Збірник наукових праць. Галузеве машинобудування, будівництво
Academic journal. Industrial Machine Building, Civil Engineering
http://journals.nupp.edu.ua/znp
https://doi.org/10.26906/znp.2025.64.4136

UDC 624.071,32

Anna Azizova*
National University «Yuri Kondratyuk Poltava Polytechnic»
https://orcid.org/0000-0002-6138-2757

Dmytro Ovsii
National University «Yuri Kondratyuk Poltava Polytechnic»
https://orcid.org/0000-0001-7007-185

Oleksandr Semko
National University «Yuri Kondratyuk Poltava Polytechnic»
https://orcid.org/0000-0002-2455-752X

Mykola Ovsii
Private enterprise "BUDEKSPERTYZA"

Strength and force distribution of lap-welded composite longitudinal reinforcing bars formed during strengthening of reinforced concrete beam elements by increasing the cross-section in the tension zone

Abstract. The article experimentally investigated the strength and stress-strain state of eccentrically stretched specimens from welded overlapped longitudinal reinforcing bars, which have cross-sections varying in length and are interconnected by electric arc welding. The strength of reinforcing bars of a composite cross-section was compared with the strength of individual centrally stretched reinforcing bars. As a result of the experiment, the influence of the main factors on the strength of the bars was investigated: electric arc welding; stress concentration; eccentricity of the application of longitudinal tensile force, as well as the distribution of forces in the sections of each element along the length of the composite reinforcing bar-sample

Keywords: reinforced concrete beams, strengthening, additional longitudinal reinforcement, cross-sections, reinforcing bars, welding connections, tensile strength

*Corresponding author E-mail: galinska@i.ua

Received: 20.02.2025 Accepted: 06.05.2025 Published: 26.06.2025

Introduction.

As a result of long-term service of reinforced concrete beam structural elements in aggressive environments, surface corrosion damage develops in the cross-sections of their longitudinal tensile reinforcement, leading to a decrease in both load-bearing capacity and deformability. To eliminate physical deterioration and restore the load-bearing capacity of reinforced concrete beam elements, it is necessary to implement repair or strengthening measures for their damaged sections. According to Clause 6.4.2 of DBN B V.3.1-2:2016 [1], one of the methods of strengthening reinforced concrete beam structures and elements is the partial enlargement of the longitudinal reinforcement area in their tensile zone by welding additional reinforcing bars to the existing reinforcement using intermittent welds.

In studies [2–7], researchers Rymar Ya. V., Blikharskyi Z. Ya., Khmil R. Ye., Kovalchuk B. F., Kholod P. F., and Tytarenko R. Yu. experimentally investigated reinforced concrete beams strengthened with additional reinforcing bars either by directly welding them to the existing longitudinal reinforcement or by connecting them with short reinforcing segments (short links), numbering from two to four along the specimen length. Figures 1 and 2 show the appearance of selected reinforced concrete beams during testing on the stand.

In [2], the strengthening of reinforced concrete beams was carried out at load levels η=0, 0,3, 0,5, and 0,75 of the ultimate bending moment, when the stresses in the existing longitudinal reinforcement reached the yield strength. The strengthening effect resulted in a 30%-45% increase in load-bearing capacity compared with reference specimens without strengthening. The load-bearing capacity of the beams was significantly affected by the load level at which strengthening was performed: in the absence of load, the capacity was maximal, while under maximum loading during strengthening, the capacity was minimal [2].

In study [7], strengthening of reinforced concrete beams at a load level equal to half of the cracking moment ($\eta=0,5\times M_{cr}$) using additional non-prestressed reinforcement increased their flexural strength by 89%, while the use of prestressed additional reinforcement increased it by 93%.

In the work of B. A. Boyarchuk [8], two strengthening cases were considered: without prior loading, and strengthening under loading with an effort of 0,6-0,7 of the ultimate load. Compared to unstrengthened specimens, all strengthening methods increased the load-bearing capacity by 30-60%, and the cracking resistance by approximately 30% [7].

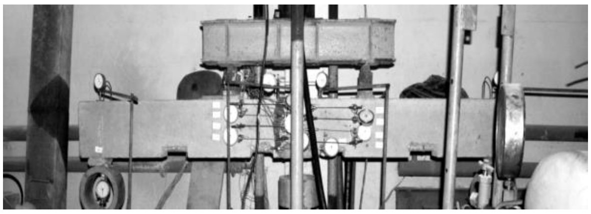


Figure 1 – The appearance of reinforced concrete beams from series 2 and beams from series 3, which were strengthened under load by welding directly to the existing longitudinal reinforcement or to short reinforcement segments (short bars) (top photo), tested in study [2] by researcher Ya. Rymar.

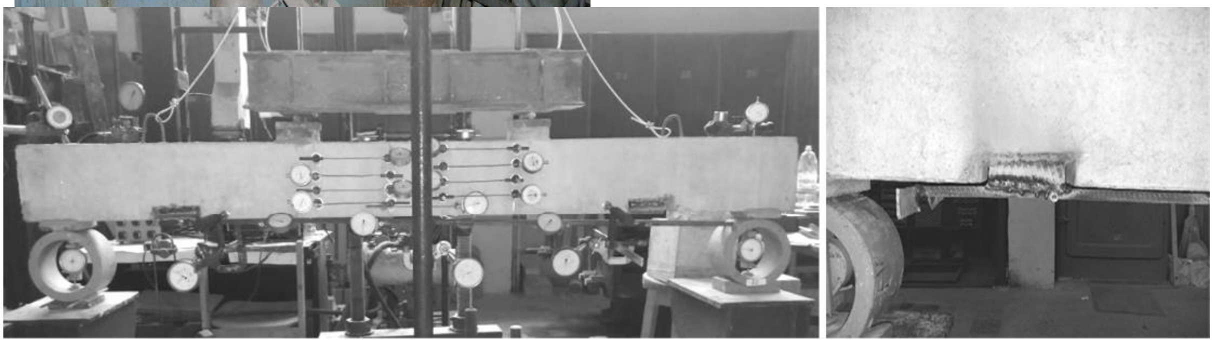


Figure 2 – The appearance of one reinforced concrete beam from the series strengthened under load using short reinforcement segments (short bars), which were tested in study [6] by researchers B. Kovalchuk, Ya. Rymar*, Z. Blikharskyy, and P. Kholod.

In studies [9, 10], experimental investigations of the flexural capacity of reinforced concrete beams strengthened with external steel bars were conducted by Gul A., Alam B., Khan F. A., Badrashi Y. I., Shahzada K., et al. Six reinforced concrete beams were strengthened by attaching external steel bars to the bottom layer of shear reinforcement using welding, while two specimens without external steel bars were tested as control beams. The test results of the strengthened specimens demonstrated, in comparison with the control beams, a significant improvement in flexural capacity due to the attachment of external bars [9, 10].

The analysis of the stress–strain state of tested reinforced concrete beam specimens, presented in [2, 11], identified several factors influencing the failure mode and overall load-bearing capacity. The flexural and shear strength of beam cross-sections was affected by the following factors, arising from the arc welding of additional bars–shorter than the beam span–to the existing longitudinal reinforcement bars in the lower tensile zone:

– a reduction in the strength of the longer reinforcement bar in the region near its welded joint with the shorter bar, associated with the arc welding process;

– an uneven distribution of the tensile force (N_s) along the cross-sections of the longer and shorter bars over the beam span;

– a stress gradient (stress concentration) in the longer bar near the end of the shorter bar, caused by the action of an additional bending moment ($M_s=N_s\times e$), leading certain cross-sections to prematurely enter the elastic-plastic or fully plastic stage. Here, N_s denotes the longitudinal force applied to the longer bar, and e is the eccentricity of the longitudinal force Ns relative to the centroid of the composite reinforcement cross-section.

With an increase in eccentricity (e) of the applied longitudinal force N_s, directly related to the use of additional connecting elements (short reinforcing segments of various diameters), the elastic–plastic stage occurs earlier in the cross-section near the joint of the additional bar rather than at midspan. The onset of the elastic–plastic stage in the beam cross-section leads to the formation and propagation of cracks in the support region under shear or at midspan under bending, followed by the crushing of the compressed concrete zone above (see photos of beam specimen failure modes in [2], Fig. 3).

With effective reinforcement of beam cross-sections and an optimal location for connecting the ends of the additional reinforcing bar within the span, the failure of a reinforced concrete beam may occur simultaneously due to both flexural and shear capacity loss. This manifests in the concurrent appearance of critical inclined and vertical cracks, accompanied by the crushing of the compressed concrete zone in the corresponding cross-sections.

In study [2], Ya. Rymar, based on a comparison of theoretical strength values of beams with experimental results, established that theoretical predictions exceeded the experimental data by up to 6.0%. Such a discrepancy is unacceptable from the perspective of ensuring a safety margin in the design of beams strengthened under load with additional reinforcement. To provide sufficient strength when designing the strengthening of beams by enlarging the cross-section with additional reinforcement, Ya. Rymar [2] proposed introducing a reinforcement working condition factor within the range γ_{sr}=0,5…1,0, This coefficient accounts for the load level, the type of welded connection, and the ratio of reinforcement bar areas.

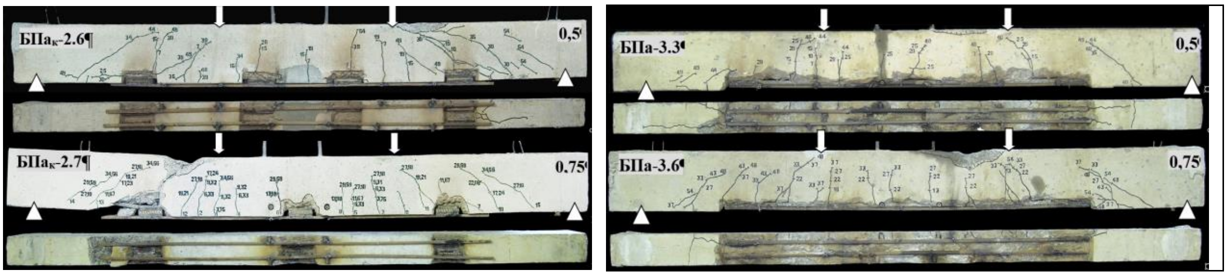


Figure 3 – Failure patterns of reinforced concrete beams from Series 2 and Series 3, which were strengthened under sustained loading at stress levels η = 0,5 and η = 0,75 and tested by researcher Ya. Rymar in study [2]. The failure of Series 2 beams (left photo), strengthened with additional reinforcing bars welded in the span using short bar segments ("short bars"), occurred in the support zones due to loss of shear capacity. The failure of Series 3 beams (right photo), strengthened with additional reinforcing bars directly welded to the existing longitudinal reinforcement of the beam specimens by intermittent welds, occurred in the span due to flexural failure of the cross-sections.

