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DEFLECTIONS OF STEEL PLATE-CONCRETE COMPOSITE BEAMS IN THE LIGHT OF EXPERIMENTAL STUDIES

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A method of calculating the deflections of steel plate-concrete composite beams is proposed. In the hybrid work of such beams the properties of reinforced concrete and composite structures are combined. This convention should be followed in considering their ultimate capacity and serviceability limit state. The proposed solution has been verified in experimental studies performed by the authors. Good compatibility of theoretical calculations and experimental results has been obtained. It allows the theoretical solution to be used in the analysis of other cases with parameters different than those of the discussed beams. In the experiments done by the author six beams of total length of 5.20 m and theoretical length of 5,00 m were used. The cross section was rectangular, 0.24 m in width and 0.49 m in height. The steel plate 4.74 m long was 6.10 and 16 mm thick. The diameter of the flexible connectors was 13 mm. Their spacing varied between 80 and 200 mm. Owing to the flexibility of the connectors the interface slip between the steel and concrete parts was included in the theoretical solutions. The results of an in-depth analysis indicate that the deflections of steel plate-concrete composite beams are affected by the compressive strength of concrete and the yield point of steel as well as connectors' diameter and spacing. This impact varies, that of the yield point of the steel from which the plate is made being the highest.

*Keywords**:** deflections, composite beams.*

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1. Introduction

Steel plate-concrete composite beams are structurally (but not geometrically) similar to Möller's beams that were used in bridge engineering in the late 19th c. and early 20th c. Originally designed by Professor Möller from Braunschweig, such structures were built in Germany and in the region of what is now northern Poland [3]. Their construction was discontinued in the 1920s because of their appearance incompatible with the tendency, general in the period, of shaping load bearing structures [3, 11]. Möller proposed the use, innovative at the time, of steel and newly introduced reinforced concrete. The idea was to combine the steel tendon anchored in the upper flange in the support area with a ribbed concrete slab.

Möller's classic beams combine the features of the arch, cable and beam members. The beams' variable depth fitted the curve of the tendon subjected to the load of its own weight. Most frequently it was made from flat bars of width equal to the concrete web. A scheme of such a solution is shown in figure 1 [3]. In the following years Möller's classic structures were not used. They were substituted by structural solutions in which the bent reinforced concrete members were strengthened with flat steels. What made them different, however, was the manner of connecting the flat steels (plates) with the concrete (reinforced concrete) part. Besides, the flat steels entered the interaction only during the transfer of loads that began to operate after the flat steels were bonded with the concrete part. In Möller's structures the interaction took place over the entire load range.

Modern examples of steel plate-concrete composite members include the Wilde Gera arch bridge (cf. Fig. 2). It was built in Germany in 2001 on the A71 highway route near Ilmenan [11]. Its total length is 552 m, width 26 m and height 3.74 m. The span of beams is 42 m. The elevation over the valley is 110 m. What is a characteristic feature of the viaduct is the use of composite cantilevers.

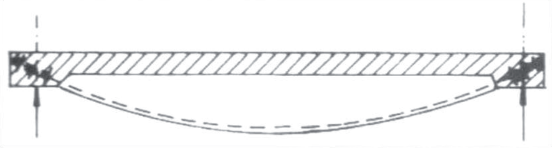

Fig. 1. Structural design of Möller's beam [3].

Fig. 2. The Wilde Gera bridge (http://www.highestbridges.com/wiki/images/f/1WildeGeraBridge.jpg).

Steel plate-concrete composite structures are sometimes treated as RC structures in which rebars fixed in the concrete environment are replaced with steel plate placed outside the concrete section. Such identification of RC members with composite members in question is not justifiable for at least four reasons:

- in RC members under useful loads there is practically no interface slip between rebars and the surrounding concrete,
- concrete shrinkage increases its adhesion to rebars,
- the process of cracking of concrete in tension develops in a different way,
- rebars increase concrete extensibility, which is not observed in a steel plate.

