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ТЕОРЕТИЧНІ ДОСЛІДЖЕННЯ ДЕФОРМАТИВНОСТІ СТАЛЕЗАЛІЗОБЕТОННХ БАЛОК, ЩО ПОСИЛЕНІ ЗОВНІШНІМ СТАЛЬНИМ АРМУВАННЯМ

ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ ДЕФОРМАТИВНОСТИ СТАЛЕЖЕЛЕЗОБЕТОННЫХ БАЛОК, УСИЛЕННЫХ НАРУЖНЫМ СТАЛЬНЫМ АРМИРОВАНИЕМ

EXPERIMENTAL RESEARCH OF COMPOSITE STEEL BEAMS DEFLECTION, STRENGTHENED BY STEEL REINFORCEMENT

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В статті розглянуті питання теоретичних досліджень деформативності стале залізобетонних балок, посилених зовнішнім сталевим армуванням

В статье рассмотрен вопрос теоретических исследований деформативности сталежелезобетонных балок, усиленных наружным стальным армированием

The given article deals with theoretical researches of composite and reinforced concrete beams deflection strengthened by external steel reinforcement.

Ключові слова:
Сталезалізобетон, підсилення, міцність, стальне зовнішнє армування.
Сталежелезобетон, усиление, прочность, стальное наружное армирование.
Composite and reinforced concrete, strengthening, strength, external steel reinforcement.

Problem definition. Any renovation or reconstruction of building, as a rule, is accompanied by changing of loadings on building structures, and the amendment of theirs primary design schemes.

All these factors lead to the necessity of determination of theirs standard performance residue, decision-making about theirs further destiny like to strength, reconstruct or replace them.

The necessity of strengthening or renewal of building structures appears not only during the reconstruction or technical upgrading but also as a result of premature corrosion or mechanical deterioration.

Loss of serviceableness can appear in the result of the complications or unforeseen by the project changes in the production technology, different damages, defects, etc. This question provokes the high interest to the problem of strengthening and reconstruction of the existing building structures.

Predominantly during the reconstruction process, the strengthening of an element is performed via building-up of cross-section of a structural element. Qualitative adhesion of a structure under strengthening and strengthening material (adhesive) as well as providing of their efficient interaction is an important problem. The above mentioned information argues that the given problem is quite actual and of both practical and theoretical importance.

Literature review. The history of bonded external reinforcement in the UK goes back to 1975with the strengthening of the Quiton Bridges on the M5 motorway.

Switzerland at the Swiss Federal Laboratories for Material Testing and Research (EMPA) (Ladner and Weder). Bending tests were carried out on RC beams 3700mm in length, and the plate width-to-thickness (*b/t*) ratio was studied whilst maintaining the plate cross-sectional area constant. The external plate continued through and beyond the beam supports, with which they were not in contact, for a distance such that the bonded area (48000mm2) was the same for each plate width. The external plate was not bonded to the concrete beam except in the anchorage areas beyond the supports [1-4].

The results clearly showed that thin plating was more effective than thick narrow plating, as noted in studies conducted in the UK. The effective anchorage length *l*a which allowed the plate to reach yield before shear failure adjacent to the bonded areas was found to be inversely proportional to the *b/t* ratio.

Therefore, as *b/t* increased (wide, thin plates), the anchorage length decreased. The ultimate behavior of steel plated RC beams appears to be closely related to the geometry of the plated cross-section. For thin plates, failure usually occurs in flexure. However, if the plate aspect ratio falls below a certain value, separation of the plate from the beam can occur, initiating from the plate end and resulting in the concrete cover being ripped off.

These observations are consistent with the fact that simple elastic longitudinal shear stresses are inversely proportional to the plate width.

Consequently, as the steel plate width decreases, the longitudinal shear stresses increase. In addition, the bending stiffness of the plate increase, thereby increasing the peeling stresses normal to the beam.

