ISSN 1330-3651
UDC/UDK 624.072.2.014.2:624.21

RESEARCH INTO FILLER-BEAM DECK BRIDGES WITH ENCASED BEAMS OF VARIOUS SECTIONS

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Preliminary notes

The paper presented focuses on the experimental research into filler-beam deck bridges with encased beams of various sections. These types of bridges were previously designed and constructed using I-section beams. The research programme in progress at the Institute of Structural Engineering at the Civil Engineering Faculty of the Technical University in Košice pertains to the theoretical and experimental verification of such bridges but with encased modified steel sections (filler beam decks) designed to take advantage of the interaction of a concrete floor slab with steel sections, thereby considerably saving the consumption of steel.

Keywords: *beams, bridges, experiment, resistance moment, specimens*

Istraživanje rasponskih konstrukcija mostova s ubetoniranim čeličnim nosačima različitih presjeka

Prethodno priopćenje

Predstavljen članak usredotočuje se na eksperimentalno istraživanje rasponskih konstrukcija mostova s ubetoniranim čeličnim nosačima različitih presjeka. Ove vrste mostova ranije su konstruirane i izrađene pomoću greda I-presjeka. Istraživački program koji je u toku u Institutu za konstrukcije na Građevinskom fakultetu Tehničkog sveučilišta u Košicama odnosi se na teorijsku i eksperimentalnu provjeru takvih mostova, ali s ubetoniranim gredama od čelika modificiranog presjeka (filler-beam decks) konstruiranim za iskorištenje interakcije betonske podne ploče s čeličnim presjecima, radi znatne uštede potrošnje čelika.

Ključne riječi: *grede, eksperiment, moment otpora, mostovi, uzorci*

1 Introduction
Uvod

Load-bearing structures of deck railway bridges with encased filler beams have been used for short and middle spans of a maximum of 24 metres. For over a hundred years they have been designed in cases with little headroom. The first bridges were constructed with no interaction between steel beams and concrete floor slabs, the structural steel working as a bearing element and the concrete in the structure as a hardening and filling element. Later, in the second half of the 20th century, more developed bridge designs were introduced where encased steel beams were used acting compositely with a concrete floor slab – the concrete transmitting actions in compression and the steel acting in tension. These structural designs were based on the method of permissible stresses and have been in use up to present. According to [6] it can be assumed that bridges designed employing this methodology meet the requirements stipulated in the current technical standards.

Filler-beam deck bridges with encased steel beams are more and more commonly used nowadays, especially in construction and reconstruction of railways. In reconstructions, they are mainly used in replacement of bridges with direct railway bedding that do not comply with relevant standards in terms of the required velocities and operational aspects. Basic rules and requirements set for the design of filler-beam deck bridges are provided in STN EN 1994-2, a European standard that specifies some common structural design and verification rules for sections based either on the plastic theory (providing that cross-sections are classified as Class 1 or 2 according to the above-mentioned standard) or on the elastic theory. According to the specified standard, mechanical shear connection need not be provided.

Rolled or welded I-sections have been used in the majority of recently designed and built filler-beam deck bridges. The research programme in progress at the Institute of Structural Engineering at the Civil Engineering Faculty of the Technical University in Košice pertains to the theoretical and experimental verification of such bridges but with encased modified steel sections (filler beam decks) designed to take advantage of the interaction of a concrete floor slab with steel sections, thereby considerably saving the consumption of steel.

2 Test specimens
Uzorci za ispitivanje

The sections and dimensions of the test specimens were designed to meet the structural requirements placed on this type of bridge and allow experimental testing in the setting of the laboratories of the Civil Engineering Faculty. The experiments were carried out in two variants and the specimens were designed so that the equal resistance was reached in each of the variants.

2.1 Design of specimens
Konstrukcija uzoraka

One variant of specimens marked as SPC is made from encased rolled IPE-200 sections. The concrete cover above the steel beam is 70 mm. The overall depth of the deck is 270 mm and the width is 670 mm, which corresponds to the axial distance of steel beams in deck bridges. There are three concrete reinforcing bars 12 mm in diameter at the upper edge of the deck. Transverse reinforcement consists of stirrups 12 mm in diameter placed in an axial distance of 300 mm. The length of specimens is 3000 mm. Both cross-section and longitudinal section are shown in Fig. 1.

