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STRENGTH AND DEFORMABILITY OF NORMAL CROSS SECTIONS OF REINFORCED CONCRETE BEAMS, REINFORCED IN THE TENSION AREA WITH ADDITIONAL SHEET REINFORCEMENT WITHOUT THE BOND

The results of the experimental research of the strength and deformability of normal cross sections of reinforced concrete beams reinforced in tension area with additional sheet reinforcement without the bond.

Key words: reconstruction, reinforcement, additional reinforcement, concrete beams, strengthening structures, important, flexural members, seet reinforcement, stretched zone, experimental samples.

Наведено результати експериментальних досліджень міцності та деформативності нормальних перерізів залізобетонних балок, підсилених у розтягнутій зоні додатковою листовою арматурою без зчеплення.

Ключові слова: реконструкція, арматура, додаткова арматура, залізобетонні балки, підсилення, згинальні елементи, листова арматура, розтягнута зона, експериментальні зразки.

Statement of the problem. Over time, existing buildings and structures expose to weathering, corrosion processes. So often the operation of buildings and structures that stood for decades, can be dangerous. We need to restore the performance of these buildings before re-using them for other purposes. Additionally, buildings constructed very long time ago are outdated and no longer meet the requirements of modern times. In this case, the reconstruction of buildings provides their "new birth "within the current situation. The reconstruction of industrial buildings is often associated with the need to modernize the production, manufacture or change the functional purpose of these buildings. It is often the reconstruction of industrial buildings and structures that should be performed without termination or suspension of the production process. Any reconstruction of a building or structure is accompanied usually by changing loads on structures, changing their original design schemes. All this leads to the necessity of determining the residual life of their performance, a resolution to their fate, the restoration, enhancement or replacement.

Strengthening structures in terms of the technical re-equipment and reconstruction of existing enterprises need to design with the following factors: taking into account the mass of work, work in the shortest possible time, taking into consideration technology requirements and conditions of work, unify elements for strengthening structures. Given these factors new technologies of enhancement and restoration of building structures have been developed.

The important question now is reinforcement of the flexural members as overlapping bolts and coverage often have traces of physical deterioration, decay and become unfit for normal use. When these elements are reinforced the problem of effective use of existing materials with appropriate strength characteristics occurs. This problem can be solved by using an additional sheet reinforcement, ensuring that it works together with the existing concrete structures. This combined system solves several problems: reduces material consumption in the process of reconstruction, crack deflection and structural elements of the building. They make it possible to significantly increase the size of the payload and flown with little change in altitude of the bearing beam elements

Strengthening structures by increasing the reinforcement in the tension area is one of the most effective ways to reinforce the flexural members. Moreover, that construction reinforced, usually after a long time of operation, which strengthens the compressed zone due to the increase of concrete strength, and it is possible compressed zone paging through additional reinforcement. In the process of the reinforcement of flexural members, the use of sheet reinforcement without grip allows you to perform work with minimal interruptions in service buildings. Collaboration between both valves having close to each other strains can be achieved by the same modulus of elasticity of steel. Steel plate is rather cheap material compared with the latest high performance materials. Price ratios for strengthening of structures using these materials is in the range of 10-12 times. Therefore, the use of alternative reinforcement steel is economically feasible.

Scientific novelty of the research is to evaluate the collaborative reinforced concrete beams with an additional sheet reinforcement, defining issues include an additional reinforcement in the work and its impact on the carrying capacity of beams.

Problem of reinforcement of flexural members in which the reinforcement by additional prestressed sheet steel is performed under the load of different levels, is of practical and theoretical importance, is relevant because its solution will improve the economic efficiency of reinforcement of concrete structures by taking into account the initial and residual load bearing capacity.

Analysis of recent research and publications. A brief historical review of methods for amplification.

Reinforcement of concrete structures was first engaged a long time ago. One of the first who wrote this milestone in the history of the building were British. In England in 1912, attempts were made in strengthening structures, as reflected in the forthcoming technical literature. Then the first rules for strengthening structures appeared. To restore the application of a uniform layer applied plaster, inserting a layer of reinforced concrete, brush a thin layer of the solution (often with applications of metallic chips) and shotcrete. In 1919, using clips with additional reinforcement and winding successfully applied engineer Struve VA in reinforced structures. Placing clips carried in repairing the roof beams and frames overlap locomotive depot. The lack of density of concrete and its small protection layer, reinforcement of the beams was damaged by corrosion from flue gases. In 1931, at one of the cement factories of the Soviet Union specific clips were used to enhance and restore structures of the fuel bulk, which were deformed and partially milled because of technical conditions violation. In order to strengthen reinforced concrete beams, which are present inclined cracks due to insufficient pitch diameter and clamps, Henri Lossye in 1936 applied the clamps, which had previously been strained. He recommended by the lack of longitudinal reinforcement invest more prestressed steel. In 1938 the method of reinforcement of beams by the means of the tension rod previously mechanically stressed by tensioning bolts was patented in England. Often various clips and unloading of construction are applied. Although the question of strengthening was raised by many engineers and scientists (R.Zaliher, Lapreht, A.Kleynlehel, E.Freysine, A. Lossye etc.), their experience is not generalized.