Concentrations of shear and normal stress arise at the plate ends of beams subjected to flexure as a result of stiffness incompatibility between the plate and concrete, which can only be accommodated by severe distortion of the adhesive layer.

Methodology for calculation of composite steel beams deflection. The deflection of composite steel beams, strengthened by external steel plates is calculated according to the general rules of structural mechanics depending on the bending and axial deformable characteristics of elements in cross-sections along the length (curvature, angle of deflection) and the bounded plastic deformations criterions [5].

The value of composite beam deflection, strengthened by external steel plate is determined by following equation:

- on the stage of designing

$$f = f_M k_f^{pl} - f_{CP} k_f^{pl} \tag{1}$$

- on the stage of reinforcement

$$f = f_O k_f^{pl} + f_M k_f^{pl} - f_{CP} k_f^{pl} \tag{2}$$

where: f_M -deflection value of the beam from the action of external load (design bending moment M – on the stage of designing, or M-M_0-on the stage of reinforcement), f_0-value of initial (existing) deflection of the beam (bending moment M_0), f_{CP} - of deflection of the beam from steel plate action of P_o, k_f^{pl} - coefficient which intends dependence of beam deflection under development of strains at the bottom fiber of the beam cross-section, which exceed the criterions of bounded plastic deformations $\varepsilon_{\max} \geq 0.001$ (elastic and plastic state of beam cross-section) and in case when the development of strains at the bottom fiber of the beam cross-section do not exceed the criterions of bounded plastic deformations $\varepsilon_{\max} < 0.001$ (plastic state of design cross-section of the beam).

For freely supported beams with constant cross-section along the whole length of the element, values of deflection f_M and f_0 are determined, by the following equation, assumed that the curvature is changed proportionally to the value of bending moment:

$$f_M = S \cdot l^2 \left(\frac{1}{r}\right) \tag{3}$$

where: S - the coefficient, which is determined by the rules of structural mechanics, depending on the design scheme of element and type of external load, $\frac{1}{r}$ - curvature in cross-section with the largest bending moment, which is used for deflection determination, l – design span of the beam.

For determination of deflection of freely supported beam, value of coefficient S , under the action of two symmetrically concentrated forces on the distance a, is defined by following equation:

$$S = \frac{1}{8} - \frac{a^2}{6l^2} \tag{4}$$

The curvature $\frac{1}{r}$ of composite steel beams under the action of external load, except stress from steel plate is determined by following equation:

$$\frac{1}{r} = \frac{M}{0.85 \cdot I_{red} E_c} \tag{5}$$

where: M - design bending moment M or initial moment M_0, which acts at the design cross-section of the beam, 0.85 - coefficient, which is taken into account the development of non-elastic deformations of concrete under the action of short-term load and 0.04 is assumed, under the action of constant and long-term loads, E_c – elastic modulus of concrete, I_{red} – moment of inertia of design cross-section of the beam, which is adduced to concrete cross-section and where the tensile zone is excluded.

Experimental set-up. To determine the bearing capacity and deflection of the composite steel structures, strengthened by external steel plates, as well as its influence the strength and deformability, there were designed and manufactured the following specimens:

- Composite steel c elements (beams), using different concrete mixtures of different strength class;

By the way of the external load application, specimens of each type are divided into 2 series in accordance to the accepted geometrical characteristics of experimental specimens. Series (A) were beams without reinforcement, and series (B) with external steel reinforcement.

The specimens of each series, in their turn, are differ one from another by the availability and type of the adhesive-bonded joint.

Therefore, the basic factors are: the geometrical characteristics of structure, concrete strength class, and availability of adhesive-bonded joint. So, all these distinctions can influence the adhesive joint's bearing capacity value, as well as the strength and deformability of experimental specimens (beams).

During experimental investigations procedure it is planned to study the dependence of bearing capacity and deflection of composite steel beams from availability and type of the adhesive and way of attachment of steel reinforced plates.

