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# Experimental research on composite deck bridges with encased steel beams

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## ABSTRACT

Deck bridges with encased steel beams are commonly used for short-spans bridge structures. This type of bridge structures minimizes steel consumption without significantly affecting the overall resistance of the structure [1 and 2]. The paper presents basic information and partial results from experimental research on composite steel-concrete deck bridges with different types of encased steel beams. The paper also provides an overview about the experimental program, the production process of the tested members, an explanation of the applied load and the measurement of monitored strains and deflections of the tested members.

***Keywords:*** *Deck bridges, Encased beams, Experimental tests, Composite beams*

## 1. Introduction

Composite steel-concrete structures are increasingly used in bridges. The combination of these materials enables the effective use of positive concrete properties acting in compression and steel in tension, thanks to which the resulting structure is stronger with a smaller cross-section height compared to structures made of concrete, or steel separately. Deck bridges with encased steel beams create an effective option for combining the mentioned materials. Currently, the design of deck bridges with encased steel beams is based on STN EN 1994-2, which only allows the use of rolled or welded I-shaped cross-sections [3 and 4]. The verification and calculation of deck bridges with modified cross-sections of encased steel beams are not specified in the currently valid standards. A significant improvement of the shear connection with the concrete part of the deck can be achieved by appropriate modification of the upper parts of the steel beams, which are encased in the bridge deck. At the Institute of Structural and Transport Engineering of the Faculty of Civil Engineering in Košice, extensive theoretical and experimental research focused on deck bridges with encased steel beams of modified shapes was carried out [5, 6, 7, 8 and 9].

## 2. Basic idea and objectives

As mentioned before, the currently valid standards allow the calculation of rolled or welded I-shaped cross-sections with flat flanges encased in the concrete deck. No detailed design methodology or construction procedures are available for deck bridges with encased steel beams of modified profiles. The mentioned facts stimulated the idea of supplementing the missing data and the effort to use steel parts more efficiently.

This led the research team of our Institute to develop steel profiles that would act mainly in the tensile zone of the composite bridge. Various steel profiles were included in the research study, from T-profiles with different methods of composite (shear) action to perforated hollow profiles as shown in Figure 1.

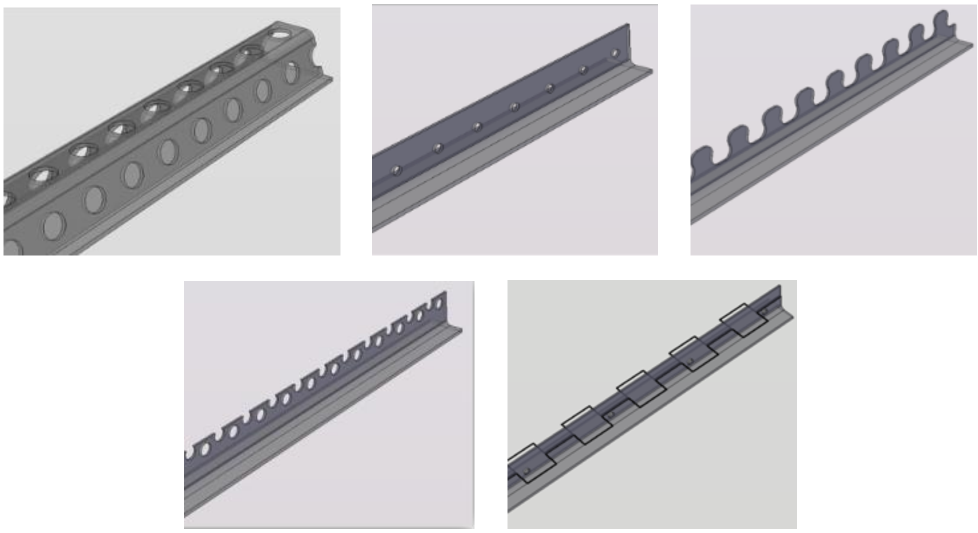


Fig. 1. Designed types of steel beams

## 3. Description and preparation of supporting documents

The necessary theoretical studies, documents and preparation of tested members for experimental research were carried out in accordance with the assumptions stated in the previous chapter.