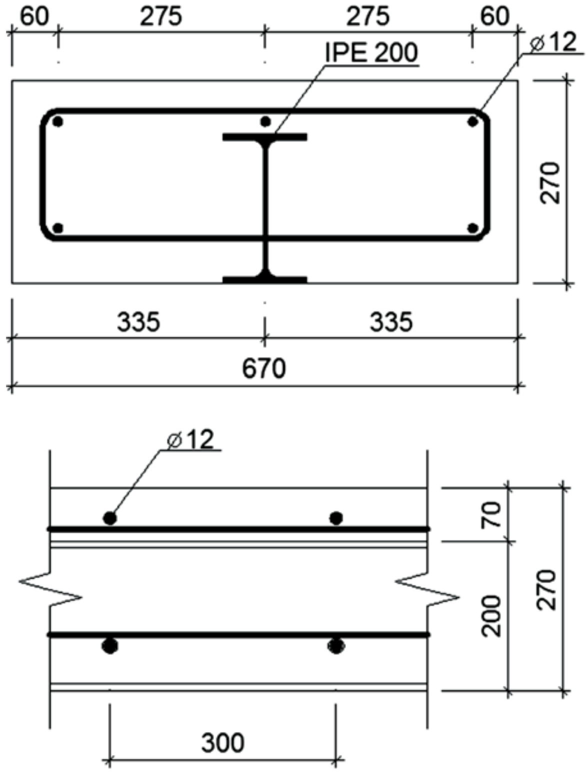

Figure 1 *Cross section and longitudinal section of SPC specimen*
Slika 1. *Poprečni i uzdužni presjek SPC uzorka*

The other variant of specimens marked as SPP is made from encased rolled IPE-220 sections cut half longitudinally so that two T- sections are made. The concrete cover above the beam is 160 mm. The dimensions of the specimens and reinforcement bars are identical to those in variant one. Again, the cross-section and longitudinal section are shown in Fig. 2.

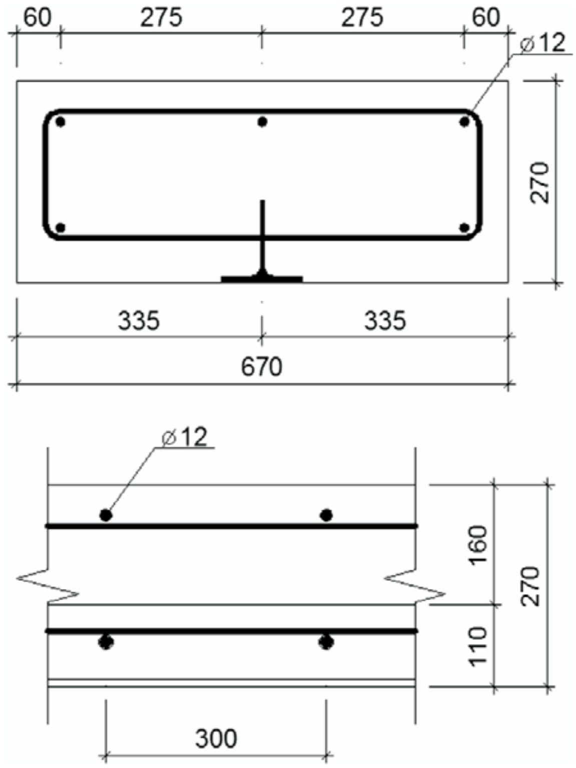

Figure 2 *Cross section and longitudinal section of SPP specimen*
Slika 2. *Poprečni i uzdužni presjek SPP uzorka*

2.2 Material properties
Svojstva materijala

The concrete used in the experiments was made in a central mixing plant. Concrete specimens used for the determination of material properties were cast along with some other research specimens. Concrete cubes cast in a 150 mm cubical mould at an age of 28 days were subjected to a standard crushing test.

Table 1 *Values of cube strength measured in a cube test*
Tablica 1. *Vrijednosti čvrstoće kocke mjerene ispitivanjem kocke*

Nr	Index	Dimensions $d_1 \times d_2 \times d_3$ / mm	Weight / kg	Load / kN	$f_{ck,cube}$ / MPa
1	036/09/1/a K1 – a	149,4 × 149,5 × 149,4	7,776	680	30,4
2	036/09/1/b K2 – b	149,5 × 149,5 × 149,6	7,791	685	30,6
3	036/09/1/c K3 – c	149,5 × 149,6 × 149,1	7,648	670	30,0
$f_{ck,cube}$ - compressive cube strength					

The average cube strength of 30,3 MPa was detected in the cube test. For the calculation of the resistance of test specimens of bridge elements the compressive cylinder strength f_{ck} = 25 MPa was used, the magnitude of which was specified in compliance with [1]. All tests were carried out in the laboratory of the Institute of Structural Engineering of the Civil Engineering Faculty at the Technical University in Košice (Fig. 3).