Consequently, the operation of steel plate-concrete is hybrid in character, combining the properties of RC and composite structures. Following this convention, their ultimate states of load bearing capacity and serviceability should be considered. However, the calculation principles quoted in [19], valid for the classic steel-concrete composite members, do not apply.

The aim of the paper is to propose a method of calculating the deflections of steel plate-concrete composite beams, including the interface slip between the steel plate and concrete section. The results of the author's of [11] experimental studies have been used. It should be noted that these studies were performed in the framework of an extensive research programme connected with the doctoral thesis [11].

2. Adopted assumptions

In the analysis of the issue of steel plate-concrete composite beams deflection the validity of the principle of plane sections and the principle of superposition in static calculations over the load range from zero to steel plate plasticization was adopted. In the case of strength calculations the principle of plane sections is valid separately for the steel and concrete parts. The concrete-steel plate interaction is secured by exible connectors of bolt type. The bonding between the The difference in the temperature of the steel and concrete parts was also disregarded, as it has no significant effect because of the small cross-section of the steel plate compared with that of the concrete part [6, 9]. For cases when the thermal effects are included, the data are available in [31].

Owing to connectors' flexibility, in the theoretical solutions the interface slip between the steel plate and concrete part was taken into account. Consequently, the flexural rigidity of the beams in question is lower than the calculated one on the assumption of non-flexible connection, with no slip, so the calculated deflections are higher.

In solving the problem of deflections, the operation of section identical as in the case of RC members was initially assumed [11, 14, 18]. At lower loads (compared with the failure load) this assumption has practically no impact on the quality of calculation results. At higher loads the specificity of steel plate-concrete composite members, including the interface slip between the component parts was taken into account. As a result, the design model was approximated to the real design of the element. The other assumptions are given where they apply.

3. Experimental tests done by the authors

The experimental tests were performed on six beams of the total length of 5.20 m. and the theoretical one of 5.00 m. The cross section was rectangular 0.24 m in width and 0.49 m in height. The steel plate of 4.74 m length was 6.10 and 16 mm thick. The plate ends did not reach the supports to enable the slip. The flexible connectors' diameter was 13 mm. Their spacing varied and was between 80 and 200 mm. The typical longitudinal and cross sections are shown in figure 3. The beams' notation is given in table 1.

Table 1. Beams' notation, their reinforcement and steel plate's thickness.

No.	Beam	s_{con} [mm]	Concrete part	h_s [mm]	d_{sl} [mm]	d_{ss} [mm]	s_{sl} [mm]
1.	BZ-1	160	I	6.0	12	12	160
2.	BZ-2	200	II	6.0	12	12	160
3.	BZ-3	160	I	10.0	16	16	160
4.	BZ-4	120	II	10.0	12	12	100
5.	BZ-5	80	II	16.0	16	16	60
6.	BZ-6	160	II	16.0	16	16	120
s_{con} – connectors' spacing, h_s – steel plate's thickness, d_{sl} – diameter of horizontal bars, d_{ss} – diameter of stirrups, s_{sl} – stirrups' spacing,							

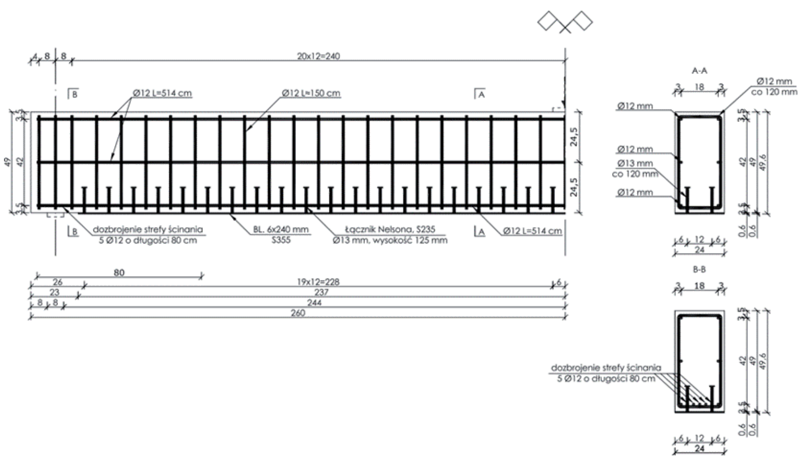

Fig. 3. Dimensions and reinforcement of beams.