Review of the research sources and publications

A considerable number of scientific studies have been devoted to the investigation of the strength of welded joints of reinforcement bars. Depending on the research objectives, these studies can be classified into several directions: investigations into the influence of the chemical composition of reinforcing steels on the strength of welded joints [12, 13, 14, 15]; studies examining the effect of welding technology under various service conditions and environmental factors on the strength of welded bar connections [12, 13, 14, 15]; and works focused on the influence of structural design solutions on the strength of joints of reinforcement bars of the same or different steel grades [16-20].

In study [12], researchers T. Moustafa, W. Khalifa, M. R. El-Koussy, and N. Abd El-Reheem investigated the effect of metallurgical structure and chemical composition on the effective weld length of hot-rolled reinforcing bars and Tempcore rods, as well as the properties of their lap and butt welds. Experimental results indicated a negligible effect of welding on the yield strength of hot-rolled bars (a reduction of up to 1%), while Tempcore bars exhibited a 4% decrease in yield strength. Moreover, ductility was reduced by more than 50% in all welded specimens [12].

In the article [13], O. Falodun, S. Oke, and M. Bodunrin conducted a critical analysis of the influence of residual stresses and post-weld heat treatment on the microstructural evolution, mechanical properties, and corrosion resistance of welded joints in carbon steel. The review of existing studies revealed the following effects of residual stresses in welded joints of carbon steel and their adjacent areas: deterioration of structural integrity due to non-uniform thermal expansion, contraction, and phase transformations (thermal gradients during welding); localization of tensile and compressive stress fields, exacerbated by joint geometry, material heterogeneity, and external constraints; increased susceptibility of welded structures to fatigue, brittle fracture, and stress corrosion cracking under significant (high) levels of residual stress, particularly in the heat-affected zone; and exceeding of the material's yield strength, leading to critical stress concentrations that reduce the service life of welded joints [13].

In the dissertation work of Sk Basiruddin MB [15], a microstructural investigation was conducted to examine the effect of thermomechanical treatment on reinforcement bars with diameters of Ø10, Ø12, and Ø16 mm containing relatively higher carbon content (~0,2…0,25 wt.%). The study revealed the presence of three distinct microstructural regions across the cross-sections of all examined bars: the outer rim zone, the transition zone, and the inner core region. The microstructure in the rim zone was composed of tempered martensite. In the transition zone, a significant proportion of bainite (≈50%) was observed together with ferrite, pearlite (mostly degenerated pearlite), and martensite. High-resolution cross-sectional images indicated the predominance of granular bainite and upper bainite within this region. Degenerated pearlite and bainite were also found in the core, alongside ferrite and lamellar pearlite. The microstructural parameters obtained from the rim and core regions were characterized in detail and presented in Table 7.2 of [15].

The reinforcement bars with a diameter of Ø16 mm exhibited the smallest martensitic packet size in the rim, the lowest ferrite fraction, and the highest proportion of degenerated pearlite and lower bainite in the core. The ferrite present in the core region was predominantly quasi-polygonal and of smaller size (≈7 μm), along with approximately 3–5% Widmanstätten ferrite. These characteristics may result from the higher intensity of water quenching during the thermomechanical treatment of Ø16 mm bars. In contrast, the core microstructure of Ø12 mm bars was dominated by quasi-polygonal ferrite and lamellar pearlite. The core of Ø10 mm bars consisted of polygonal ferrite formed along prior austenite grain boundaries, lamellar pearlite, and upper bainite [15].

In the article [16], K. Kubicki conducted an analysis to identify the advantages and disadvantages of lap and strip joints of reinforcement bars connected by longitudinal fillet welds in comparison with butt joints. A drawback of lap joints is the non-axial transfer of longitudinal forces between the connected bars. Furthermore, such joints cannot always be applied due to insufficient space for proper concrete cover of the reinforcement. Butt joints, on the other hand, are more difficult to execute and therefore require a higher level of welder expertise compared to joints with fillet welds. However, they offer several advantages: they occupy less space, require significantly fewer materials, provide sufficient load-bearing capacity, and allow axial transfer of tensile forces without eccentricity [16].

In the study [17], Issa C. A. and Nasr A. investigated the effect of different lap-weld joint techniques on the tensile strength of reinforcement bars with diameters of Ø12, Ø14, and Ø16 mm. The results showed that bar failure in welded joints occurred in the area located at a distance of 1–2 diameters from the start of the weld, thus ensuring the reliability and effectiveness of bar splicing along the full length of the lap weld [17].

In the research by Ahmed Ghafur [18], the influence of the welding process on reinforcement properties was studied through testing 48 samples with five different bar diameters, divided into six groups. Various parameters were analyzed in different welded joints [18], including: the properties of non-welded bars; the strength, ductility, and density of the weld metal; the reduction of strength and ductility due to high heating temperatures in lap and cross welds; the effect of welding on the bending properties of the bars; the performance of different types of joints; the characteristics of three types of welded grooves on bar ends in butt joints; as well as the location and modes of failure. The experimental results [18] demonstrated the following:

- the strength of the weld metal is directly related to the size and thickness of the weld. When the weld area was increased by 2 and 10 times, the yield strength decreased by 13% and 33%, respectively. The density of the weld metal was similar to that of carbon steel bars, approximately ρ=7850 kg/m³.
- the strength and elongation of the weld metal and the bar cross-sections near the weld decreased by 10-40% and 30-60%, respectively, depending on the weld size. To avoid catastrophic failure of reinforced concrete structures, the stress level in welded bars should not exceed 0,5 of the elastic limit (σ_t) of the bars.
- technical welding of cruciform joints of reinforcement bars had a minor effect on the strength of the transverse bars, but measures must be taken to preserve their ductility, since their elongation may be reduced by up to 40%. Therefore, it is recommended to minimize the effect of high temperature during welding to the lowest permissible level.
- cold bending of welded bars should be avoided, especially for bars with diameters of Ø16 mm or larger. Alternatively, bars should be preheated to at least T=160°C before bending.
- groove welds should be avoided, as these welds do not ensure adequate elongation, which may decrease by 70-90%. Groove welds tend to result in more brittle failure than bars made of ductile steel.

In the article [20], V. Scholz and B. Robers conducted a study of welded joints of reinforcing bars of two steel grades: 300E, characterized by a minimum yield strength σ_y=300 MPa and a minimum uniform elongation of 15%, and 500E, with a minimum yield strength σ_y=500 MPa and a uniform elongation of 10%. The tested configurations of bar joints included: a double V-shaped butt joint; a double beveled butt joint; a longitudinal eccentric lap joint; a longitudinal symmetrical butt joint with splice plates made of two short bars; a longitudinal butt joint with a flat backing plate made of steel strip; and a longitudinal butt joint with a backing plate made of angle steel.; A T-shaped joint with external fillet welds; a T-shaped butt joint with full penetration; a cross-shaped joint with double external fillet welds; and a T-shaped joint with internal penetration welds were tested. The test results indicate a clear influence of the steel strength class, the diameter of the tested bars, and the joint symmetry on the variation of their initial mechanical properties. Thus, all 300E bars demonstrated consistent strength and ductility values across all tested joint configurations, whereas the 500E bars exhibited satisfactory results only for the longitudinal symmetrical butt joint with two additional short bars used for welding. In the case of asymmetrical joints made of 500E bars, the minimum yield strength was achieved; however, in certain instances, the tensile strength was 10-15% lower than the original value [20]. The longitudinal butt joint of bars with a backing plate made of rolled angle steel satisfied the tensile yield ratio requirements for both tested diameters; however, the ductility of bars with a diameter of Ø25 mm was lower, with a measured total elongation of 5% [20]. Similar results were obtained for the longitudinal butt joint of bars with a flat backing plate made of steel strip, where both the tensile-to-yield strength ratio and the elongation were lower for the Ø25 mm bars [20]. In asymmetrical longitudinal lap joints, the development of a bending moment due to the eccentric alignment of the bars led to the formation of cracks at the beginning and end of the welds. This effect was particularly pronounced in joints made of higher-strength 500E bars. In these cases, the welds failed at stress levels above the required yield strength but below the ultimate tensile load, exhibiting a brittle fracture behavior [20].

Longitudinal bar joints using angle or flat plate backing showed better performance than the standard lap joint configuration; however, particularly for larger-diameter bars, the size of the angle or plate becomes critical to prevent joint rotation [20]. The authors of [20] emphasize that all the above-mentioned factors must be taken into account when designing reinforcing bar joints for structures located in seismic regions.

In the article [21], Ch. Apostolopoulos, P. Savvopoulos, and L. Dimitrov conducted a numerical simulation study to assess the reliability and behavior of welded lap joints of reinforcing bars under loads within the elastic range up to the yield point of the reinforcing steel. Welded lap joints of reinforcing bars are prone to eccentric tension and potential damage to the surrounding concrete due to their kinematic behavior and significant end displacements within the joint. In the elastic tension stage, stresses exceeding the yield strength of the reinforcing steel were observed in areas near the bar ends of the lap joints. The authors of [21] emphasize the necessity of reassessing and improving existing design codes to account for the complex behavior of welded lap joints under tension or compression. They also highlight the need for further research into welding methods for reinforcing bar joints that would enhance and ensure the safe performance of reinforced concrete structures, particularly during strengthening with additional reinforcement elements.