Figure 3 *Cube test*
Slika 3. *Ispitivanje kocke*

Tensile tests for the steel material used in the fabrication of beams were conducted by the Department of Material Studies at the Metallurgical Faculty of the Technical

University in Košice. Two samples from the beam flange were taken for analysis - Test 1 and Test 2 and two more samples from the web region - Test 5 and Test 6.

***Table 2** Values measured in a tensile test*
***Tablica 2.** Vrijednosti čvrstoće rastezanja mjerene vlačnim ispitivanjem*

Index	F_m / N	$R_{p0,2}$ / MPa	R_{eH} / MPa	R_m / MPa	A^* / %
Test 1	58832	293	294	409	33,16
Test 2	59746	293	293	408	33,40
Test 5	86633	256	257	392	36,00
Test 6	86239	252	-	395	30,00

F_m - maximum force
$R_{p0,2}$ - proof strength
R_{eH} - upper yield strength
R_m - tensile strength
A^* - percentage elongation after fracture

The test results proved that the properties in the flange region differ from those in the web region of the beams. For the calculation of the ultimate resistance, the average tensile yield strength of steel for flange f_{yf} = 293,5 MPa was used.

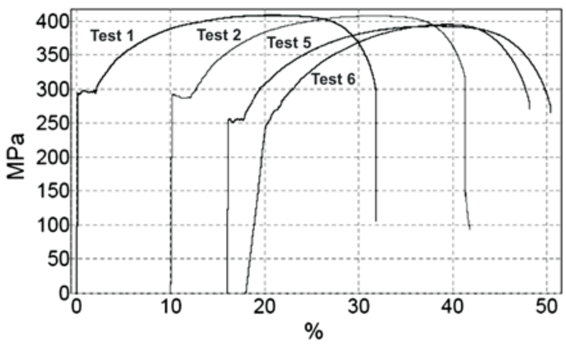

***Figure 4** Stress-strain curves for steel specimens*
***Slika 4.** Krivulje naprezanje-deformacija za čelični uzorak*

2.3 Calculation of the anticipated bending resistance of specimens
Izračun očekivanog otpora savijanju uzoraka

Prior to the experiments plastic resistance moments M_u were calculated for individual specimen variants. The values of the ultimate strength of all materials determined in the laboratory tests were assumed in the calculations.

Non-linear stress distribution in concrete can be considered as linear and the value of stress is given as $0{,}85 f_{ck}$.

Material properties:
f_y = 273,5 MPa
f_{ck} = 25 MPa

Specimen dimensions:
depth h = 270 mm
width b = 670 mm
length l = 3000 mm

SPC Variant
the cross-sectional area $A_{a,1}$ = 2612,8 mm^2

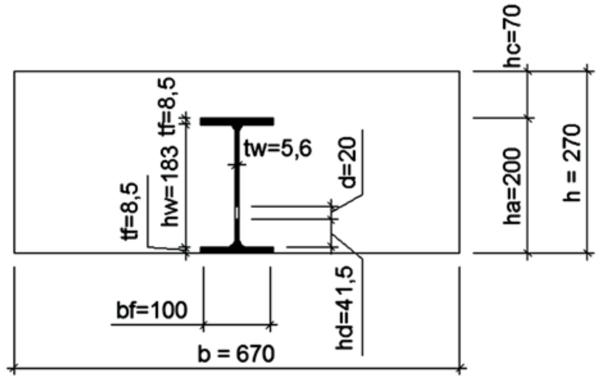

***Figure 5** Cross section dimensions for SPC specimen*
***Slika 5.** Dimenzije poprečnog presijeka za SPC uzorak*

The position of the neutral axis can be determined from the equation (1):

$$N^- = N^+. \tag{1}$$

In detail:

$$b \cdot z_{pl} \cdot 0{,}85 \cdot f_{ck} = A_a \cdot f_y \tag{2}$$

After the substitution of the numerical values into the equation, the position of the plastic neutral axis is $z_{pl,1}$ = 53,86 mm.

The neutral axis is situated in the upper flange of the steel beam (Fig. 6).