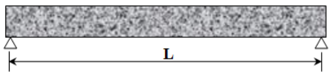
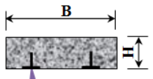
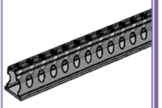
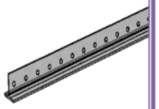
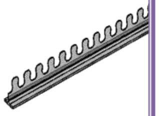
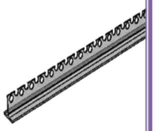
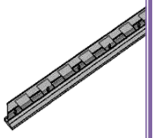
| **Beam type** |  <br>**Description** |  |
|---|---|---|
| **B1** | • Contains two encased steel beams of welded hollow profiles.<br>• The lower flange with overhanging ends is made of 6 mm thick sheet metal. The upper flange and the webs are made of 6 mm thick sheet metal bent into a U shape.<br>• There are holes with a diameter of 50 mm at an axial distance of 100 mm in the webs and the upper flange. |  |
| **B2** | • Contains two encased steel beams of T-shaped profiles, made by cutting IPE 220 profiles with a straight cut.<br>• There are holes in the web with a diameter of 20 mm at distances of 100 mm (for inserting concrete reinforcement).<br>• The holes are placed 55 mm above the lower edge of the beam. |  |
| **B3** | • Contains two encased steel beams of T-shaped profiles, made by IPE 220 cross-sections, cut as a strip in the form of a comb waves. |  |
| **B4** | • Contains two encased steel beams of T-shaped profiles, made by IPE 220 cross-sections. The edges of the web is specially adjusted into a perforated shape, which ensures a more perfect shear connection<br>• The holes in the web are at distances of 90 mm (for inserting concrete reinforcement). |  |
| **B5** | • Contains two encased steel beams of T-shaped profiles, made by cutting IPE 220 profiles with a straight cut.<br>• In addition, there are welded loops of concrete reinforcement with dimensions of 50x100 mm.<br>• The loops are welded to the web 60 mm above the lower edge of the beam. |  |

Fig. 2. Description and illustration of the designed beams

For the upcoming theoretical-experimental research, different types of composite steel-concrete beams with five variants of steel encased parts were designed in advance. The beams had a length of 6000 mm, span L = 5800 mm, width B = 900 mm, height H = 270 mm and were marked as B1, B2, B3, B4 and B5. The description and illustration of the beams is presented in Figure 2.

After designing, drawing and estimating the expected resistances of all composite beams, listed in Figure 1, the process of project and production preparation was started [10, 11 and 12].

For the implementation of static, dynamic and long-term tests, 10 beams from each variant were produced (3 for static tests, 3 for dynamic tests and 4 for long-term testes). Thus, the experimental program consisted of 50 beams.

## 4. Preparation for experiments and production of composite beams

Except the demanding works that required special preparations, all other works were carried out directly at the Center of Research and Innovation in Construction under the management of the Institute of Structural and Transport Engineering and its research team.

The following procedure was applied to prepare the experiments:

- First of all, a detailed drawings and approximate calculation of the theoretical resistance of each variant were realized.
- According to the prepared drawings, steel beams (Figure 1.) were ordered through a specialized company.
- According to the achieved theoretical resistances, concrete and reinforcements were also ordered through specialized company.
- Next step was the concreting of individual composite beams at the Center of Research and Innovation in Construction.

Figure 3 presents the model, section drawing and manufacturing process of composite beams B1.

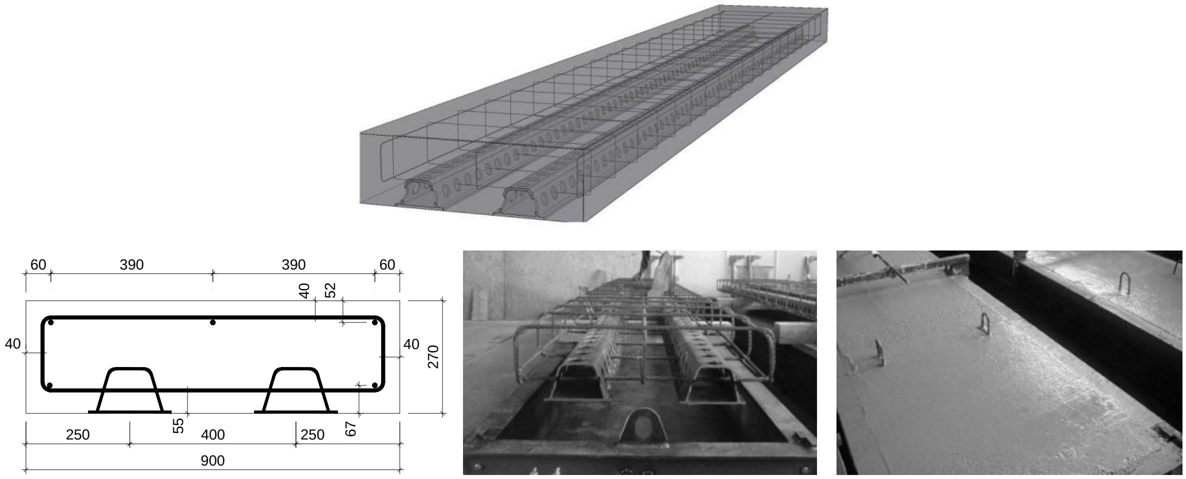


Fig. 3. Composite beam B1, general overview

Before starting of loading process, the properties of all used materials were determined by means of standardized tests as follows:

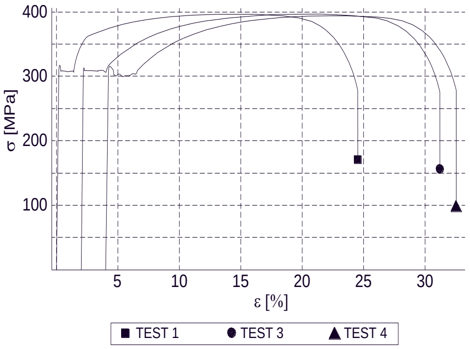


Fig. 4. Graphical results of tensile tests

Tab. 1. Obtained properties of the used steel and considered average values

| **Test no.** | $f_y$ **[MPa]** | $f_{y,\ aver.}$ **[MPa]** | $f_u$ **[MPa]** | $f_{u,\ aver.}$ **[MPa]** |
|---|---|---|---|---|
| **1** | 317 | 315,3 | 397 | 396,0 |
| **3** | 313 | | 397 | |
| **4** | 316 | | 394 | |

- The material properties of the steel used in the encased beams were determined by tensile tests of 3 samples for each variant and the average values of the yield and ultimate stresses ($f_y$, $f_u$) were considered in the calculation, as shown in Figure 4 and Table 1.
- In order to determine the properties of concrete used in the composite beams, cube and cylinder strength tests were performed for each delivery of concrete. The tests were carried out at the Center of Research and Innovation in Construction 28 days after the concreting, as shown in Figure 5, Table 2 and 3. Average values of the concrete strengths $f_c$ were taken into account in the calculation.

Fig. 5. Selected samples from cube and cylinder strength tests

Tab. 2. Results from selected samples subjected to cube strength tests

| **Test no.** | **Weight [kg]** | **Load [kN]** | $f_{c,max}$ **[MPa]** |
|---|---|---|---|
| **1** | 7,726 | 870 | 38,76 |
| **3** | 7,636 | 895 | 40,06 |
| **4** | 7,608 | 900 | 40,35 |
| **Average value of cube strength** | | | **39,72** |

Tab. 3. Results from selected samples subjected to cylinder strength tests

| **Test no.** | **Weight [kg]** | **Load [kN]** | $f_{c,max}$ **[MPa]** |
|---|---|---|---|
| **1** | 11,18 | 680 | 32,78 |
| **3** | 10,91 | 685 | 31,55 |
| **4** | 10,75 | 670 | 32,18 |
| **Average value of cylinder strength** | | | **32,17** |

Actual dimensions of all produced composite beams were measured before starting the experimental tests. Taking into account the measured dimensions and the calculated average values of $f_y$, $f_u$ and $f_c$ obtained from the above mentioned tests, 3D models of each beam variant were created using Ansys and Abaqus software, see Figures 6 and 7. These figures are presented here to illustrate the created 3D models, not to present the results.

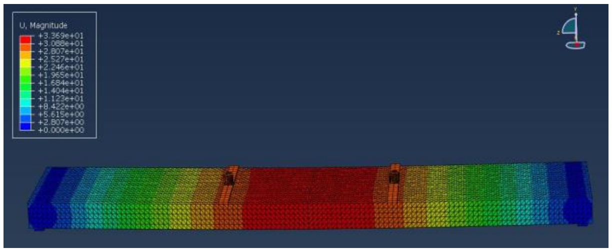


Fig. 6. Composite beam B1 - Overall deflection [mm]

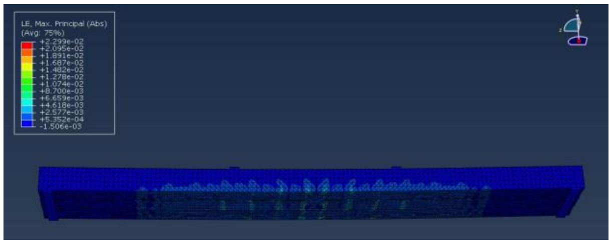


Fig. 7. Composite beam B1 - plastic strains in the concrete [%]

## 5. Experimental tests

During the static and dynamic experimental tests, four-point bending tests were applied, performed by the action of two vertical forces, as shown in Figures 8 and 9.