The beams were reinforced with six bars 12 or 16 mm in diameter. Four bars were located in the corners, and two at the mid-height of the reinforced concrete section. Moreover, at the supports segments additional horizontal bars were used at the bottom, compensating for the lack of steel plate. All the reinforcing bars were provided with an adequate coating. The reinforcement with stirrups secured the shear strength by at least 50% higher than the transverse force at beam failure load. The idea was that beams' carrying capacity should be determined by the bending moment rather than the transverse force [5, 11].

During the tests the beams were loaded with a concentrated force of the value ranging from zero to that corresponding to the beam's reaching its bending strength. The test stand is shown in figure 4, the location of the essential measuring instrumentation in figure, 5. Both figures illustrate the scheme of loading and support conditions (The optical measurements covered also deflections and strains, and were used in creating stress maps, which are not presented in this paper).

While the beams were subjected to loads measurements were taken of strains and displacements using mechanical, electrical resistance based as well as inductive and optical instrumentation.

The mechanical properties of the materials for the manufacture of the beams were identified each time on the basis of the results of tests performed on six elements. The tests were performed according to standards [20, 21, 22, 23, 24, 25, 26]. The following results were obtained [11]:

– concrete mean compressive strength for the first batch of concrete mix f_c = 57.6 MPa; standard deviation s_c = 1.16 MPa, coefficient of variation v_c = 2.01%,
– concrete mean compressive strength for the second batch of concrete mix f_c = 94.37 MPa, standard deviation s_c = 6.7 MPa, coefficient of variation 7.1%.

Fig.4. The test stand.

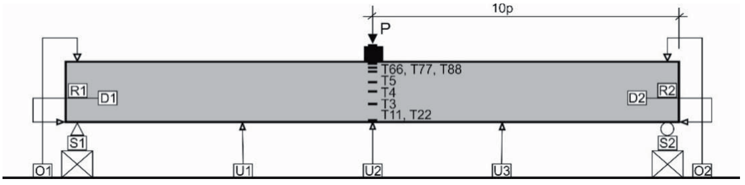

Fig.5. Scheme of test stand and location of measuring instrumentation.

In figure 5 the following symbols were adopted:
– U1, U2, U3 – inductive sensors for recording displacements (range of up to 200 mm);
– S – dynamometer (range of up to 600 kN);
– S1, S2 – force detectors (range of up to 300 kN);

– T – electric resistance strain gauges;

– 01, 02 – dial indicators for measurement of support settlement;

– D1, D2 – sensors for measurement of slip on beams fronts;

– R1, R2 – inclinometers;

– P – measurement points in non-contact vision measurement of slip,

– elasticity modulus of concrete – mean value for the first batch E_c = 35.48 GPa,

– elasticity modulus of concrete – mean value for the second batch E_c = 45.48 GPa,

– yield point of reinforcing bars 12 mm in diameter (steel B500SP) was f_y = 529.1 MPa at standard deviation of s = 2.4 MPa and coefficient of variation of ν = 0.5%, while for the rebars 16 mm in diameter f_y = 559.2 MPa at standard deviation of s = 25.5 MPa and coefficient of variation of ν = 3.8%,

– yield point the steel of the plate was: of thickness 6 mm – 445.0 MPa at extensibility of 30.2, that of thickness of 10 mm – 424.0 MPa at extensibility of 25.0% and the thickness of 16 mm – 420.0 MPa at extensibility of 31.0%,

– strength characteristics of connectors' steel (S235J2+C470) 13 mm in diameter and height of 125 mm were: yield point 515.0 MPa, ultimate limit strength 546.0 MPa, limit extensibility 19.0%.