In Ukraine in 1934 PhD Litvinov I.M. carried out experimental work on strengthening reinforced concrete elements clip. In 1937 and 1938 he spent a large amount of research and their subsequent publication. The main research themes - strengthening concrete structures unilateral build-up with the addition of reinforcement. During this period the engineer Sharov I.F. carried out experimental research method on shotcrete linings shirts and adding fittings and clamps to reinforce tee beams. Engineer Sudarikov A.A. in 1938 executed tests on reinforced concrete beams reinforced with straight and oblique reinforcement with its further concreting. Further experiments were carried out on reinforced concrete beams using steel rods. Engineer Strukin A.D. was in charge of these studies. This enabled further continuation of research in the field of discharging constructions. Considerable experimental study on methods of strengthening concrete structures with special means of unloading such as prestressed ties and spacers in 1950-1953 were performed by Onufriy N.M. in mechanical laboratory "LYSY". They were performed both on both single-span girder elements and continuous beams, thereby increasing the scope of use of such constructions at the enterprises of that time and became very common. Since 1949. Professor Yu.I.Lozovyy developed and implemented ways to reinforce concrete structures that are under stress. In most cases, existing structures enhance the introduction of new items by adding reinforcement, spatial relations compression systems, one-way links with initial lengthening or shortening. Stressed state elements are generated by thermal, electrothermal or thermomechanical methods. Ph.D. Chekanovych M.G. developed a lever-rod system with external reinforcement in the form of tightening and stretching and explored the work of lever-rod construction that allows reallocate effort between compressed and stretched zones of the bending moment. The main feature of the developed structures are strengthening efforts redistribution between compressed and stretched zones proportional to the correspondence of shoulders of lever system using external reinforcement. In 2010, the Lviv Polytechnic National University conducted experimental study to determine the strength and deformability of reinforced concrete beams reinforced with a stress build-up fixtures. These were headed by the scholar Rimar Y. V. The result of this work was the following: among the two methods of increasing reinforcement, such as rebar reinforcement rods welded to the core through bearing blocks and directly without bearing blocks, the second method is structurally efficient; with welded reinforcement through bearing blocks by increasing the load on the beam principal reinforcements "turned" in the place of end bearing block and cracks appear along the main reinforcement in the stop area. Also the bond between the main reinforcement and concrete is lost as well as premature beam destruction; in case of direct welding rebar reinforcement rods fixed to the main armature "turn" practically does not occur, thus eliminating the premature destruction of beams.

Today amplification of the stretched zone sections that are normal to the longitudinal axis of the concrete elements shall be performed by the following methods: by installing additional elements of reinforcing steel or polymer strands of fiberglass that are welded to the existing one by discontinuous seams or are glued to concrete; through the establishment of additional elements of rolled metal (sheet, angles, channels, beams), which are welded to the existing longitudinal reinforcement welded seams intermittent or glued to concrete and fastened with additional anchors, by setting trussed puffs from a rolling metal (plates, angles, channels, beams) and reinforcement steel, which are welded to the existing longitudinal reinforcement welded seams intermittent or glued to concrete and fastened with additional anchors, by arrangement of monolithic concrete holders or additional layer that is built up from the bottom of elements.

The purpose and objectives of research. Experimental samples were designed with concrete S20/25. This choice was caused by preventing the destruction of the beam in the compressed zone of concrete. Estimated value of the compressive strength of concrete is $f_{cd} = 13.5 МПа$. This class of concrete is used in most unprestressed flexural members which are reinforced with rebar physical platform fluidity. Concrete used granite gravel of fraction 5-20 mm. As the fine aggregate silica sand of Mykolayiv quarry was used. Its module size is Mk = 2.1.As a binder - cement of Mykolayiv cement factory mark M400 was used. Drinking quality water was taken from the public waterwork system. The mixture was produced in the concrete mixersputting it further in a metal casing, sealing was carried out with the help of vibrator. Initial curing of concrete occurred in steaming chambers, with further hardening before the project strength - Indoor temperature of 12-18 ° C and humidity of 60-75%. All works connected with the production of reinforced concrete beams were carried out at the "Lviv concrete products plant № 2." Physical and mechanical properties of concrete (strength class of concrete) were determined by testing cubes size 150h150h150 mm [8]. Light load conditions studies measuring strain and the method of determining the initial elastic modulus of concrete were taken as recommended [8]. Basic fittings adopted rod ø12A400S beams, additional reinforcement armature sheet, corresponding brand VSt3ps steel (S285). Fittings in the compressed zone of concrete adopted constructive ø8 A400S. Transverse reinforcement and constructive ø8 A240S. Mechanical embedded parts were made of sheet steel (grade VSt3ps) that was welded to the frame of the samples by hand arc welding. Physical and mechanical properties of steel were determined by testing standard specimens of steel in tensile machine with simultaneous recording charts relationship between strains and stresses, the test results are presented in Table 1. Steel tests were conducted by G.V. Karpenko PMI of NAS of Ukraine.