The plastic resistance moment can be calculated from the equation (3):

$$M_u = b \cdot \frac{z_{pl}^2}{2} \cdot 0{,}85 \cdot f_{ck} + A_a \cdot \left(h - z_{pl} - z_a\right) \cdot f_y . \tag{3}$$

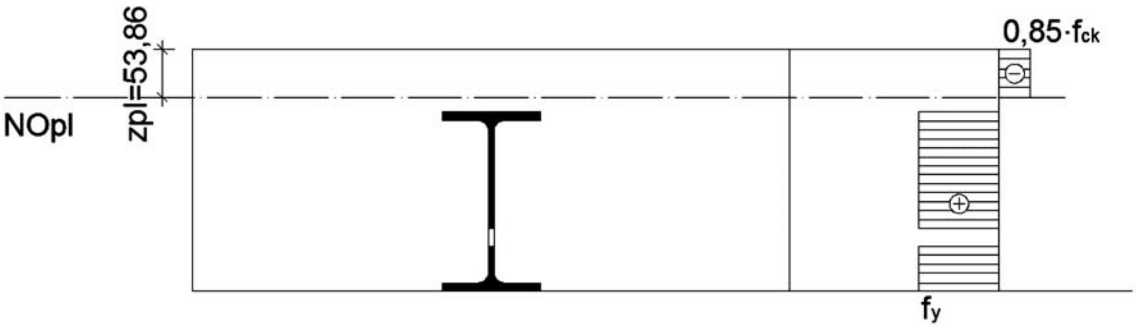

***Figure 6** Position of the plastic neutral axis in SPC specimen*
***Slika 6.** Položaj plastične neutralne osi u SPC uzorku*

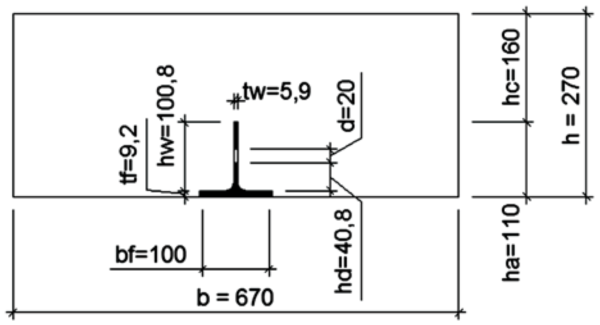

***Figure** 7 Cross section dimensions for SPP specimen*
***Slika** 7. Dimenzije poprečnog presjeka za SPP uzorak*

After the substitution of the numerical values into the equation, the plastic resistance moment $M_{u,1}$ = 108,4 kN·m.

SPP Variant
the cross-sectional area $A_{a,2}$ = 1488,7 mm^2.

The position of the neutral axis can be calculated from the equation (1) above, in more detail from the equation (4):

$$b \cdot z_{\mathrm{pl}} \cdot 0{,}85 \cdot f_{\mathrm{ck}} = A_{\mathrm{a}} \cdot f_{\mathrm{u}}. \tag{4}$$

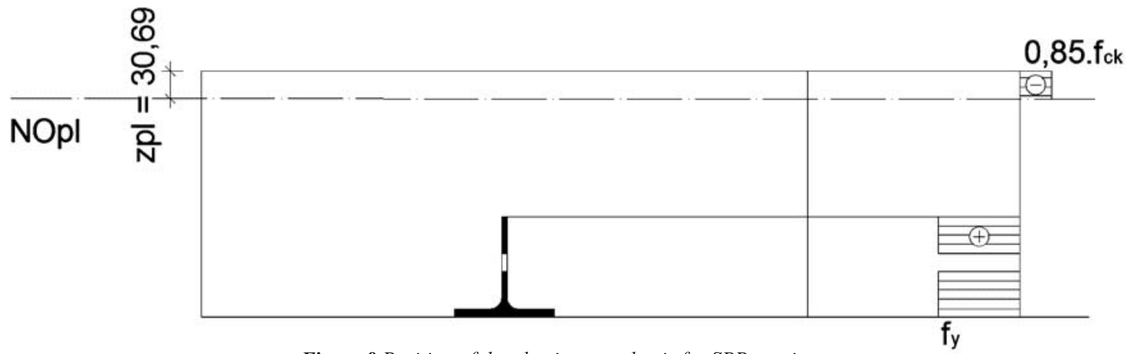

***Figure** 8 Position of the plastic neutral axis for SPP specimen*
***Slika** 8. Položaj plastične neutralne osi za SPP uzorak*

After the substitution of the numerical values, the position of the plastic neutral axis is $z_{pl,2}$ = 30,69 mm.

The plastic resistance moment can be calculated from the equation (5):

$$M_{\mathrm{u}} = b \cdot \frac{z_{\mathrm{pl}}^2}{2} \cdot 0{,}85 \cdot f_{\mathrm{ck}} + \\ + \left[t_{\mathrm{w}} \cdot (h_{\mathrm{w}} - d - h_{\mathrm{d}}) \cdot \left(h_{\mathrm{c}} + t_{\mathrm{f}} + \frac{h_{\mathrm{w}} - d - h_{\mathrm{d}}}{2} - z_{\mathrm{pl}} \right) \right] \cdot f_y + \\ + \left[t_{\mathrm{w}} \cdot h_{\mathrm{d}} \cdot \left(h - t_{\mathrm{f}} - \frac{h_d}{2} - z_{\mathrm{pl}} \right) + b_{\mathrm{f}} \cdot t_{\mathrm{f}} \cdot \left(h - \frac{t_{\mathrm{f}}}{2} - z_{\mathrm{pl}} \right) \right] \cdot f_y \tag{5}$$

After the substitution of the numerical values, the plastic resistance moment $M_{u,2}$ = 101,6 kN·m.