Definition of unsolved aspectsof the problem

As a result of summarizing the findings presented in the aforementioned publications, the main factors influencing the strength characteristics and reliability of welded joints of reinforcing steel bars can be identified as follows:

- The mechanical properties of welded joints in hot-rolled reinforcing bars are influenced by thermal contact heating, the intensity of which directly depends on the welding method and mode, the thickness of the welded metal, and the welding configuration. Within the heat-affected zone (HAZ), several subregions can be distinguished, where uneven temperature distribution causes different structural changes in the steel depending on temperature levels, namely: aging at T=200…300°C; tempering at T=250…650°C; incomplete recrystallization at approximately T=700-800°C; normalization at T=840-1000°C; overheating at T=1000–1250°C; and melting of the steel near the weld seam at T>1250°C.
- During heating in the range of T=700-900°C, the ferrite and pearlite structure of the steel transforms into austenite. At T=900–1000°C, rapid growth of austenitic grains begins, with an average diameter near the weld zone of δ = 0,1-0,15 mm for manual arc welding; δ=0,2-0,3 mm for single-pass submerged arc welding of steels with a thickness t=15-20 mm; and δ=0,4-0,8 mm for electroslag welding of thick steels t=100-200 mm. In regions with temperatures near or below T=900°C, the austenitic grain size decreases to a minimum. At temperatures above T=1250°C, the metal structure changes drastically, reducing the quality of the welded joint.
- As a result of thermal effects in welded joints of reinforcing steels, depending on the heating temperature, the yield strength (σ_T ($\sigma_{0,2}$)), ultimate tensile strength (σ_B), elongation at break (δ_5), and initial modulus of elasticity (E_s) may decrease, leading to reduced ductility and increased brittleness. For hot-rolled reinforcing steels of grades A240 C (A-I), A400 C (A-III), and A500 C, a monotonic decrease in yield strength is observed when heated to T=100°C and above: at T=400°C, the reduction can reach up to 50% of the initial value, and at T=500°C – up to 65%.
- The resistance of welded joints to the formation of hot and cold cracks depends on their chemical composition and the crystallization conditions of the weld metal, which are determined by: the type of electrodes, fluxes, and shielding gases; the type of assembly joint; welding parameters; the thickness of the welded elements; the rigidity of the joint; and the thermal conditions during welding. The effect of chemical composition on the weldability of reinforcing bars is defined by their carbon equivalent (CE). Steels with CE=0,2…0,35% are well weldable. When the carbon equivalent exceeds CE = 0,45…0,5%, hot and cold microcracks may form in the heat-affected zones, which necessitates preheating of the joint elements prior to welding.
- The strength characteristics of welded joints in reinforcing steels are also influenced by the structural configuration of the joint, which affects the stress concentration factor and can reduce both the static and fatigue strength of bars near the welded area.

The above-mentioned factors must be taken into account when designing reinforcement elements for strengthened reinforced concrete beams, as they directly affect the stress–strain state and the load-bearing capacity of the structure at failure.

Problem statement

The purpose of this study is to experimentally investigate the tensile strength, stress distribution, and failure behavior of lap-welded composite reinforcing bars with various structural configurations under tensile loading that simulates the prestressing stage.

The experimental program was carried out to determine the influence of the factors mentioned in the introduction on the strength of eccentrically tensioned lap-welded composite reinforcing bars, compared to the strength of centrally tensioned reference bars, for one of the most commonly used classes of reinforcing steel.

Basic material and results

To study the effect of stress concentration and the weakened metal zone in the cross-section of the longer reinforcing bar near the fracture point of the shorter one – where the bars were joined by arc welding during the strengthening of reinforced concrete beams by increasing the cross-sectional area of longitudinal reinforcement in the tensile zone –sixteen composite reinforcing bar specimens with different structural configurations were designed and tested, grouped into six series (I-VI) (see Fig. 4).

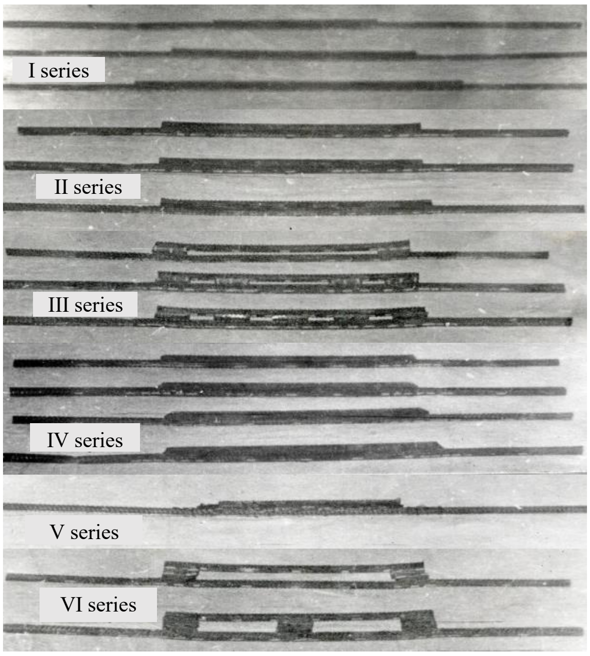
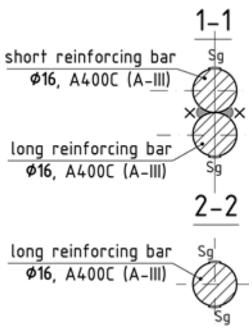
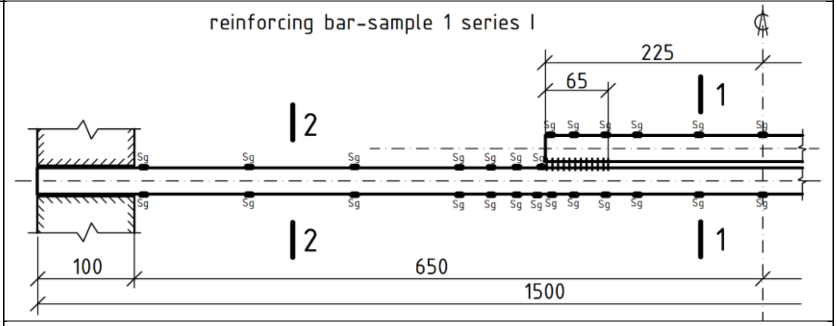
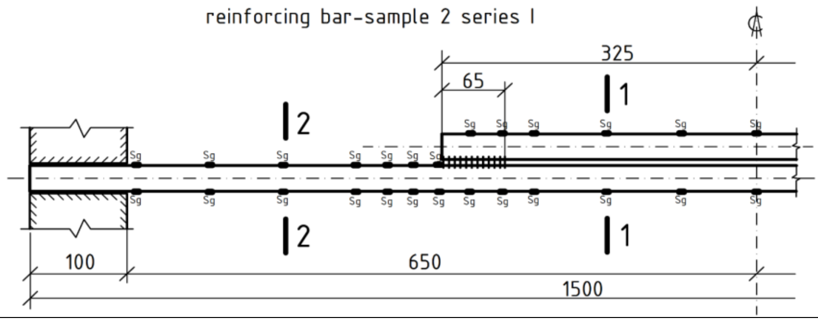
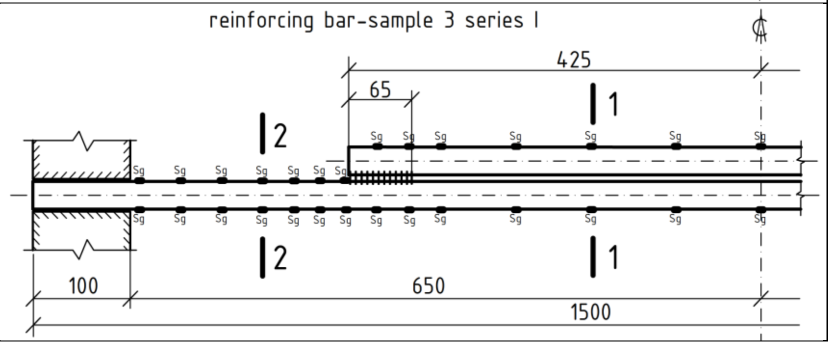


Figure 4 – General view of the composite reinforcing bar specimens of series I–VI that were tested.

Table 1 – Design solutions and dimensions of reinforcing bars samples according to series I

Batch and sample number		Design solutions and dimensions of reinforcing bars-samples according to series I. Locations of strain gauges of type PKB-5-100 in sections along the length of the bars-samples	
		Cross sections	Scheme of the design solution of the reinforcing bar sample
I	1		
	2		
	3		

The experimental composite reinforcing bar specimens consisted of a longer reinforcing bar to which a shorter bar was symmetrically attached with respect to its midpoint using either intermittent welds or a two-component epoxy adhesive. The length of the longer bar was L=1,5 m for series I specimens and L=1,0 m for series II-VI. The length of the shorter bar in the specimens varied from l = 0,3…0,65×L of the longer one.

The structural configurations and dimensions of the reinforcing bar specimens for series I-VI are presented in Tables 1-5. The constituent elements of the specimens were made of reinforcing steel grade A-III (A400C) with a diameter of d=16 mm. The welding in series I-IV and VI specimens was performed using E-50-A type electrodes (UONI) with a diameter of d_e=3 mm. The length of the double-sided intermittent welds along the connection zones was taken as four times the diameter of the smaller reinforcing bar being joined. The weld metal deposition in the end welds was carried out from the fracture point of the shorter bar toward its end, with the weld starting 2-5 mm away from the fracture point. In the series V specimens, the bars were bonded together along their entire length using a two-component epoxy-based adhesive, which allowed for studying the stress distribution between the elements in the elastic stage (prior to the failure of the adhesive joint due to shear stresses).

Each series was designed to examine a specific factor influencing stress concentration in the cross-section of the longer bar near the fracture of the shorter one, as well as its strength and stiffness compared to single reinforcing bars of the same diameter tested under axial tension.

In series I, the variable parameter was the relative length of the shorter reinforcing bar, which was l=0,35×L; l=0,5×L; and l=0,65×L of the longer one. The shorter bar was welded to the longer one only at both ends using fillet welds (see Table 1).

Table 2 – Design solutions and dimensions of reinforcing bars samples according to series II