Table 1

The test results of samples of steel

№	l_0, мм	d, мм	t, мм	b, мм	$P_в$, кг	$P_т$, кг	$\sigma_в/\sigma_т$ кг/мм^2
Sheet reinforcement							
1	90	-	2	20	1517	1175	38/30
2	90	-	2,1	19,8	1508	1170	37/29
3	90	-	2,1	19,9	1512	1180	37/29
Rod reinforcement Ø12 (A400C)							
1	75	8	-	-	3065	2550	61/51
2	75	8.1	-	-	3071	2555	60/51
3	75	8.1	-	-	3080	2560	60/51

With the described materials two concrete beams of rectangular section length - 2600 mm, width - 120 mm, height -240 mm. were produced. Reinforced by welded frames. Basic physical and mechanical properties of test specimens of flexural elements is listed in Table 2.

Initial modulus of elasticity of concrete was determined using the following empirical formula :

$$E_{ck} = \frac{43000 \cdot f_{ck,cube}}{\left(21 + f_{ck,cube}\right)}$$

where $f_{ck,cube}$ - cubes strength of concrete , MPa

Table 2

Physical and mechanical properties of test items

Make sample	Beams H-I	Beams H-II
Heavy concrete strength class C16/20 C20/25		
$f_{ck,prism,}$ MPa	17,1	17,1
E_{ck} , MPa	25533	25533
Reinforcement of stretched area- rod A400C		
Ø, мм	12	12
f_{yk} , MPa	510	510
E_s,x10^5 MPa	2,7	2,7
Reinforcement of compressed area - rod A400C		
Ø, мм	8	8
f_{yk} , MPa	405	405
E_s,x10^5 MPa	2,1	2,1
Cross reinforcement - rod A240C		
Ø , мм	8	8
f_{yk} , MPa	245	245
E_s,x10^5 MPa	2,1	2,1
Additional reinforcement (strengthening) - sheet, class S285		
t , мм	2	2
R_{yk} , MPa	290	290
E_s,x10^5 MPa	1,8	1,8

For the experiment , as test samples , we used two beams of width - 120 mm , height - 240 mm, length - 2600 mm from the working span of 2400 mm. The design of the experimental beams with additional reinforcement is shown in Figure 1.

In beams H- I and H- II two longitudinal rods Class A400S ø8 were designed in the compressed zone of concrete to eliminate the premature destruction of the beam in the compressed zone of concrete. All beams have transverse reinforcement of ø8 class A240S, in supporting areas in increments of 100 mm in the zone of pure bending a length of 800 mm there are two transverse rods . In supporting areas cross reinforcement is constructed, excluding demolition beams on inclined sections . In the stretched zone of research elements rod grade 12 A400S was designed. For additional reinforcement sheet steel width - 100 mm and thickness - 2 mm. was used. The cross rebar’s of frame KP-1 served as the transverse reinforcement to counter the emergence of inclined cracks arising from pricking stresses near the supports , and ensure teamwork concrete compressed zone of the reinforcement in the tension zone. From the design requirements and the perception of significant shear forces along the plane of the connection of additional sheet reinforcement and concrete at the base parts of the research elements tight end stops were designed . As reinforcement of the sheet reinforcement was performed without bond with concrete along the length of the beam , the collaboration between reinforcement and concrete was provided only by end stops at the edges of the beam. End stop was designed with one edge of the rib with thickness of 3 mm and a length of 100 mm. Mechanical shoe plate 8 mm thick was attached to the rib by two vertical welded back-to-back an gles seams. Also, the plate 4 mm thick was welded to the rib and to which additional sheet reinforcement was rigidly attached by the two longitudinal fillet welds.