4. THEORETICAL DEFLECTIONS

For a general case the formula for beam deflection f can be written as:

$$f = \alpha_k \frac{ML^2}{EI} \tag{1}$$

where:

α_k – factor determined by beam static scheme and loading manner,

M – bending moment,

L – beam support (theoretical) span,

E – equivalent modulus of elasticity of material (usually concrete),

I – equivalent moment of inertia of the section reduced to a single material (usually concrete).

In the case of the same section the bending moment varies, determined by the beam cracking state as well as the degree of plasticization of both concrete and steel. Prior to concrete cracking the following can be assumed:

$$EI = E_c I_I \tag{2}$$

where:

E_c – modulus of elasticity of concrete,

I_t – equivalent bending moment of section for phase I, reduced to the concrete section.

Bending moment M_{cr} can be calculated from formula:

$$M_{cr} = \frac{f_{ct} I_I}{J_t} \tag{3}$$

where:

f_{ct} – tensile strength of concrete,

I_t – equivalent moment of inertia in the uncracked state (phase I),

J_t – distance of the centre of gravity (neutral axis) of section from the beam edge in tension.

Concrete cracking is followed by phase II. Then the rigidity of section is lower, and the deflection under the same load is bigger. Phase II lasts until the plate steel reaches the yield point, or until the concrete zone in compression is plasticized (a less frequent case). After the steel plate has been plasticized , phase III takes place.

The equivalent rigidity of the beam operating in phase II can be calculated from formula:

$$EI = B_o = \frac{E_c I_{II}}{\xi\,(1 - \frac{I_{II}}{I_I})} \tag{4}$$

where:

ξ – is a coefficient for the effect of the interaction of concrete zone in tension between the cracks, which can be calculated from formula [11]:

$$\xi = 1 - \left(\frac{M_{cr}}{M}\right)^2 \tag{5}$$

I_{II} – moment of inertia of cracked section; after [11] it can be calculated as for an RC cracked section, taking into account the steel plate section.

In the analysis of deflections of steel plate-concrete composite beams the calculations should be done separately for phases II and III. On steel plate having been plasticized (the beginning of phase III) composite beam curvature ϕ_y can be described with the formula [4, 11]:

$$\emptyset_y = \frac{\varepsilon_y}{h + h_s + x_{II}} \tag{6}$$

where:

ε_y – strain of steel plate on plasticization,

h – height of the entire concrete section (reinforced concrete),

h_s – height of the steel part (thickness of steel plate),

x_{II} – height of compression zone in cracked section (can be calculated as for RC section considering the plate section as if it were a section of reinforcement).

Bending moment M_y at which the steel plate is plasticized is [4, 11]:

$$M_y = \emptyset_y E_c I_{II} \quad (7)$$

Beam curvature in the state prior to the exhaustion of carrying capacity (phase III) can be calculated from formula:

$$\emptyset_{III}(M) = \frac{M}{B} = \frac{M}{E_c I_{III}} \quad (8)$$

where:

I_{III} is the equivalent bending moment of beam section for phase III, reduced to the concrete section.

In phase II of beam operation a minor increment of load results in disproportionately high increase of deflection. Although the load-deflection dependence is non-linear, a simplified linear dependence between the bending moment and beam curvature is usually adopted [2, 4, 6, 10, 11, 12, 13, 27, 28, 29, 30]. Then the following formula can be used [11]:

$$\emptyset(M) = \emptyset_y + \frac{M - M_y}{M_u - M_y}\left(\emptyset_u - \emptyset_y\right) \quad (9)$$

where:

$$\emptyset_u = \frac{\omega \varepsilon_{cu} b f_c}{A_s f_y} \quad (10)$$

ω – coefficient of compressive stress block averaging in the simplified method of calculating beam load carrying capacity,

ε_{cu} – ultimate strain of concrete,

f_c – compressive strength of concrete,

f_y – yield point of steel (at various values of the yield points of steel plate and reinforcement a weighted value can be adopted),

A_s – numerical section of the cross-section of steel plate and reinforcement,

b – width of member's cross-section,

M – operating bending moment,

M_u – bending strength of the composite beam.