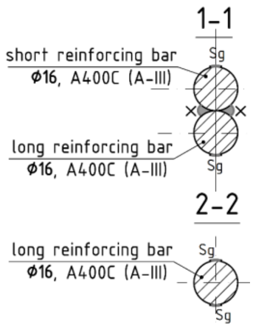
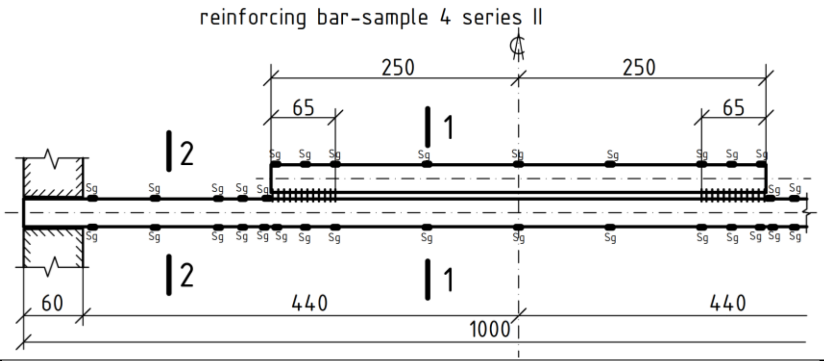
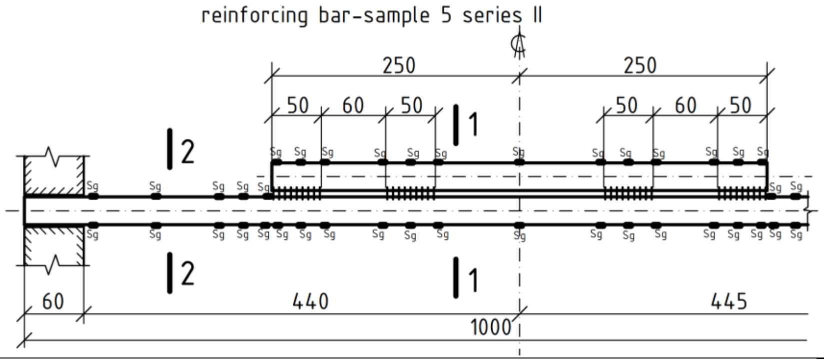
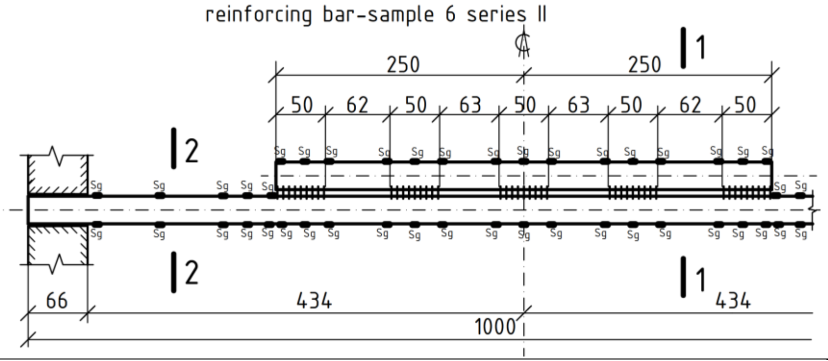
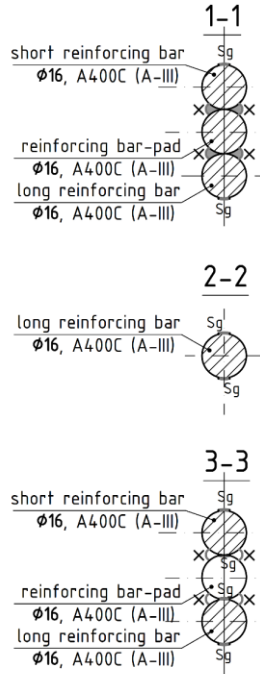
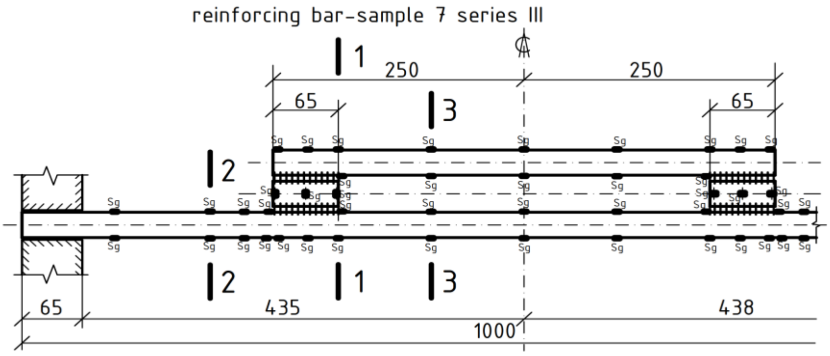
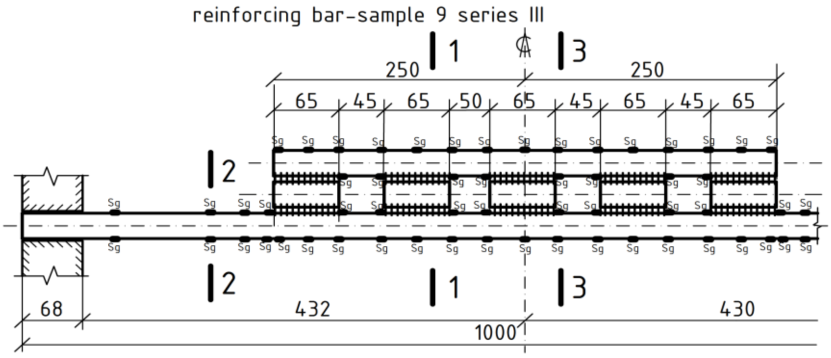
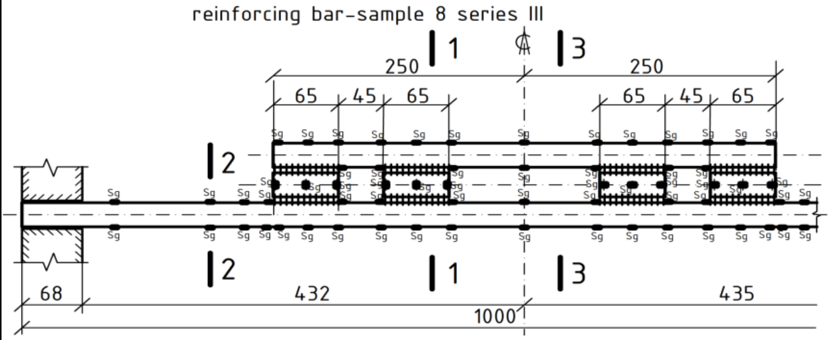
Batch and sample number		Design solutions and dimensions of reinforcing bars-samples according to series II. Locations of strain gauges of type PKB-5-100 in sections along the length of the bars-samples	
		Cross sections	Cross sections
II	4		
	5		
	6		

Table 3 – Design solutions and dimensions of reinforcing bars samples according to series III

<table>
<tr><td colspan="2" rowspan="2">Batch and sample number</td><td colspan="2">Design solutions and dimensions of reinforcing bars-samples according to series III.
Locations of strain gauges of type PKB-5-100 in sections along the length of the bars-samples</td></tr>
<tr><td>Cross sections</td><td>Cross sections</td></tr>
<tr><td rowspan="3">III</td><td>7</td><td rowspan="3">
</td><td>
</td></tr>
<tr><td>8</td><td>
</td></tr>
<tr><td>9</td><td>
</td></tr>
</table>

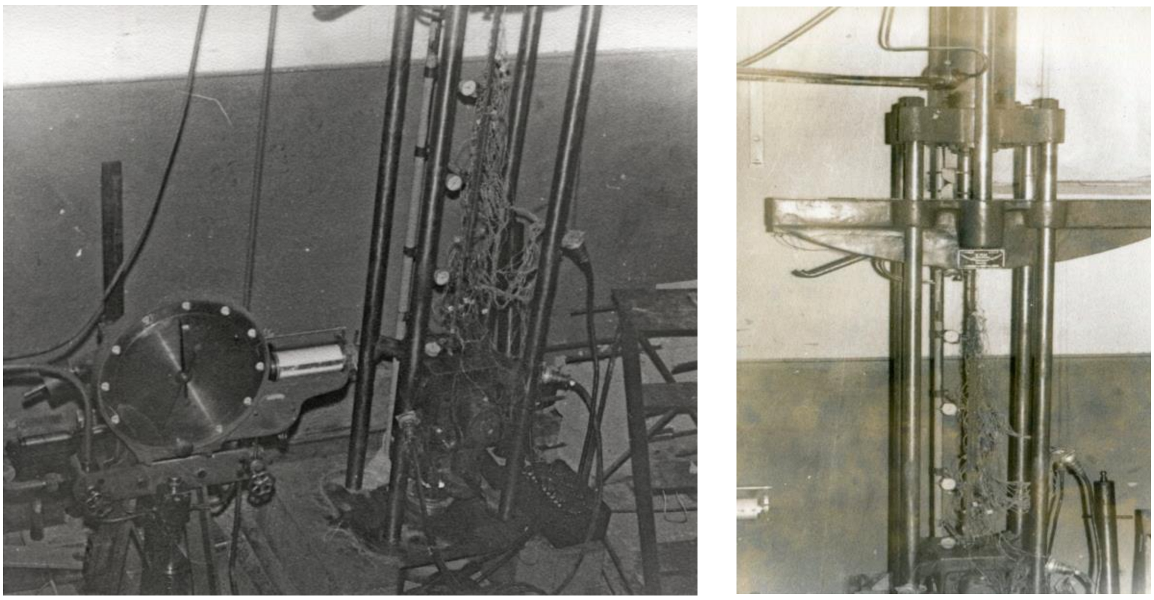


Figure 5 - Testing of a reinforcement sample with a length of l=1.5 m for tension in a universal testing machine UIM-50

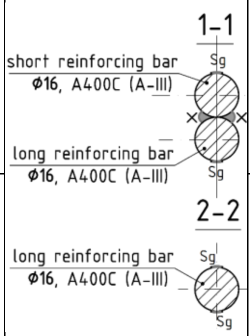
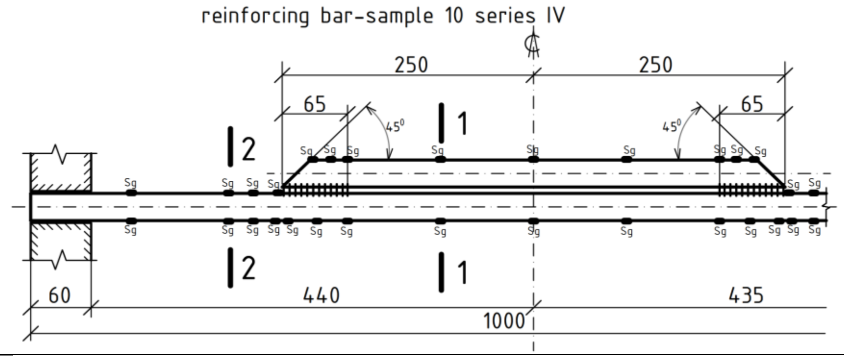
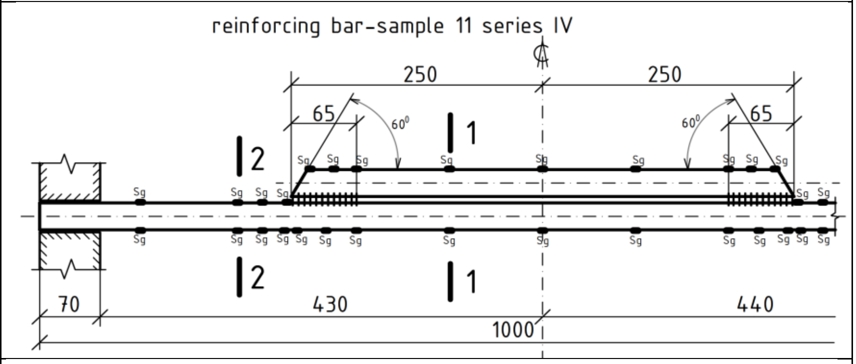
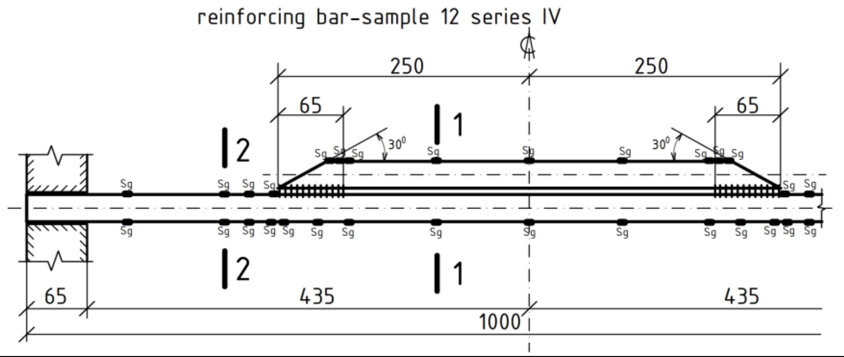
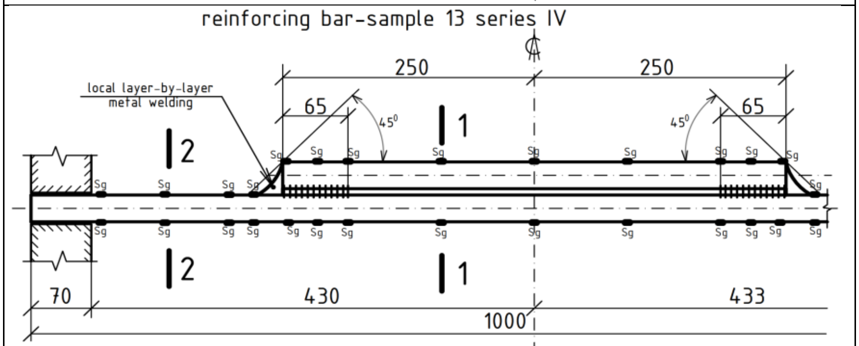
In series II, III, and IV, the eccentricity between the longitudinal axes of the longer and shorter bars and the number of intermittent welds (from two to five) along the connection zone were varied.