The Electronic Universal Testing Machine (MS-100) with maximum capacity of 500*kN* is used for normal load test of all specimens. A view of the experimental set-up and the arrangement of the measurement devices are shown in Fig. 1. Beams are tested under four-point loading.

The load applied to the mid-point of the reaction beam is divided symmetrically into two concentrated loads and applied to the specimens. The ratio of the shear span length (800 mm) to the effective depth of the beam (200 mm) and is the same for all specimens. Specimens are tested under monotonic loading to failure Fig. 1.

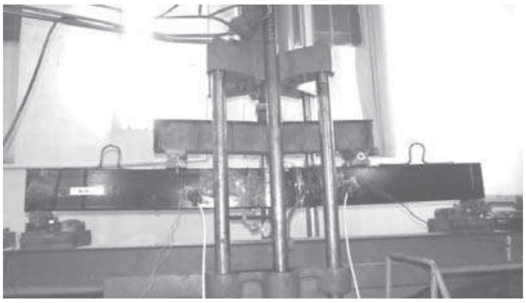

Fig. 1. A view of the experimental set-up and the arrangement of the measurement device

During the experimentation there were used the next measuring instruments: strain gauges, monometers for loading value control, and Linear Variable Differential Transformers (LVDT's) to measure mid-span deflection of the beam.

Conclusions. This part of article describes the experimental results of series A (without reinforcement) and series B (with reinforcement) composite steel beams. All the beams are designed to fail in shear even after strengthening with steel plates. The ratio of shear span to effective depth is kept constant throughout the testing of all the beams. The load-deflection behavior and ultimate load capacity for shear is observed throughout the testing to failure of beams.

The typical deflection for composite steel beam strengthened with steel plate is shown in fig.2.

Fig. 2. The typical deflection and cracking pattern of composite steel beam strengthened with steel plate

The cracking pattern of composite steel beam strengthened with steel plate is shown in fig.3.

Fig. 3. The cracking pattern of composite steel beam strengthened with steel plate

The discussion is carried out through comparison between the results determined by the analytical method with those experimentally obtained.

The load-deflection curve of all the beams is shown in fig.4. It is considered that the deflection of beams increased from the original beam B-5-1.

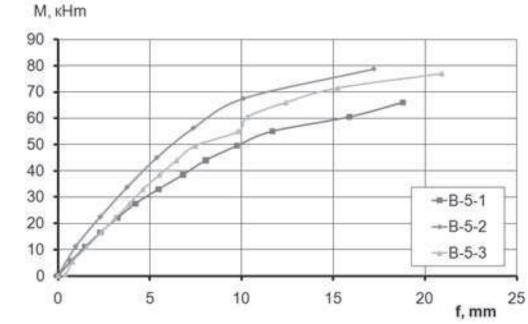

Fig. 4. The load-deflection curve of all the beams

However the beams with added plates show more ductility so that the ductility is observed to decrease as the reinforcement ratio increased Fig.5.

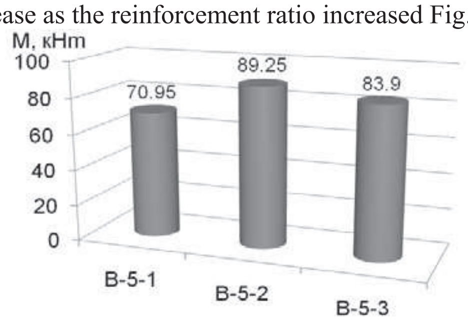

Fig. 5. The load-bearing capacity of composite steel beams

The load-bearing capacity of specimens beam strengthened with steel plate is shown in fig.5.

The effectiveness of reinforcement of composite steel beams with steel plates in tensile zone is depended on the type of joint and steel plate thickness. From the obtained results it can be concluded that load-bearing capacity of beams, strengthened with steel plate is increased on 20% comparing with original beam.

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