The moment of inertia of the composite beam in phase III is:

$$I_{III}(M) = \frac{M}{\emptyset(M)\, E_c} \quad (11)$$

Consequently, the deflection is:

$$f_{III}(M) = \alpha_k \frac{ML^2}{E_c I_{III}(M)} \tag{12}$$

In [11] the impact of the interface slip on the deflection of steel plate-concrete composite beams for phases I and II of the operation of these beams was additionally considered (cf. Fig. 6). The effect of interface slip was taken into account in, *inter alia*, [1, 6, 8, 11, 12, 15, 16, 17]. The additional deflection is [11]:

$$\Delta f = \alpha_k \frac{ML^2}{B_o} \tag{13}$$

where:

$$\xi = \frac{4\beta B_o}{\alpha_k (L-2w) L^2}\left[\frac{L-2w}{4h} + \frac{e^{\alpha w} - e^{\alpha L - \alpha w}}{2\alpha h\,((1+e^{\alpha L}}\right] \tag{14}$$

$$\beta = \frac{A' p d_c}{h} \tag{15}$$

$$\alpha^2 = \frac{\mathrm{k}}{\rho \mathrm{E_s L_0 A'}} \tag{16}$$

$$\frac{1}{A'} = d_c^2 + \frac{I_o}{A_o} \tag{17}$$

p – horizontal spacing of connectors,

k – connector's rigidity

$$d_c = 0{,}5\,(h_c + h_s) \tag{18}$$

h_c – height of concrete part,

h_s – height of steel part (thickness of steel plate),

E_s – modulus of elasticity of steel

$$I_o = I_s + \frac{I_c}{n} \tag{19}$$

I_s – moment of inertia of steel plate,

I_c – moment of inertia of uncracked concrete part

$$n = \frac{E_s}{E_c} \tag{20}$$

E_c – modulus of elasticity of concrete.

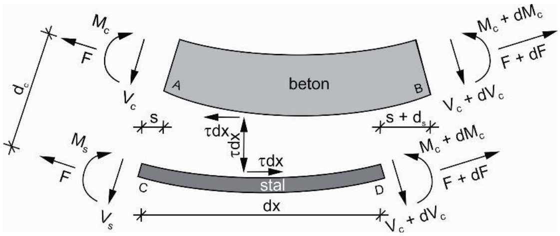

Fig.6. Interface slip between steel and concrete (reinforced concrete) parts.

5. Results of theoretical calculations and experimental studies – comparative analysis

The comparison of the results of calculations versus experimental studies is shown in figures 7 ÷ 12. The figures were plotted on the basis of [11]. All the figures concern the deflections at mid-span of the investigated beams.

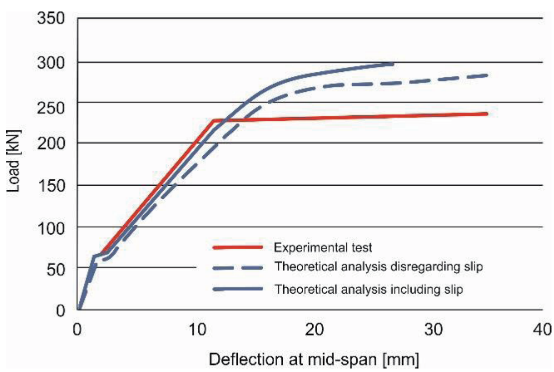

Fig.7. Results of theoretical analyses vs. experimental tests for beam BZ-1.