In series III, the shorter bars were connected to the longer ones using additional reinforcing segments (short connectors) of d=16 mm and length l_k=65 mm, with the number of connectors ranging from two to five along the length of the shorter element (Table 3).

The specimens of series VI differed from those of series III by the height of the inserts (short connectors) between the reinforcing bars, which were made of two identical reinforcing segments with a diameter of d=16 mm and a length of l_k=65 mm, welded together along their length (see Table 5).

In the series IV specimens, the cross-sectional transition near the fracture point of the shorter reinforcing bar was varied by cutting its end at angles of α=60°, 45°, and 30° to the longitudinal axis of the longer bar and forming a gradual welded transition near its end sections by depositing weld metal (see Table 4).

Table 4 – Design solutions and dimensions of reinforcing bars samples according to series IV

Batch and sample number		Design solutions and dimensions of reinforcing bars-samples according to series IV. Locations of strain gauges of type PKB-5-100 in sections along the length of the bars-samples	
		Cross sections	Cross sections
IV	10		
	11		
	12		
	13		

In the series IV specimens, the cross-sectional transition near the fracture point of the shorter reinforcing bar was varied by cutting its end at angles of α=60°, 45°, and 30° to the longitudinal axis of the longer bar and forming a gradual welded transition near end sections by depositing weld metal (Table 4).

The connection of reinforcing bars using epoxy adhesive in the series V specimens (see Table 5) made it possible to attach strain gauges to both outer contact fibers and to study in greater detail the stress–strain state of the shorter and longer bars under eccentric tension, which could not be achieved in specimens of series I-IV and VI. In those series, welding at temperatures of t=600…1200°C caused the destruction of strain gauges, making such measurements impossible.

The eccentrically tensioned tests of the experimental composite reinforcing bar specimens were carried out (see Fig. 5) using a universal hydraulic tensile testing machine (UIM-50) with a maximum load capacity of N=50 tf (500 kN). The effective (working) length of the reinforcing bar specimens, considering the clamping of their ends in the testing grips, was L_r=1,3 m for series I specimens and L_r=0,8 m for series II–VI specimens (see Figs. 5, 6, and 7).

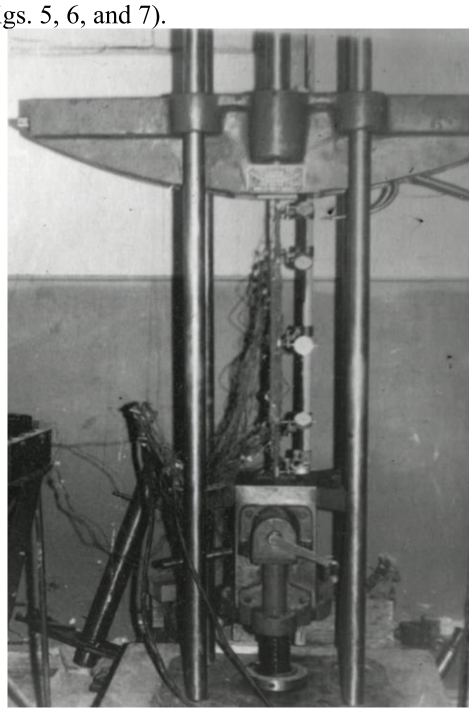


Figure 6 - Testing of a reinforcing sample with a length of l=1,0 m for tension in a universal testing machine UIM-50

During the testing of the reinforcing bar specimens using a universal testing machine (UIM-50), the diagram of "tensile force N_s – relative total elongation of the specimen Δl" was automatically recorded (the longitudinal force N_s was applied to the ends of the longer reinforcing bar in each specimen).

The obtained test results for the composite-section bar specimens were compared with the tensile strength and deformational characteristics of individual reference centrally tensioned reinforcing bars.

The distribution of forces along the cross-sections of the reinforcing bar specimens was studied by measuring the relative strains in their outer fibers using strain gauges of type PKB-5-100, which were bonded in a continuous chain along the length of each bar in quantities of 50-70 per specimen (see the layout of strain gauges in Fig. 8 and the sketches of reinforcing bar specimens in Tables 1-5).

Strain readings in the cross-sections of the specimens at each of 8-12 loading levels were recorded using a semi-automatic strain measuring device, model AVD-2M.

The horizontal displacements of the bar specimens relative to their initial position were recorded using five dial indicators, which were installed near the ends and at the midpoint of the longer reinforcing bar, as well as in the areas close to its connection with the shorter bar (see the layout of the indicators in Fig. 8).

Based on the test results, graphs were plotted to illustrate the distribution of relative displacements of the bar specimens with respect to their initial position at different stages of their stress–strain state. Figure 7 presents the distribution graph of strain values (με, mm) for reinforcing bar specimen No. 10 of Series IV as a function of the loading level $\eta=N/N_u$.

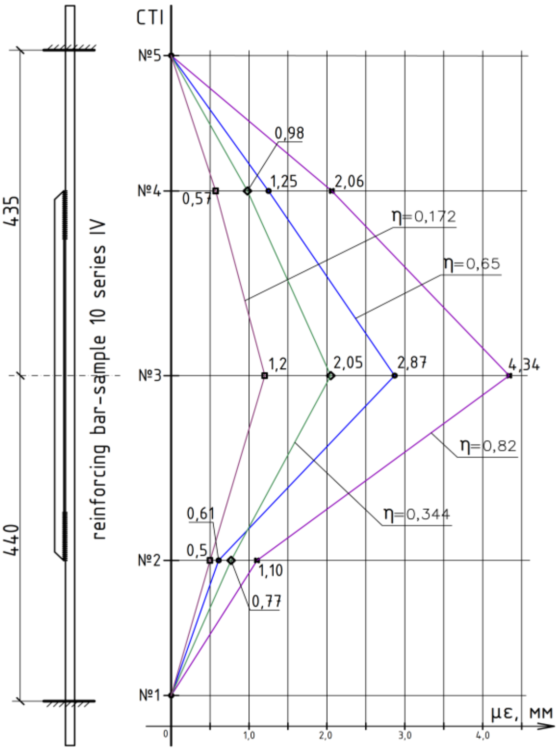


Figure 7 – Graph showing the distribution of horizontal displacements (με, mm) of reinforcing bar specimen No. 10 from Series IV with a nominal length of *l*=1,0m (calculated length l_r=0,875 m) as a function of the loading level $\eta=N/N_u$.

A significant increase in the magnitude of horizontal displacement at the midspan of the bar specimens is observed after reaching and exceeding the yield stress value (σ_T) in the cross-sections of the longer bar near the fracture zones of the shorter bar, during the elastic-plastic and plastic limit stages. The deformability of the specimens is influenced by the structural configuration of the lap joints, namely: the number of welded seams along the specimen length and the magnitude of the eccentricity (e) of the applied longitudinal tensile force N.