The above calculations demonstrate that the plastic neutral axis in deck bridges with encased I-section filler beams is situated in the upper flange of the beam.

Therefore, this part of the section contributes to the bending resistance to its minimum. In the bridge variant with encased T-sections, the calculations of the bending resistance of such beams proved that it is approximately the same as the bending resistance of I-section beams encased in deck bridges. However, the consumption of steel was only 57 per cent in comparison to the latter case.

2.4 Calculation of the anticipated ultimate load
Izračun očekivanog maksimalnog opterećenja

The specimens were simply supported, resting on both ends. At one end the bearing was fixed, the other end could move horizontally. From a structural point of view they can be considered as simple beams. The theoretical span was 2,8 m. The specimens were loaded by two forces generated by means of cylinders symmetrically arranged in a distance of 1,0 m from the support axes. The static scheme is given in Fig. 9.

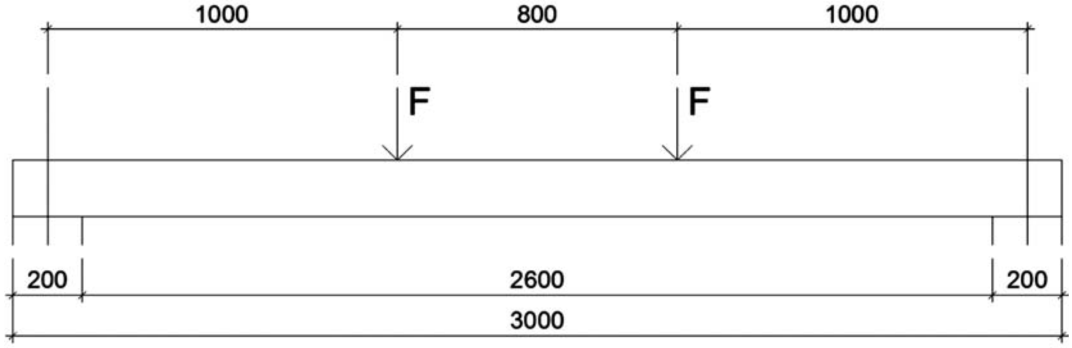

***Figure** 9 Static scheme during experiment*
***Slika** 9. Statička shema tijekom eksperimenta*

Apart from the load generated by means of the testing equipment, the specimens were subject to their own weight/gravity, which can be determined from the equation (6):

$$g = b \cdot h \cdot \gamma_c + A_a \cdot \gamma_a . \tag{6}$$

After the substitution of the numerical values:

SPC Variant:
$g_1 = 4{,}4$ kN/m

SPP Variant:
$g_2 = 4{,}3$ kN/m

Where γ_c and γ_a are specific gravities for concrete and steel, taken respectively as γ_c = 23 kN/m^3 and γ_a = 78,5 kN/m^3.

Based on the calculated plastic resistance moment and the load arrangement, it is possible to determine the anticipated forces at which the failure of the specimen should occur.

The values of forces necessary to reach the ultimate strength of the specimens can be calculated from the equation (7):

$$M_u = F_u \cdot 1{,}0 + \frac{1}{8} \cdot g \cdot 2{,}8^2 . \tag{7}$$

SPC Variant:
$F_{u,1} = 104{,}1$ kN

SPP Variant:
$F_{u,2} = 97{,}4$ kN.

3 Experiment
Eksperiment

3.1 Test specimen preparation
Priprema uzoraka za ispitivanje

The specimens were prepared in the laboratories of the Institute of Structural Engineering of the Civil Engineering Faculty at the Technical University in Košice. Rolled steel beams with pre-bored holes were utilized through which transverse reinforcement was driven. Concrete reinforcement bars were cut and bent by their supplier and the reinforcement was tied by the laboratory workers (Fig. 10 and Fig. 11). Concrete was delivered from a central mixing plant and cast in situ (Fig. 12).

3.2 Measuring device
Mjerni uređaj

The overall deflection and deformations of the steel beam and concrete were recorded. The mid-span deflections of the specimens as well as those at the points of their supports were measured by induction sensors (Fig. 13). The values were detected and recorded by computer. Moreover, strains of the steel beam were measured using strain gauges fastened at the bottom edge of the lower flange (Fig. 14).