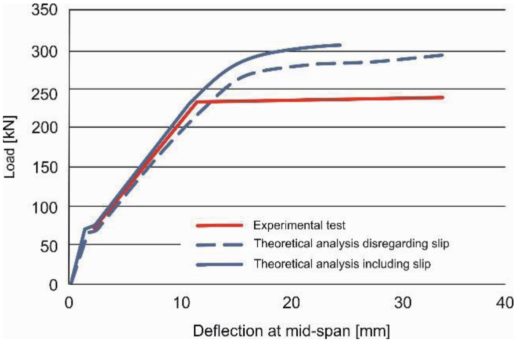

Fig. 8. Results of theoretical analyses vs. experimental tests for beam BZ-2.

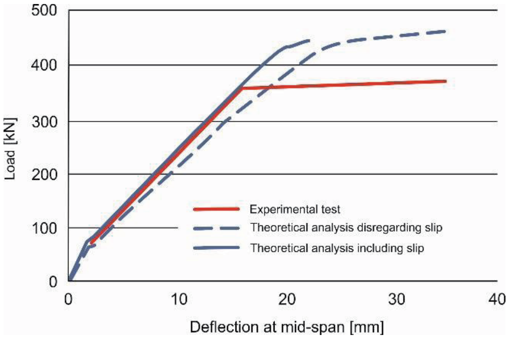

Fig. 9. Results of theoretical analyses vs. experimental tests for beam BZ-3.

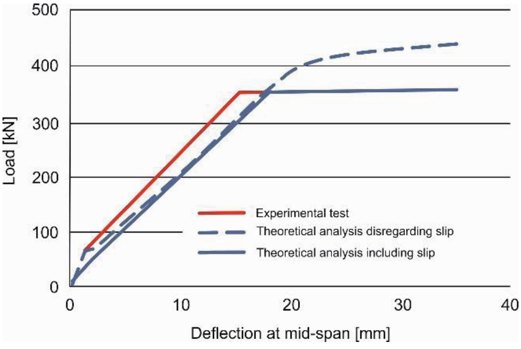

Fig. 10. Results of theoretical analyses vs. experimental tests for beam BZ-4.

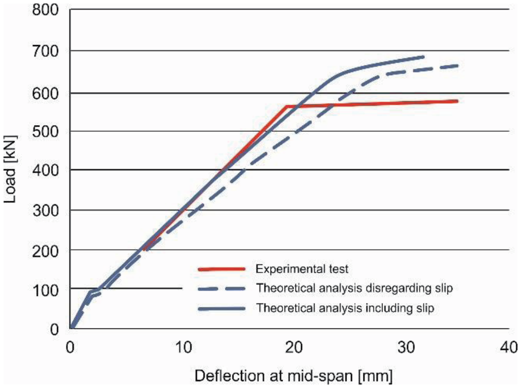

Fig. 11. Results of theoretical analyses vs. experimental tests for beam BZ-5.

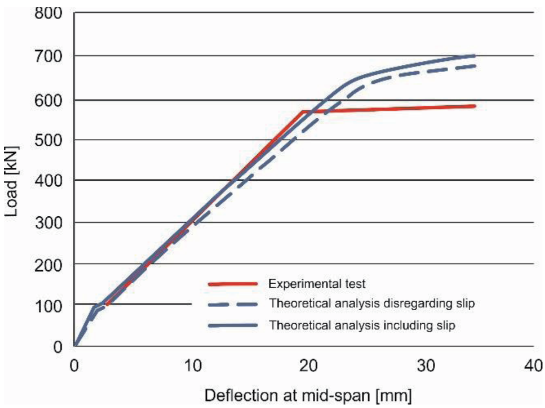

Fig. 12. Results of theoretical analyses vs. experimental tests for beam BZ-6.

