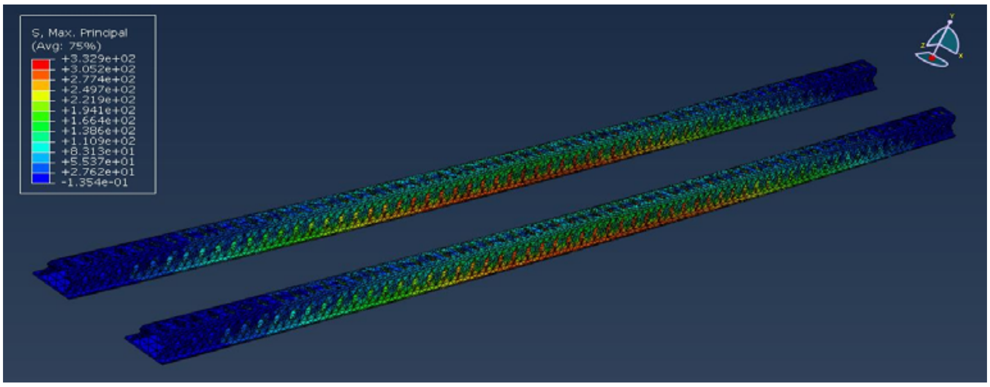


Figure 11: Plastic behavior of steel beams

Besides the strains and stresses in the section, another significant indicator of structural behaviour is the deflection of a structure. The magnitude of such deflection depends on the stiffness of a member. It is largest in the middle of the span of a beam; however, how great it depends on the stiffness of the entire member. The stiffness of encased beams is variable along their length. In the loaded parts where tensile stress in the concrete does not exceed its tensile strength, the bending stiffness of sections is given as EI_1. This stiffness is calculated providing that the whole concrete part of a section is taken into account. The stiffness of sections with fully developed cracks – EI_2 – is calculated with the elimination of concrete parts under tension. In all other parts of a beam between these two extremes, the stiffness of a beam varies continuously. The deflection of the analysed beam under the load of 120 kN per cylinder is shown in Fig.12.

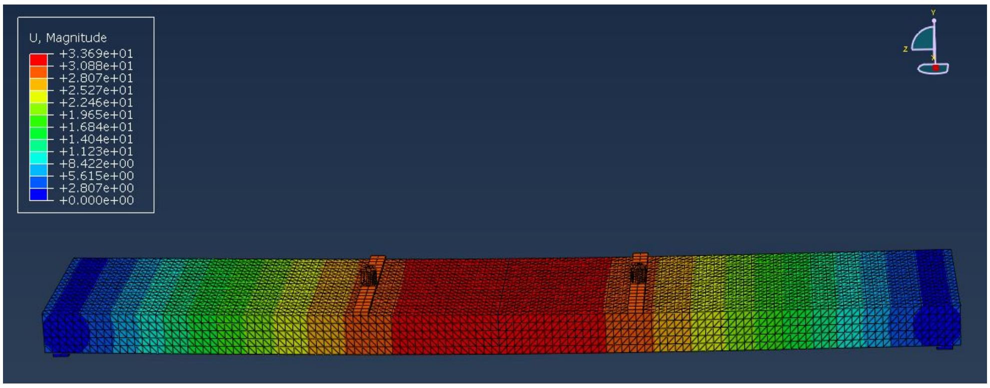


Figure 12: Deflection of a composite beam

Deflection was observed at several points in the experimental beam. The following diagram compares the deflections measured in the mid-span of the beam with the deflections obtained from the abovementioned numerical model (Fig.13). The difference between the experimental measurements and the values determined by Abaqus under the load of 120kN was 9%.

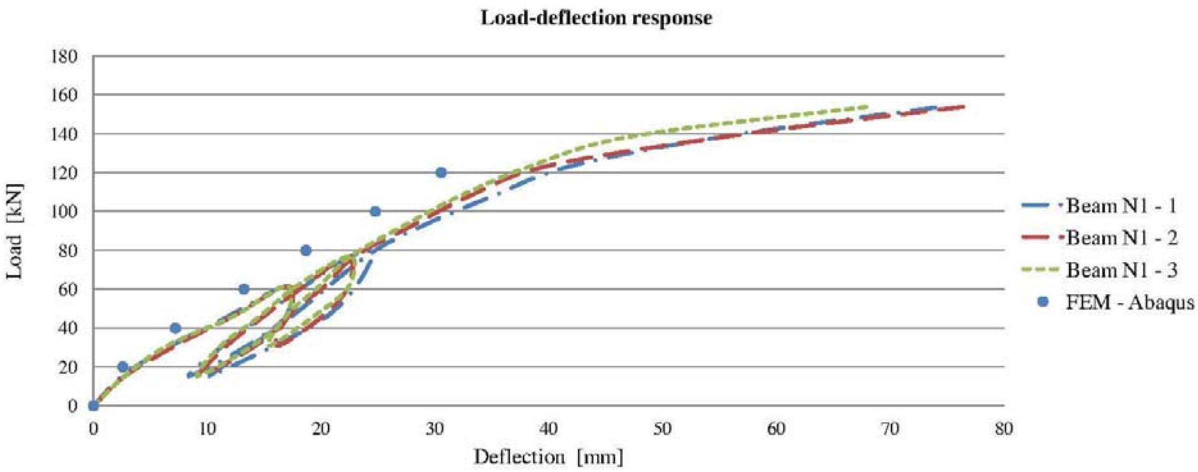


Figure 13: Comparison of the deflection values obtained from an experiment and numerical model

3 Conclusion

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 6.48%. Large deflection was observed at the stage 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 presents long-term loading tests. Specimens of composite beams have been subjected to permanent long-term load.
Finite element software application, Abaqus, provides an opportunity to model concrete in the way that simulates the formation of plastic deformations. This model best addresses the real behaviour of a structure with concrete in tensioned parts of the section. The outputs obtained by the applied computational model agree relatively well with the experimental results. Subtle differences occur with increasing loads. This is due to the unloading of a real structure which results in the permanent deformation of the structure as the cracks in the concrete have not been perfectly closed.

Acknowledgements

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References

[1] Kožlejová, V. (2009). New and traditional used manners for shear – connection in the composite steel – concrete structures, *Mladý vedec 2009*, Podbanské, 15. – 16. 4. 2009, 6 p.

[2] Kvočák, V. – Kožlejová, V. (2009). Research into filler – beam deck bridges with encase various types of composite action, *XII. Mezinárodní vědecká konference*, Brno, 20. – 22. 4. 2009, p.69-72

[3] Moore, W. P. Jr., C.D. Buckner and I. M. Viest., (1988). An Overview of Composite Construction in the United States”, *Composite Construction in Steel and Concrete, ASCE*, USA - Publication, p.186-194.

[4] Tomko M., Kmeť S., Molinne Bin. (2012). Experimental and theoretical behaviour analysis of steel suspension members subjected to tension and bending - 2012.In: *Steel and Composite Structures*. Vol. 13, no. 4, p. 343-365.

[5] Vičan, J. - Odrobiňák, J. - Gocál, J. - Hlinka, R. (2010). Remarks from Diagnostics and Load-Carrying Capacity Estimation of Existing Railway Bridges. *8th International Conference on Short and Medium Span Bridges*. Niagara Falls, Canada, 8 p.

[6] Tomko M. - Kvočák V. - Kožlejová V. (2013). Modelling of encased eteel beams. INES 2013 : IEEE. *17th International Conference on Intelligent Engineering Systems : proceedings* : June 19-21, 2013, Costa Rica. - Piscataway : IEEE, 2013 p. 255-259.