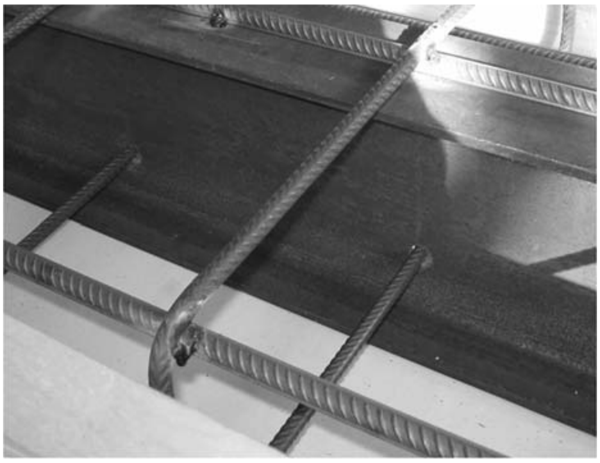

Figure 10 *Preparation of SPC beams and the method of placing reinforcement bars*
Slika 10. *Priprema SPC greda i metoda postavljanja profila za pojačanje*

Figure 11 *SPP beams and concrete reinforcement*
Slika 11. *SPP grede i betonsko pojačanje*

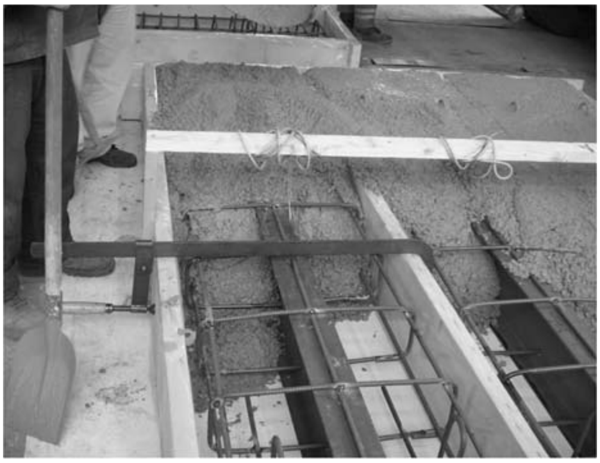

Figure 12 *Concreting*
Slika 12. *Betoniranje*

The deformation of the compression field of concrete was measured using a deformeter (Fig. 15). The values recorded were written down manually.

Figure 13 *Inductive sensor above the support*
Figure 13. *Indukcijski senzor iznad nosača*

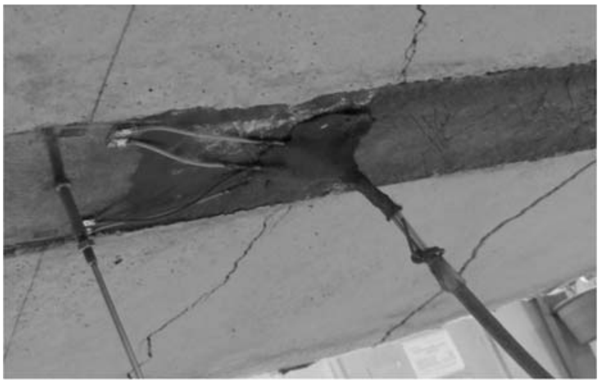

Figure 14 *Strain gauges fastened to lower flange*
Slika 14. *Mjerne otporne trake pričvršćene za donju prirubnicu*

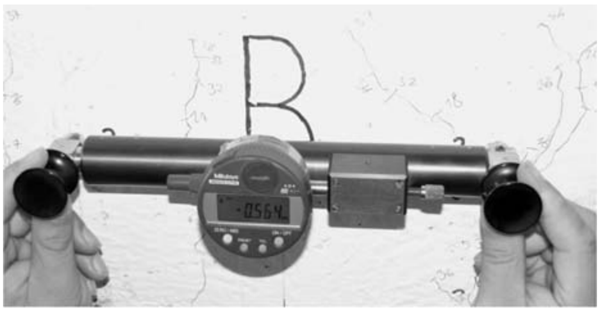

Figure 15 *Deformeter*
Slika 15. *Mjerač deformacija*

3.3
Testing procedure
Postupak ispitivanja

Both the preparations of specimens and tests were conducted in the laboratories of the Institute of Structural Engineering. Three specimens of each variant were tested. During the experiment the specimens were supported according to the assumptions. They were placed on steel support beams resting on both ends. At one end the bearing was fixed in both horizontal and vertical directions, while the other end could move horizontally. Both bearings were hinged.