6. Discussion and final conclusions

A method of calculating the deflections of steel plate-concrete composite beams is proposed. The solutions were verified empirically employing the results of experimental studies performed by the authors. Good compatibility between theoretical calculation results and those of experimental tests has been obtained. It allows the theoretical solution to be used in the analysis of other cases with parameters different than those of the discussed beams.

Unlike reinforced concrete members strengthened with steel strips, for composite beams the interface slip between the steel and concrete parts has been taken into account. This impact is registered primarily at loading more advanced degrees. It should be added that the slip increases in the direction from the beam-span toward the supports. What has a more significant impact on the deflections, however, is the beam's rigidity in its middle section, which decreases the effect of the slip on deflections.

The results of in-depth analysis indicate that the deflections of steel plate-concrete composite beams are affected by the compressive strength of concrete and the yield point of steel as well as connectors' diameter and spacing. This impact varies, that of the yield point of the steel from which the plate is made being the highest.

References

1. E. Baran, C. Topkaya, An experimental study on channel type shear connectors, Journal of Constructional Steel Research, 74 (2012), pp. 108-117.
2. G. Bradski, Kaehler A.; Learning OpenCV: Computer vision with the OpenCV library, O'Reilly, 2008.
3. M. Cichocki, Mosty systemu Möllera – dziedzictwo sztuki inżynierskiej, Inżynieria i Budownictwo, Vol. 6, 2001.
4. M. T. El-Mihilmy, J. W. Tedesco, Deflection of Reinforced Concrete Beams Strengthened with Fiber-Reinforced Polymer (FRP) Plates, ACI Structural Journal, Vol. 5, 2000, pp. 679-688, 1997.
5. C. Faella, E. Martinelli, E. Nigro, Shear Connection Nonlinearity and Deflections of Steel-Concrete Composite Beams: A Simplified Method, Journal of Structural Engineering, Vol. 129, No. 1, pp. 12-20, January 2003.
6. K. Furtak, Mosty zespolone, Wydawnictwo Naukowe PWN, Warszawa-Kraków, 1999.
7. A. M. Ibrahim, Q. W. Ahmed, Nonlinear analysis of simply supported composite steel-concrete beam, Diyala Journal of Engineering Sciences, Vol. 6, , 107-126, No. 3, 2013.
8. S. Jiang, X. Zeng, D. Zhou: Novel two-node linear composite beam element with both interface and shear deformation into consideration: Formulation and validation, International Journal of Mechanical Sciences, Vol. 85, 110-119, 2014.
9. R. P. Johnson, Composite Structures of Steel and Concrete, Vol. 1. Beams, Columns, Frames and Applications in Building, Crosby Lockwood Staples, 1975.
10. D. Kisała, A Finite Element Analysis of Steel Plate-Concrete Composite Beams Including the Influence of Stiffness of the Connectors on Deflection, Technical Transactions. Civil Engineering, 2-B, 2016.
11. D. Kisała, Nośność na zginanie i ugięcia belek zespolonych typu stalowa blacha-beton, Praca doktorska, Politechnika Krakowska, Kraków, 2017.
12. J. Kubik, Mechanika konstrukcji warstwowych, Wydawnictwo T i T, Opole, 1993.
13. L. Luu, Accuracy enhancement of digital image correlation with B-spline interpolation, Opt Lett. Aug 15, 36 (16): 3070-2, 2011.
14. A. Łapko, B. C. Jensen, Podstawy projektowania i algorytmy obliczeń konstrukcji żelbetowych, Arkady, Warszawa, 2006.
15. J. Nie, C. S. Cai, Steel-Concrete Composite Beams Considering Shear Slip Effects, Journal of Structural Engineering, Journal of Structural Engineering, Vol. 129, No. 4, pp. 495-506, April 2003.
16. J. Nie, J. Fan, C. S. Cai, Stiffness and Deflection of Steel-Concrete Composite Beams under Negative Bending, Journal of Structural Engineering, Vol. 11, 2004
17. J. Nie, J. Zhao, Flexural Behaviour of Steel-Concrete Composite Beauz, Key Engineering Materials, vols. 400-402, pp. 37-42, 2009.
18. PN-EN 1992-1-1, Projektowanie konstrukcji z betonu. Część 1-1: Reguły ogólne i reguły dla budynków.
19. PN-EN 1994-1-1, Projektowanie zespolonych konstrukcji stalowo-betonowych. Część 1-1: Reguły ogólne i reguły dla budynków.
20. PN-EN 10002-1, Metale. Próba rozciągania. Część 1: Metoda badania w temperaturze otoczenia.