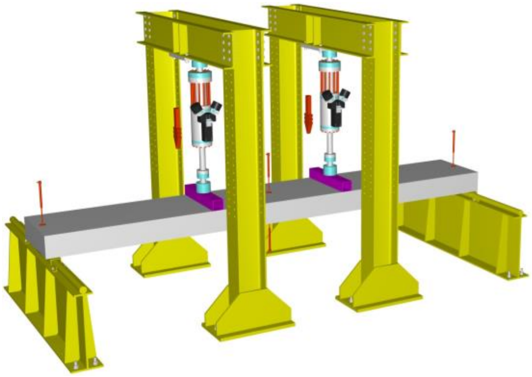


Fig. 8. Schematic view of static and dynamic tests test setup

Fig. 9. Configuration of static and dynamic tests

For realization the long-term experimental tests, pairs of mirror-faced composite beams were placed on their narrow sides with 50 mm gaps and embedded at their ends into pre-prepared special steel supports. Air-cushions were inserted into the gaps to simulate uniform loading using air compressors, as shown in Figures 10.

Fig. 10. Organization of long-term experimental tests

Strains were measured using strain gauges, directly installed inside the composite beams at characteristic positions on the steel encased beams and in the concrete parts. The installation of the gauges was carried out during the concreting process of the beams.

Deflections were measured using indicators installed at the mid-span and at the ends of composite beams from the outside.

The installation of deflection indicators was carried out before starting the tests. During the experimental tests, all strain gauges and deflection indicators were connected to special devices with monitors for direct observation, recording and evaluation of the obtained results.

In accordance with the aim of the research and for a sufficient statistical database, 3 static, 3 dynamic and 2 long-term tests were carried out for each variant of the composite beam, a total of 40 tests were performed.

All of experimental test were curried out at the Center of Research and Innovation in Construction under the management of the Institute of Structural and Transport Engineering and its research team. This Center is a part of the Faculty of Civil Engineering and cover the experimental works for the Faculty and also for other institutes and companies. The Center has a wide range of modern tools, machines and equipment that are necessary for the implementation of excellent researches of high demands.

## 6. Selected results and discussion

Due to the large number of performed experimental tests, the results are very extensive. Therefore, in this chapter, some experimental results of static tests are presented with a confrontation with theoretical assumptions.

From the bending tests, described in Chapter V, the limit values of the applied forces were experimentally obtained as shown in Figure 11.

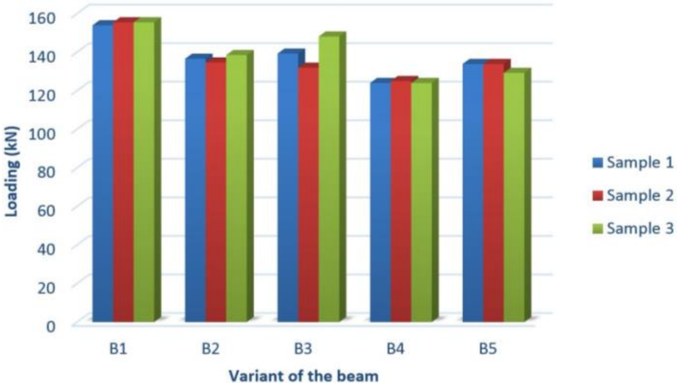


Fig. 11. Experimentally determined limit loads

Using standard calculation procedures for steel-concrete composite structures, the theoretical design moment resistance $M_{Rd,theor}$ of each beam variant was calculated.
According to the experimentally obtained limit loads, their average values were calculated for each beam variant. Using these average values, the design moment resistance $M_{Rd,exp}$ of each beam variant was also determined.
The confrontation and comparison of experimental and theoretical results is presented in Table 4.

Tab. 4. Experimental and theoretical design moment resistances

| **Beam variant** | $M_{Rd,\ exp.}$ **[kNm]** | $M_{Rd,\ theor.}$ **[kNm]** | $M_{Rd,\ exp.}$ / $M_{Rd,\ theor.}$ **[-]** |
|---|---|---|---|
| **B1** | 309,92 | 317,48 | 0,98 |
| **B2** | 273,10 | 229,45 | 1,19 |
| **B3** | 279,51 | 228,18 | 1,22 |
| **B4** | 248,67 | 234,32 | 1,06 |
| **B5** | 264,64 | 243,05 | 1,09 |

Despite the fact that the currently valid standards do not specify the procedure for verification and/or calculation of deck bridges with modified cross-sections of encased steel beams, experimental results confirmed that steel beams having modified T-profiles with active composite (shear) action are suitable for bridges of small spans.

## 7. Conclusion

The experimental results demonstrated the positive effect of the transverse reinforcements passing through the encased steel beams, see Figure 3. These transverse reinforcements significantly improved the shear action of beam variants B2 and B3 (with a straight and comb cut), which resulted in an increase in their resistance, as shown in Figure 11 and Table 4.

The obtained results expand the knowledge base regarding deck bridges with encased steel beams of modified methods of composite (shear) action. The knowledge gained from this research encourages a more consistent and thorough analysis aimed at determining the best shape of the encased steel beams.

## Acknowledgments

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## Disclosure

The authors report no conflicts of interest in this work.

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