Cylinders 70 mm in diameter used to impose load on the specimens were placed on bearing plates/mats and then on the beam while leaning against the steel loading frame (Fig. 16).

Figure 16 *Arrangement of experiment*
Slika 16. *Izvođenje eksperimenta*

The load was imposed gradually in steps by 7,5 kN per each cylinder. The specimens were unloaded twice: the first time from a load of 60 kN to 15 kN and the second time from 105 kN to 30 kN. During the loading phase, when the load reached the value of 15 kN and thus the concrete exceeded its ultimate tensile strength, hair cracking occurred in the tension field of concrete. Later, the cracks opened up and increased until they were approximately 200 mm long in the SPC variant of specimens and 230 mm in the SPP variant of specimens, which was as deep as to the anticipated position of plastic neutral axes in both cases.

The tests were finished when the load could not be increased any longer as the deflections rose rapidly and uncontrollably (Fig. 17).

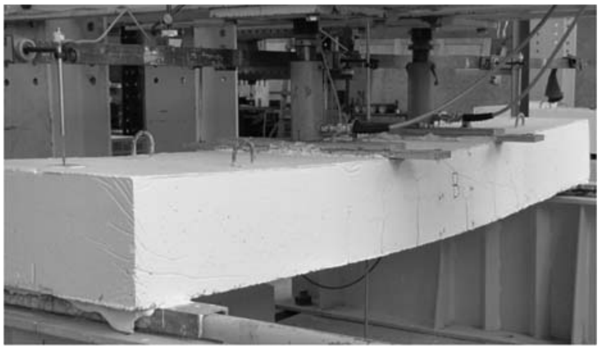

Figure 17 *Specimen after experiment*
Slika 17. *Uzorak nakon eksperimenta*

4
Test results
Rezultati ispitivanja

The values of maximum forces were measured in the situation when noticeable yield in the steel occurred. More detailed information on the resistance of the specimens is provided by the value of the moment measured just before the occurrence of this phenomenon. It happened under the load that caused a dramatic increase in deformation. The values of the corresponding forces $F_{u,exp}$ for the individual specimens are shown in Tab. 3. Based on the equation (7), the values of resistance moments $M_{u,exp}$ were determined as well as their average values for the individual variants. The experimentally observed resistance moments were then compared with the calculated data.

From the above analysis it can be concluded that the ultimate resistance moments in the laboratory conditions were in excess of those assumed in the calculations in Chapter 2.3 in all cases. A reserve of bending resistance that remained was 15 % for the variant with encased I–sections;

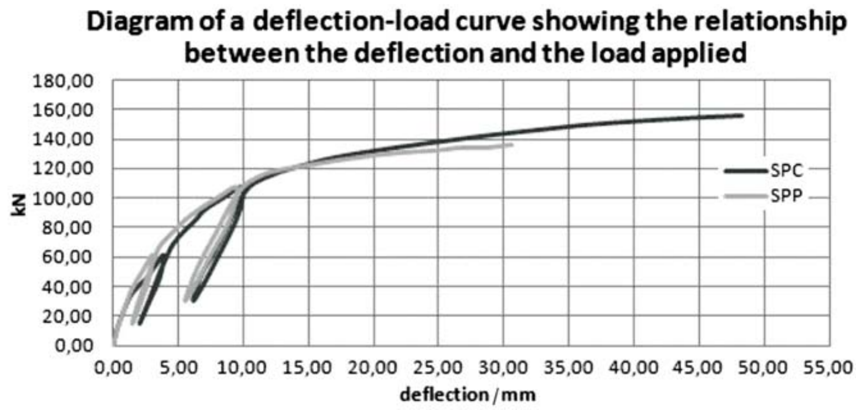

Figure 18 *Diagram of a deflection-load curve showing the relationship between the deflection and the load applied*
Slika 18. *Dijagram krivulje progib-opterećenje koji prikazuje odnos između progiba i primijenjenog opterećenja*