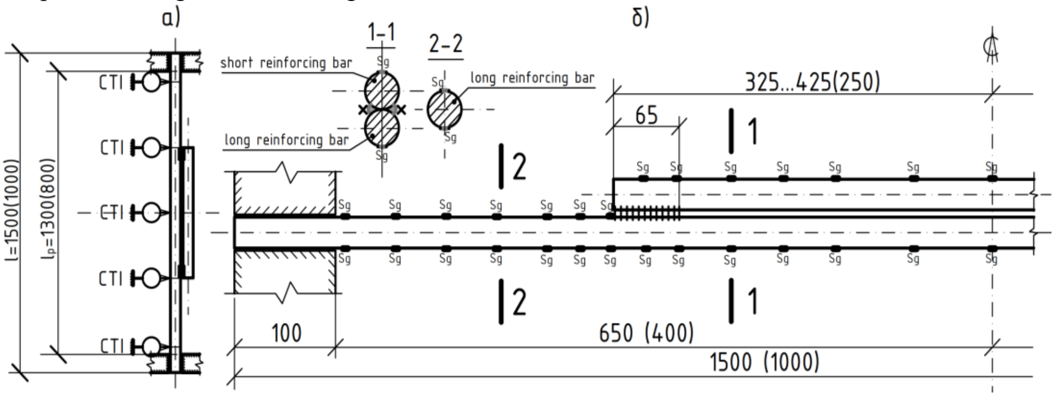
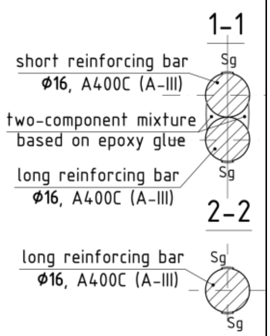
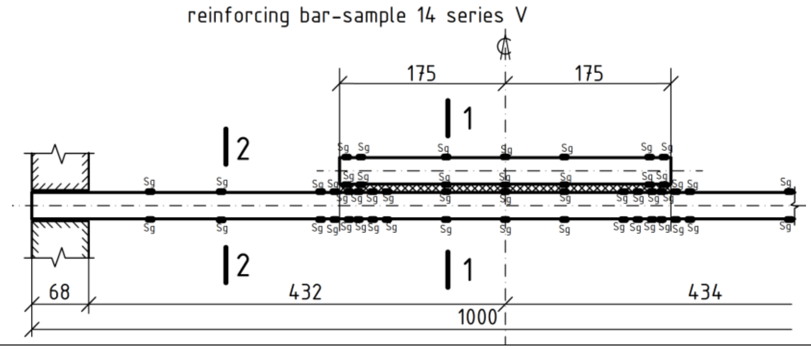
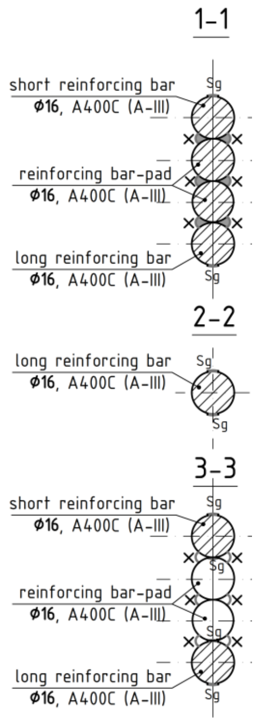
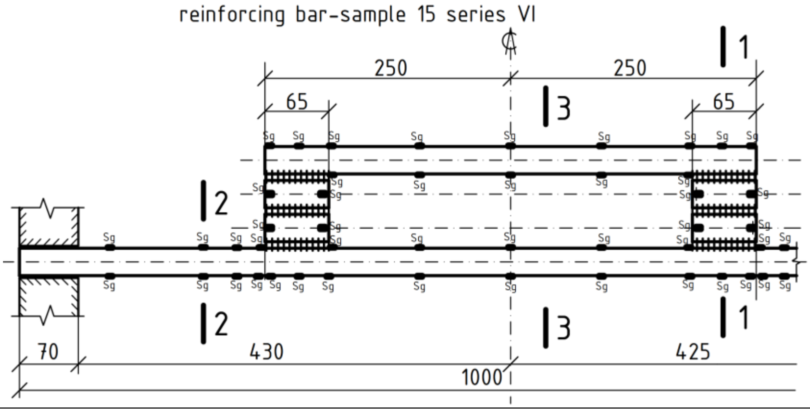
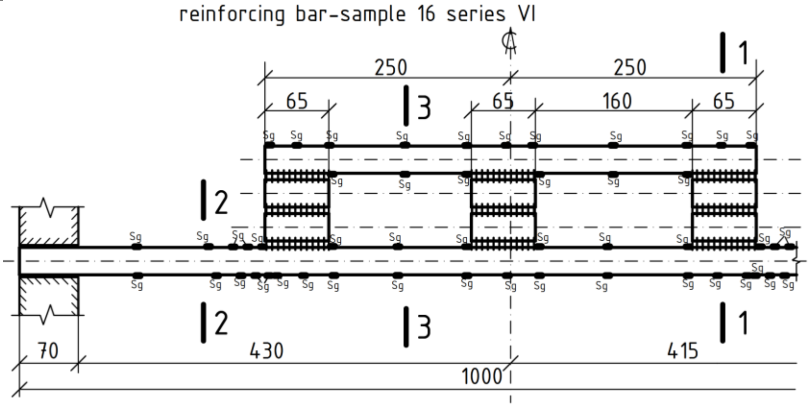


Figure 8 – Schemes of instrumentation layout during the testing of a reinforcing bar specimen of Series I: a) arrangement of dial gauges (clock-type indicators) (CTI) for measuring the horizontal displacements of the specimen sections; b) arrangement of locations for installing strain gauges (Sg) of type PKB-5-100 for measuring relative strains in the outer fibers of the design sections of the Series I specimens.

Table 5 – Design solutions and dimensions of reinforcing bars samples according to series V and VI

Batch and sample number		Design solutions and dimensions of reinforcing bars-samples according to series V and VI. Locations of strain gauges of type PKB-5-100 in sections along the length of the bars-samples	
		Cross sections	Cross sections
V	14		
VI	15		
	16		

As a result of the experimental studies of the reinforcing bar specimens, the characteristic modes of their failure were determined (see photos in Fig.9).

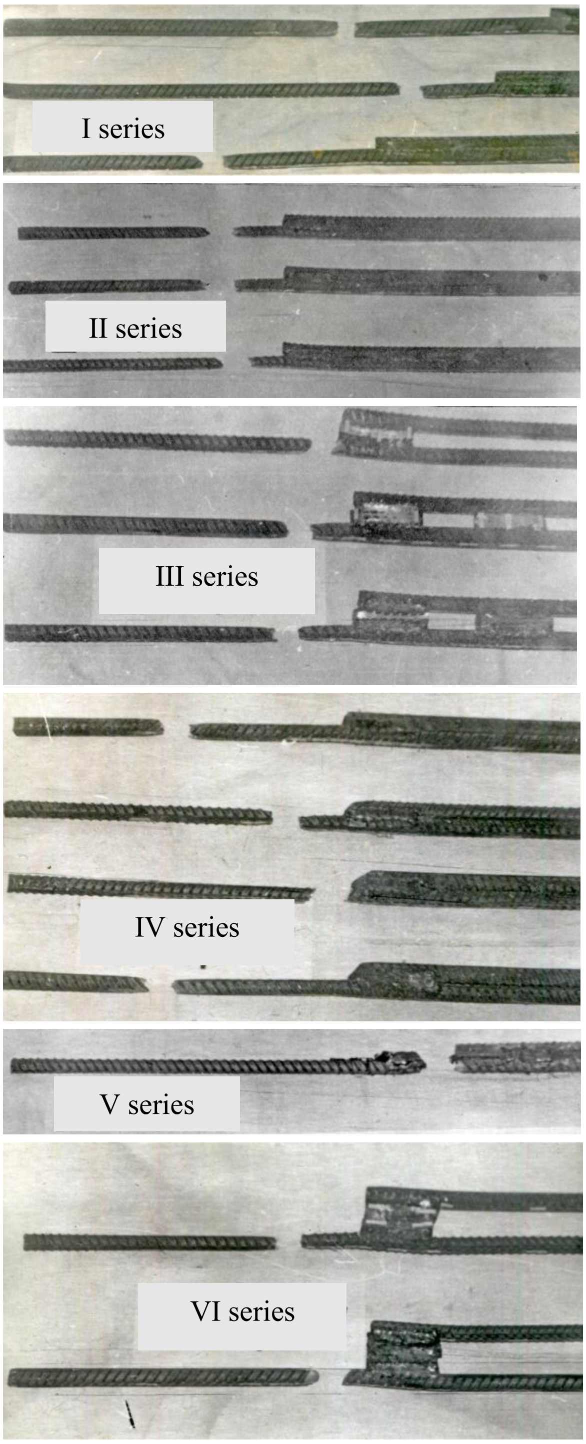


Figure 8 - The nature of the fracture and the location of the rupture of the longer reinforcing bar in the composite specimens of series I-VI that were tested for tension

In the case of plastic failure, rupture occurred in one of the cross-sections of the longer reinforcing bar at a distance equal to two or more of its diameters ($l \geq 30$ mm) from the fracture point of the shorter bar. Plastic failure in a particular cross-section of the longer bar was accompanied by significant localization of deformation prior to rupture, with partial necking of the section (formation of a "neck"), the development of a "cup-and-cone" fracture caused by crack initiation and microvoid coalescence, followed by shear along planes of maximum tangential stresses, which led to the formation of a conical fracture surface and a cup-shaped bottom at the rupture zone.

In the case of brittle failure, the rupture of the longer reinforcing bar occurred directly adjacent to the end (edge) of the shorter bar. The presence of brittle failure was confirmed by the characteristic brittle appearance of the fracture surface at the rupture zone of the longer bar and the absence of visible necking (localized deformation) on either side. Brittle failure was observed in approximately 6% of the total number of specimens.

The occurrence of brittle failure was attributed to structural changes in the physical and mechanical properties of the steel in specific cross-sections of the bars after short-term exposure to high temperatures ranging from t=600…1200°C over segments of length l=d…4d near the locations of welded joints.

By comparing the experimental values of the longitudinal force N_y, obtained during testing of the bar specimens at the conventional yield limit, with the corresponding longitudinal force N_{ye} determined from the reference tests of individual reinforcing bars, the reduction coefficients of the conditional yield strength (γ_{sy}) and the stress concentration factors ($K_{\sigma y}$) at the beginning of the elastic–plastic stage of section behavior were determined; these values are presented in Table 6.

Similarly, by comparing the experimental values of the longitudinal force N_u, obtained at the ultimate strength limit, with the reference force N_{ue} determined for the individual reinforcing bar, the reduction coefficients of ultimate strength (γ_{su}) and the stress concentration factors ($K_{\sigma u}$) for the plastic ultimate stage of section behavior were obtained; these results are summarized in Table 7.

Conclusions

As a result of the experimental investigations, data were obtained that made it possible to draw the following conclusions regarding the distribution of internal forces and the tensile strength under eccentric tension of composite reinforcing bar specimens (consisting of a long and a short reinforcing bar welded together along their length):

Failure behavior. In most cases, failure of the bar specimens occurred within a defined cross-section of the longer reinforcing bar, located at a distance of $l=0…4d$ (where d is the diameter of the longer bar) from the edge of the shorter bar. This region corresponds to the zone where the properties of the reinforcing steel were structurally altered due to the influence of arc welding heat. Brittle failure was observed in approximately 6% of the total specimens. The experimental values of the reduction coefficients of tensile strength for cross-sections of the longer bar near the welded zone, compared to the tensile strength of the reference bars not exposed to high welding temperatures, were determined as follows:

– at the yield limit: γ_{sy} = 0,785…0,961; – at the ultimate strength limit: γ_{su} = 0,874…0,955.