21. PN-EN 12390-1, Badania betonu. Część 1: Kształt, wymiary i inne wymagania dotyczące próbek do badania i form.
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26. PN-EN 12390-13, Badania betonu. Część 13: Wyznaczanie siecznego modułu sprężystkości przy ściskaniu.
27. F. D. Queiroz, P. C. G. S. Vellasco, D. A. Nethercot, Finite element modelling of composite beams with full and partial shear connection, Journal of Constructional Steel Research, Vol. 63, pp. 505-521, 2007.
28. G. Ranzi, A. Zona, A steel-concrete composite beam model with partial interaction including the shear deformability of the steel component, Engineering Structures, Vol. 29, 3026-3041, 2007.
29. H. W. Schreier, J. R. Braasch, M. A. Sutton, Systematic errors in digital image correlation caused by intensity interpolation, Opt. Eng., Vol. 39, pp. 2915-2921, 2000.
30. Y. C. Wang, Deflection of Steel-Concrete Composite Beams with Partial Shear Interaction, Journal of Structural Engineering, Vol. 10, 1159-1165, 1998.
31. H. Zobel, Naturalne zjawiska termiczne w mostach, Wydawnictwo Naukowe PWN, Warszawa, 2003.

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Rys. 12. Wyniki analiz teoretycznych a badania eksperymentalne belki BZ-6.

UGIĘCIA BELEK KOMPOZYTOWYCH Z PŁYT STALOWYCH I BETONU W ŚWIETLE STUDIÓW DOŚWIADCZALNYCH

Słowa kluczowe: ugięcia, belki kompozytowe.

STRESZCZENIE:

Zaproponowano metodę obliczania ugięć belek kompozytowych z płyt stalowych i betonu. W pracy hybrydowej takich belek łączy się właściwości konstrukcji żelbetowej i zespolonej. Tej konwencji należy przestrzegać przy rozważaniu ich ostatecznej nośności i stanu granicznego użytkowalności. Zaproponowane rozwiązanie zostało zweryfikowane w badaniach eksperymentalnych autorów. Uzyskano dobrą zgodność obliczeń teoretycznych i wyników eksperymentalnych. Pozwala to na zastosowanie rozwiązania teoretycznego w analizie innych przypadków o parametrach innych niż omawiane belki. W eksperymentach wykonanych przez autora wykorzystano sześć belek o łącznej długości 5,20 mi teoretycznej 5,00 m. Przekrój był prostokątny, miał 0,24 m szerokości i 0,49 m wysokości. Blacha stalowa o długości 4,74 m miała 6,10 i 16 mm grubości. Średnica elastycznych łączników wynosiła 13 mm. Ich rozstaw wahał się od 80 do 200 mm. Ze względu na elastyczność łączników w rozwiązaniach teoretycznych uwzględniono poślizg między elementami stalowymi i betonowymi. Wyniki dogłębnej analizy wskazują, że na ugięcia belek zespolonych stalowo-płytowych ma wpływ wytrzymałość betonu na ściskanie oraz granica plastyczności stali, a także średnica i rozstaw łączników. Wpływ ten jest różny, przy czym granica plastyczności stali, z której wykonana jest blacha, jest najwyższa.

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