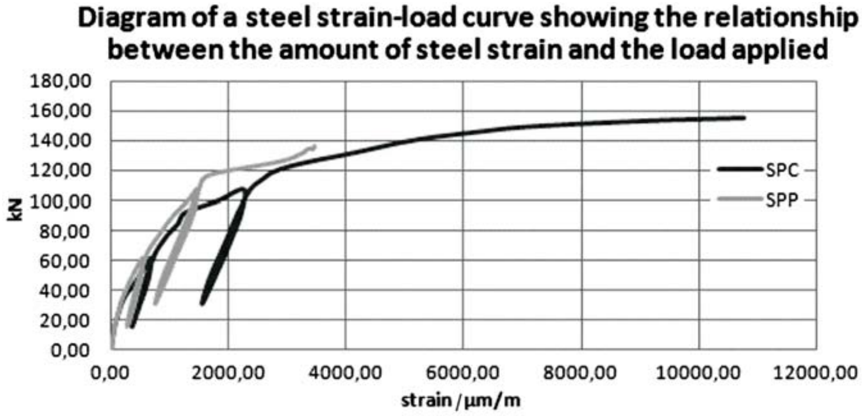

Figure 19 *Diagram of a steel strain-load curve showing the relationship between the amount of steel strain and the load applied*
Slika 19. *Dijagram krivulje deformacija-opterećenje čelika koji prikazuje odnos između iznosa deformacije čelika i primijenjenog opterećenja*

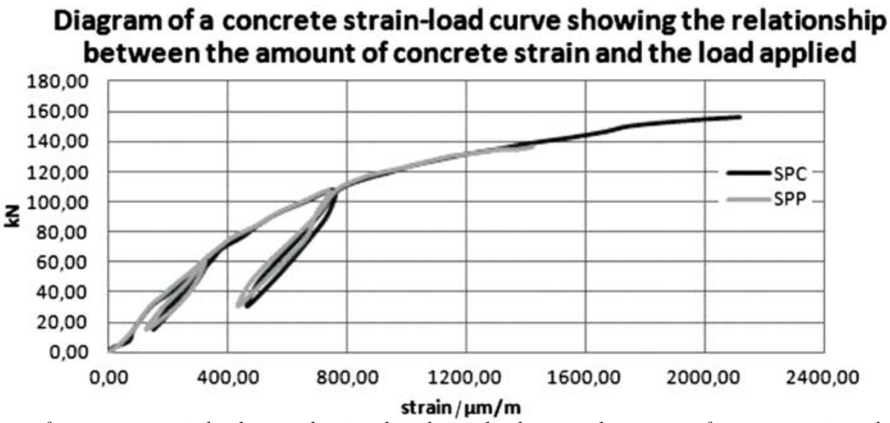

Figure 20 *Diagram of a concrete strain-load curve showing the relationship between the amount of concrete strain and the load applied*
Slika 20. *Dijagram krivulje deformacija-opterećenje betona koji prikazuje odnos između iznosa deformacije betona i primijenjenog opterećenja*

Table 3 *Measured values of ultimate resistance moments in comparison to calculated values*
Tablica 3. *Izmjerene vrijednosti maksimalnih momenata otpora u usporedbi s izračunatim vrijednostima*

Spec.	$F_{u,exp}$ /kN	$M_{u,exp}$ /kN·m	$M_{u,exp,av}$ /kN·m	M_u /kN·m	Diff. /%
SPC-1	123,1	127,4	124,8	108,4	+15
SPC-2	119,2	123,5			
SPC-3	119,2	123,5			
SPP-1	115,4	119,5	122,1	101,6	+20
SPP-2	119,2	123,4			
SPP-3	119,2	123,4			

$F_{u, exp}$ - measured values of maximum forces
$M_{u, exp}$ - experimental values of ultimate resistance moments
$M_{u, exp,av}$ - average values of experimental ultimate resistance moments
M_u - calculated values of ultimate resistance moments

however, it was 20 % for T–sections. Furthermore, it is clear from the correlations shown above that the maximum strains in the specimens with T–sections were lower than those in the specimens with encased I–section beams. That was due to the fact that the effect of slip at the interface between the concrete and steel section that occurred in the specimens with T–section beams was greater than that in the case with I-section beams.

5 Conclusion
Zaključak

The anticipated values of ultimate bending moments in the individual variants of deck bridges were reached in all experiments. The results confirm that the utilization of

T-sections in filler beams is an appropriate solution from the point of view of their bending resistance. Nevertheless, the composite action between steel and concrete in such deck structures remains problematic as the bonding between the two materials is not sufficient. As a result, the research into filler-beam deck bridges with encased T–section beams at the Institute of Structural Engineering of the Civil Engineering Faculty will continue with the emphasis placed on the optimisation of the method of composite action in order to ensure the action between both concrete and steel parts of the section and to meet the requirements placed on such type of bridge.

Acknowledgment
Zahvala

The research was funded by the project ITMS "26220220124" "Research into Filler - beam Deck Bridges with Encased Beams of Modified Sections" and Grant VEGA No. 1/0135/10: "Theoretical and Experimental Analysis of Steel and Composite Structural Members, Joints and Systems under Static and Variable Loading" of the grant agency VEGA of the Ministry of Education of the Slovak Republic and the Slovak Academy of Science.

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