Table 7 – Ultimate tensile forces (N_y) in reinforcing bar specimens and the values of the stress reduction coefficients (γsy) and stress concentration coefficients ($K_{\sigma y}$) in the elastic–plastic stage at the yield limit

Series No.	Specimen No.	Longitudinal force (N_y) at the yield limit according to the force–displacement diagram from the UIM-50 testing machine: reference specimen (single reinforcing bar) – N_{ye}; composite specimen (long + short reinforcing bars) – N_{yi}, kN		Stress reduction (γ_{sy}) and concentration coefficients ($K_{\sigma y}$) in the cross-sections of the longer bar of the composite specimen in the elastic–plastic stage at the yield limit	
		N_{ye}	N_{yi}	γ_{sy}	$K_{\sigma y}$
I	1	86,16	73,15	0,849	1,178
	2		72,03	0,836	1,196
	3		74,70	0,867	1,153
II	4		80,73	0,937	1,067
	5		74,35	0,863	1,158
	6		78,57	0,912	1,096
III	7		67,63	0,785	1,274
	8		82,80	0,961	1,040
	9		67,80	0,787	1,271
IV	10		75,90	0,881	1,135
	11		73,06	0,848	1,179
	12		75,65	0,878	1,139
	13		79,35	0,921	1,085
V	14		78,23	0,908	1,101
VI	15		77,63	0,901	1,110
	16		78,83	0,915	1,093

Table 8 – Ultimate tensile forces (N_y) in reinforcing bar specimens and the values of the stress reduction coefficients (γ_{sy}) and stress concentration coefficients ($K_{\sigma y}$) in the plastic stage at the yield limit

Series No.	Specimen No.	Longitudinal force (N_y) at the yield limit according to the force–displacement diagram from the UIM-50 testing machine: reference specimen (single reinforcing bar) – N_{ye}; composite specimen (long + short reinforcing bars) – N_{yi}, kN		Stress reduction (γ_{sy}) and concentration coefficients ($K_{\sigma y}$) in the cross-sections of the longer bar of the composite specimen in the plastic stage at the yield limit	
		N_{ue}	N_{ui}	γ_{su}	$K_{\sigma u}$
I	1	129,6	120,01	0,926	1,080
	2		123,38	0,952	1,050
	3		116,90	0,902	1,108
II	4		118,06	0,911	1,097
	5		122,60	0,946	1,057
	6		121,43	0,937	1,067
III	7		119,88	0,925	1,081
	8		120,01	0,926	1,080
	9		121,95	0,941	1,062
IV	10		120,40	0,929	1,076
	11		113,27	0,874	1,144
	12		119,62	0,923	1,083
	13		123,77	0,955	1,047
V	14		122,60	0,946	1,057
VI	15		120,14	0,927	1,078
	16		123,00	0,949	1,054

♦ Stress concentration effects. In the outer fibers of the longer reinforcing bar cross-section, located near the fracture end of the shorter bar, stresses exceeding the yield stress were recorded at a load level of $\eta=N_s/N_u$=0,6-0,7, while the average stress in the section reached $\sigma_s \geq 0,6 \times f_{sy}$. The experimentally determined stress concentration coefficients in the cross-sections of the longer bar were:

– in the elastic–plastic stage at yield: $K_{\sigma y}$=1,04…1,28;

– in the plastic stage at ultimate strength: $K_{\sigma u}$=1,047…1,145.

♦ Load distribution. The experimental results showed that the distribution of the longitudinal tensile force Ns between the longer and shorter bars varied in the ratio from 2:1 to 5:1 depending on the stress–strain stage of the specimen.

When designing and calculating the structural elements for strengthening reinforced concrete beam structures by increasing the area of longitudinal reinforcement in the tensile zone through the addition of supplementary bars welded to existing ones, it is necessary to consider the reduction in the design tensile resistance of the reinforcing steel. This reduction should be accounted for by applying the experimentally derived coefficients of tensile strength reduction (γ_{sy}) and stress concentration ($K_{\sigma y}$) proposed in Table 6.

References

1, ДБН Б В.3.1-2:2016 Ремонт і підсилення несучих і огороджувальних будівельних конструкцій та основ будівель і споруд. [Текст]: Наказ Мінрегіону від 24.06.2016 №182, чинний з 2017-04-01, – К.: ДП "УкрНДНЦ", 2017. – 72 с.

2. Римар Я. В. Міцність та деформативність залізобетонних балок, підсилених під навантаженням нарощуванням арматури: автореферат дисертації на здобуття наукового ступеня кандидата технічних наук: 05.23.01 – будівельні конструкції, будівлі та споруди / Ярослав Васильович Римар; Національний університет "Львівська політехніка". - Львів, 2010, - 20 с. - Бібліографія: с. 16–17 (10 назв). https://ena.lpnu.ua/items/ c9bb0ff1-f732-46a4-b437-442074daf15f

3. Бліхарський З.Я. Експериментальні дослідження залізобетонних балок, підсилених нарощуванням арматури / З.Я. Бліхарський, Я.В. Римар // *Ресурсоекономні матеріали, конструкції, будівлі та споруди. Збірник наук. праць НУВГП. Випуск 13* – Рівне: НУВГП.– 2005.– С. 346-351,

4. Бліхарський З.Я. Підсилення залізобетонних балок нарощуванням арматури під навантаженням / З.Я. Бліхарський, Я.В. Римар // *Ресурсоекономні матеріали, конструкції, будівлі та споруди. Збірник наук. праць НУВГП. Випуск 14.* – Рівне: НУВГП.– 2006.– С. 449-454.

5. Бліхарський З.Я. Залізобетонні балки, підсилені нарощуванням арматури під навантаженням / З.Я. Бліхарський, Я.В. Римар, Р.Є. Хміль // *Вісник Національного університету "Львівська політехніка".*- Львів: Видавництво Національного університету "Львівська політехніка", 2005.- №545: Теорія і практика будівництва. - С. 15–19. https://ena.lpnu.ua/handle/ntb/47302

6. Бліхарський З. Я. Методика експериментального дослідження міцності нормальних перетинів залізобетонних балок, підсилених додатковою попередньо напруженою арматурою під навантаженням / З. Я. Бліхарський, Р. Є. Хміль, Я. В. Римар, Б. М. Ковальчук, Р. Ю. Титаренко // Вісник Національного університету "Львівська політехніка". Теорія і практика будівництва.- 2015.- № 823.- С.21-26. http://nbuv.gov.ua/UJRN/VNULPTPB_2015_823_6

7. Міцність залізобетонних балок, підсилених попередньо напруженою арматурою / Б. М. Ковальчук, Я. В. Римар, З. Я. Бліхарський, П. Ф. Холод // Вісник національного університету "Львівська політехніка". Серія: Теорія і практика будівництва. - Львів: Видавництво Львівської політехніки, 2017. - № 877. - С. 109–114. http://ena.lp.edu.ua:8080/handle/ntb/44184

8. Боярчук Б. А. Міцність, тріщиностійкість та деформативність залізобетонних конструкцій при різних способах підсилення розтягнутої зони: дис. канд. техн. наук: 05.23.01 / Б. А. Боярчук. – Луцьк, 2003. – 157с.

1, DBN B V.3.1-2:2016 (2017) Structures of buildings and structures. Steel-reinforced concrete structures. Basic Provisions. Ministry of Regional Development of Ukraine, effective from 01,09.2011, - Kyiv, Minregion Ukraine, 2017. - 72 p. (in Ukrainian).

2. Rymar Ya.V. The strength and deformability of reinforced concrete beams strengthened under the load by building up reinforcement: abstract of the dissertation for obtaining the scientific degree of candidate of technical sciences: 05.23.01 - construction structures, buildings and structures/ Yaroslav Vasyliovych Rymar; Lviv Polytechnic National University.- Lviv, 2010,- 20 p.- Bibliography: p. 16–17 (10 titles). (in Ukrainian) https://ena.lpnu.ua/items/c9bb0ff1-f732-46a4-b437-442074daf15f

3. Blikharskyi Z.Ya. Experimental studies of reinforced concrete beams strengthened by building up reinforcement/ Z.Ya. Blikharskyi, Ya.V. Rymar // *Resource-saving materials, constructions, buildings and structures. Collection of sciences works of NUVHP. Issue 13.* – Rivne: NUVHP.– 2005.– pp. 346-351, (in Ukrainian).

4. Blikharskyi Z.Ya. Reinforcement of reinforced concrete beams by increasing reinforcement under load / Z.Ya. Blikharskyi, Ya.V. Rymar // *Resource-saving materials, constructions, buildings and structures. Collection of sciences works of NUVHP. Issue 14.* – Rivne: NUVHP.– 2006.– pp. 449-454. (in Ukrainian).

5. Blikharskyi Z.Ya. et al. Reinforced concrete beams strengthened by increasing by the reinforcement under load / Z.Ya. Blikharskyi, Ya.V. Rymar, R.E. Khmil` //` *Bulletin of the National University "Lviv Polytechnic".* - Lviv: Publishing House of the National University "Lviv Polytechnic", 2005.- #545: Theory and practice of construction. - pp. 15–19. (in Ukrainian). https://ena.lpnu.ua/handle/ntb/47302

6. Blikharskyi Z.Ya. et al. / Methodology for experimental study of the strength of normal sections of reinforced concrete beams reinforced with additional prestressed reinforcement under load / Z. Blikharskyi, R. Khmil, Ya. Rymar, B. Kovalchuk,`R. Tytarenko //` *Bulletin of the National University "Lviv Polytechnic".* Theory and practice of construction. - 2015.- #823.- pp. 21–26. (in Ukrainian). http://nbuv.gov.ua/UJRN/VNULPTPB_2015_823_6

7. Strength of the reinforced concrete beams, strengthened by the prestressed reinforcing bars / B. Kovalchuk, Ya. Rymar, Z. Blikharskyy, P. Kholod // Visnyk natsionalnoho universytetu "Lvivska politekhnika". Serie: Teoriia i praktyka budivnytstva. — Vydavnytstvo Lvivskoi politekhniky, 2017. - № 877. - pp. 109–114. (in Ukrainian) http:// ena.lp.edu.ua:8080/handle/ntb/44184

8. Boiarchuk B. A. Strength, crack resistance and deformability of reinforced concrete structures with different methods of strengthening the stretched zone. Avtoref. dys. na zdobuttya nauk. stupenya kand. tekhn. nauk: 05.23.01. – Lutsk, 2003. – 157 p. (in Ukrainian)

9. Gul A., Alam B., Khan F. A., Badrashi Y. I., & Shahzada K. (2015) Strengthening and evaluation of reinforced concrete beams for flexure by using external steel reinforcements / *International Journal of Scientific Engineering and Technology*, April 2015, vol.4 (№4), pp. 260–263. https://doi.org/10,17950/ijset/v4s4/409

10, Gul A, Alam B, Ahmed W, et al. (2020) Strengthening and Characterization of Existing Reinforced Concrete Beams for Flexure by Effective Utilization of External Steel Elements. *Advances in Structural Engineering*. 2020;24(2):243-251, doi:10,1177/1369433220950614

11, Митрофанов В.П. Експериментальне дослідження напружено-деформованого стану складених арматурних стержнів, випробуваних окремо і в складі залізобетонних балок / В.П. Митрофанов, М.О. Овсій // *Збірник наукових праць «Галузеве машинобудування, будівництво». Вип. 1,* – Полтава: Полт.НТУ, 1998. – С. 53-62.

12. Moustafa, T.; Khalifa, W.; El-Koussy, M.R.; Abd El-Reheem, N. (2016) Optimizing the Welding Parameters of Reinforcing Steel Bars. *Arab. J. Sci. Eng.*, **41**, 1699–1711, https://doi.org/10,1007/s13369-015-1929-x

13. Falodun, O., Oke, S. Bodunrin, M. (2025) A comprehensive review of residual stresses in carbon steel welding: formation mechanisms, mitigation strategies, and advanced post-weld heat treatment techniques. *Int J Adv Manuf Technol 136,* 4107–4140, https://doi.org/10,1007/s00170-025-15088-8

14. Nadimi, N.; Pouranvari, M. (2023) Transition in Interfacial Failure Mechanism of Resistance Spot Welds during Tensile–Shear Loading: Role of Fusion Zone Hardness. *Metals*, 13, 1076. https://doi.org/10,3390/met13061076

15. Sk Basiruddin MB (2022) Heat treatment and effect of microstructural constituents on impact toughness of low carbon steel (Doctoral dissertation, Indian Institute of Technology Kharagpur). – p.320, https://www.researchgate.net/publication/370263171

16. Kubicki, K. (2023) Technical and economic aspects of load-bearing welded joints in reinforcing steel. *Construction of Optimized Energy Potentia*l, 12(1), 228–235. DOI: 10,17512/bozpe.2023.12.25

17. Issa C.A., Nasr A. (2006) An experimental study of welded splices of reinforcing bars. *Build Environ*. **41**, 1394–1405. https://doi.org/10,1016/J.BUILDENV.2005. 05.025

18. Ahmed, Ghafur (2015) Mechanical Properties of Welded Deformed Reinforcing Stee*l Bars. Aro, The Scientific Journal of Koya University*, 3 (1). pp. 28-39. ISSN 24109355 https://doi.org/10,14500/aro.10059

19. Li, D., Xu, K., Zhang, X. et al. (2024) Experimental Study on Brittle Fracture Mechanism and Mechanical Properties of HRB400E Rebar Cross-Spot Welding. J Fail. Anal. and Preven. 24, 344–351, https://doi.org/10,1007/s11668-023-01844-z

20, Scholz, W. and Robers, B. (2000). Welding Newly Developed, High Strength SeismicGrade Reinforcing Bar / 12th World Conference on Earthquake Engineering. – p.8. https://www.iitk.ac.in/nicee/wcee/article/1173.pdf

21, Apostolopoulos, Ch.; Savvopoulos, P. and Dimitrov L. (2011) Design Problems in Lap Welded Joints of Reinforcing Steel Bars, Greece: Department of Mechanical Engineering and Aeronautics, University of Patras. Scientific Proceedings VIII International Congress "MACHINES, TECHNOLOGIES, MATERIALS" 2011, YEAR XIX, Vol. 3, pp. 48-54 https:// mtmcongress.com/ proceedngs/2011/3/12.DESIGN%20PROBLEMS%20IN%20LAP%20WELDED%20JOINTS%20OF%20REINFORCING%20STEEL%20BARS.pdf

9. Gul, A., Alam, B., Khan, F. A., Badrashi, Y. I., & Shahzada, K. (2015) Strengthening and evaluation of reinforced concrete beams for flexure by using external steel reinforcements / *International Journal of Scientific Engineering and Technology*, April 2015, vol.4 (№4), pp. 260–263. https://doi.org/10,17950/ijset/v4s4/409

10, Gul A, Alam B, Ahmed W, et al. (2020) Strengthening and Characterization of Existing Reinforced Concrete Beams for Flexure by Effective Utilization of External Steel Elements. *Advances in Structural Engineering*. 2020;24(2):243-251, doi:10,1177/1369433220950614

11, Mitrofanov V.P. Experimental study of the stress-strain state of composite reinforcing rods tested separately and as part of reinforced concrete beams / V.P. Mitrofanov, M.O. Ovsii // *Academic journal. Industrial Machine Building, Civil Engineering, Vol. 1,* – Poltava: Polt.NTU, 1998. – pp. 53-62. (in Ukrainian).

12. Moustafa, T.; Khalifa, W.; El-Koussy, M.R.; Abd El-Reheem, N. (2016) Optimizing the Welding Parameters of Reinforcing Steel Bars. *Arab. J. Sci. Eng.*, **41**, 1699–1711, https://doi.org/10,1007/s13369-015-1929-x

13. Falodun, O., Oke, S. Bodunrin, M. (2025) A comprehensive review of residual stresses in carbon steel welding: formation mechanisms, mitigation strategies, and advanced post-weld heat treatment techniques. *Int J Adv Manuf Technol 136*, 4107–4140, https://doi.org/10,1007/s00170-025-15088-8

14. Nadimi, N.; Pouranvari, M. (2023) Transition in Interfacial Failure Mechanism of Resistance Spot Welds during Tensile–Shear Loading: Role of Fusion Zone Hardness. *Metals*, 13, 1076. https://doi.org/10,3390/met13061076

15. Sk Basiruddin MB (2022) Heat treatment and effect of microstructural constituents on impact toughness of low carbon steel (Doctoral dissertation, Indian Institute of Technology Kharagpur). – p.320, https://www.researchgate.net/publication/370263171

16. Kubicki, K. (2023) Technical and economic aspects of load-bearing welded joints in reinforcing steel. *Construction of Optimized Energy Potentia*l, 12(1), 228–235. DOI: 10,17512/bozpe.2023.12.25

17. Issa C.A., Nasr A. (2006) An experimental study of welded splices of reinforcing bars. *Build Environ*. **41**, 1394–1405. https://doi.org/10,1016/J.BUILDENV.2005. 05.025

18. Ahmed, Ghafur (2015) Mechanical Properties of Welded Deformed Reinforcing Stee*l Bars. Aro, The Scientific Journal of Koya University*, 3 (1). pp. 28-39. ISSN 24109355 https://doi.org/10,14500/aro.10059

19. Li, D., Xu, K., Zhang, X. et al. (2024) Experimental Study on Brittle Fracture Mechanism and Mechanical Properties of HRB400E Rebar Cross-Spot Welding. J Fail. Anal. and Preven. 24, 344–351, https://doi.org/10,1007/s11668-023-01844-z

20, Scholz, W. and Robers, B. (2000). Welding Newly Developed, High Strength SeismicGrade Reinforcing Bar / 12th World Conference on Earthquake Engineering. – p.8. https://www.iitk.ac.in/nicee/wcee/article/1173.pdf

21, Apostolopoulos, Ch., Savvopoulos, P. and Dimitrov L. (2011) Design Problems in Lap Welded Joints of Reinforcing Steel Bars, Greece: Department of Mechanical Engineering and Aeronautics, University of Patras. Scientific Proceedings VIII International Congress "MACHINES, TECHNOLOGIES, MATERIALS" 2011, YEAR XIX, Vol. 3, pp. 48-54 https://mtmcongress.com/proceedngs/2011/3/12.DESIGN%20PROBLEMS%20IN%20LAP%20WELDED%20JOINTS%20OF%20REINFORCING%20STEEL%20BARS.pdf

Азізова А.Г.*
Національний університет «Полтавська політехніка імені Юрія Кондратюка»
https://orcid.org/0000-0002-6138-2757

Овсій Д.М.
Національний університет «Полтавська політехніка імені Юрія Кондратюка»
https://orcid.org/0000-0001-7007-1857

Семко О.В.
Національний університет «Полтавська політехніка імені Юрія Кондратюка»
https://orcid.org/0000-0002-2455-752X

Овсій М.О.
Приватне підприємство «БУДЕКСПЕРТИЗА», м. Полтава

Міцність та розподіл зусиль зварених внакладку складених поздовжніх арматурних стержнів, які утворюються при підсиленні залізобетонних балкових елементів шляхом нарощування перерізу в розтягненій зоні

Аннотація.Відповідно до п. 6.4.2 ДБН Б В.3.1-2:2016 [1] одним із варіантів підсилення залізобетонних балкових конструкцій і елементів способом часткового нарощування перерізів їх розтягнутої зони є нарощування площі поздовжньої арматури шляхом приварення переривистими зварними швами додаткових арматурних стержнів безпосередньо до неї чи через допоміжні накладки із коротких арматурних відрізків прямолінійної чи зигзагоподібної форми.
В статті експериментально досліджено міцність та напружено-деформований стан позацентрово розтягнених зразків із зварених внакладку складених поздовжніх арматурних стержнів, які мають перемінні по довжині перерізи та з'єднанні між собою за допомогою електродугового зварювання. Міцність складених арматурних стержнів зіставлялася з міцністю окремих арматурних центрально-розтягнених стержнів. В результаті експерименту було досліджено вплив на міцність стержнів основних факторів: електродугового зварювання; концентрації напруження; ексцентриситет прикладення поздовжнього зусилля розтягу, а також розподіл зусиль в перерізах кожного елементу по довжині складеного арматурного стержня-зразку.Авторами статті в результаті порівняння величин граничних поздовжніх зусиль були отримані значення коефіцієнтів пониження міцності та концентрації напружень на межі плинності та межі міцності стержнів-зразків, величини яких приведені в табл. 6 та табл.7 роботи.

Ключові слова: залізобетонні балки, посилення, додаткове поздовжнє армування, поперечні перерізи, арматурні стержні, зварювальні з’єднання, міцність на розтяг.

*Адреса для листування E-mail: galinska@i.ua

Надіслано до редакції:	20.02.2025	Прийнято до друку після рецензування:	06.05.2025	Опубліковано (оприлюднено):	26.06.2025

Suggested Citation:

APA style	Azizova, A., Ovsii, D., Semko, O., & Ovsii, M. (2025). Strength and force distribution of lap-welded composite longitudinal reinforcing bars formed during strengthening of reinforced concrete beam elements by increasing the cross-section in the tension zone. *Academic Journal Industrial Machine Building Civil Engineering*, *1* (64), 39–54. https://doi.org/10.26906/znp.2025.64.4136
DSTU style	Strength and force distribution of lap-welded composite longitudinal reinforcing bars formed during strengthening of reinforced concrete beam elements by increasing the cross-section in the tension zone/ A. Azizova et al. *Academic journal. Industrial Machine Building, Civil Engineering*. 2025. Vol. 64, iss. 1. P. 39–54. URL: https://doi.org/10.26906/znp.2025.64.4136.