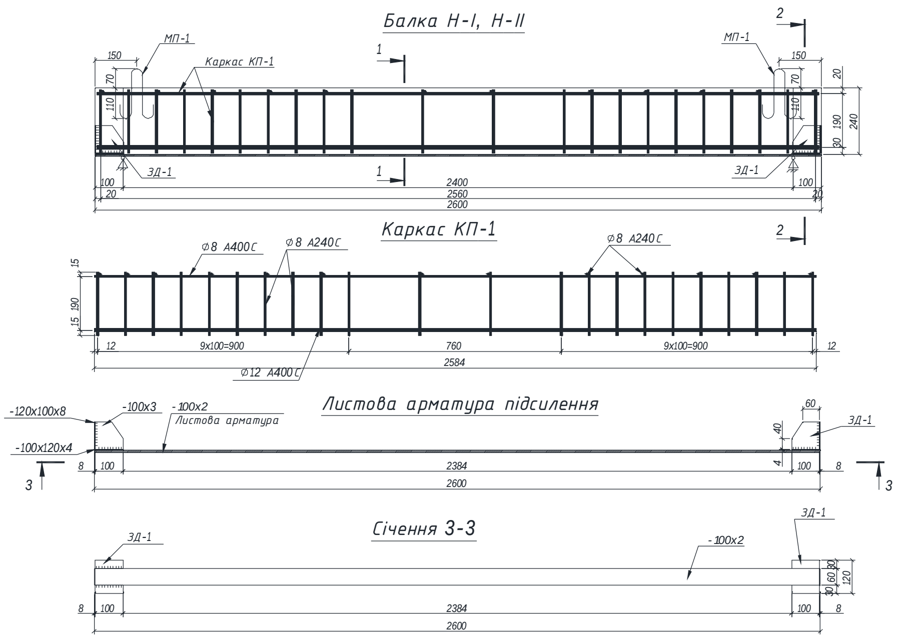


Fig. 1. The design of the experimental beams with additional reinforcement

Reinforced-concrete element under research was tested according to the scheme of single-span hinged beam on the bending moment action. The moment was created by two concentrated forces Tests were conducted on the mains stand with the 2400 mm working span of researched element. Investigation of strength and deformability of concrete cubes was carried out on a hydraulic press of mark number P250 1343. Research of the strength of beams was carried out on the test bench. Its load was passed through the distributional traverse to the upper border of the researched element in two concentrated forces symmetrically relative to the middle of the beam, the distance of the supports was 800 mm. The load created by a hydraulic jack was controlled by the size of the reference reaction, which was measured using two ring dynamometers, which were respectively pivotally movable and immovable prop. Loop dynamometers were previously branded. Hinged fixed bearing is designed as a ring dynamometer bearings of its radius, the hinge resistance movement supporting parts were made flat.

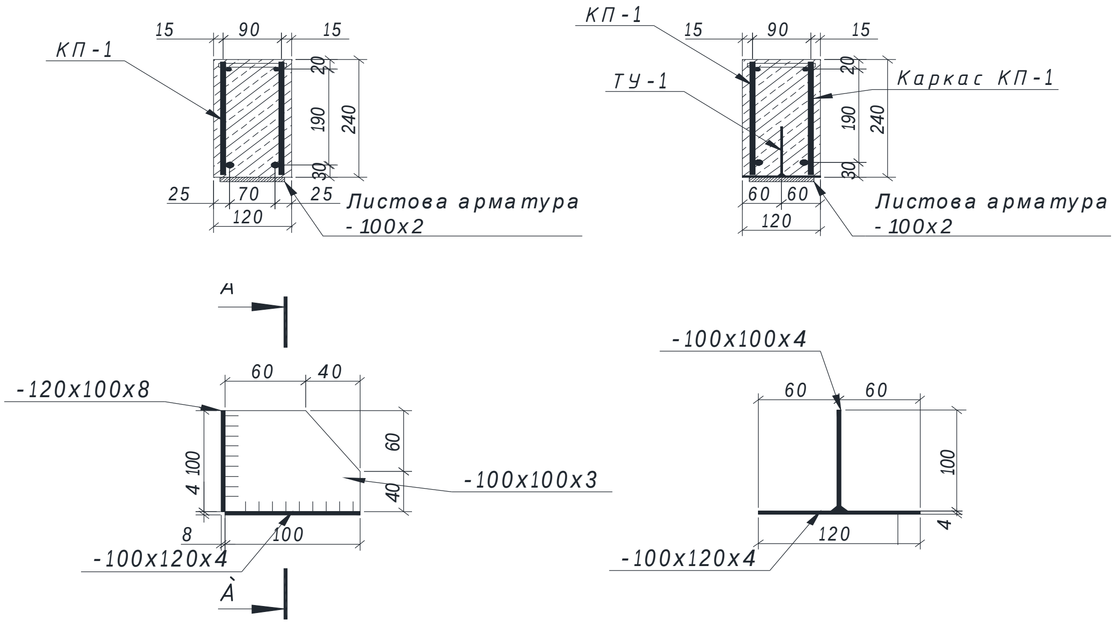


Fig. 2. The design of the experimental beams with additional reinforcement (section 1-1, section 2-2)

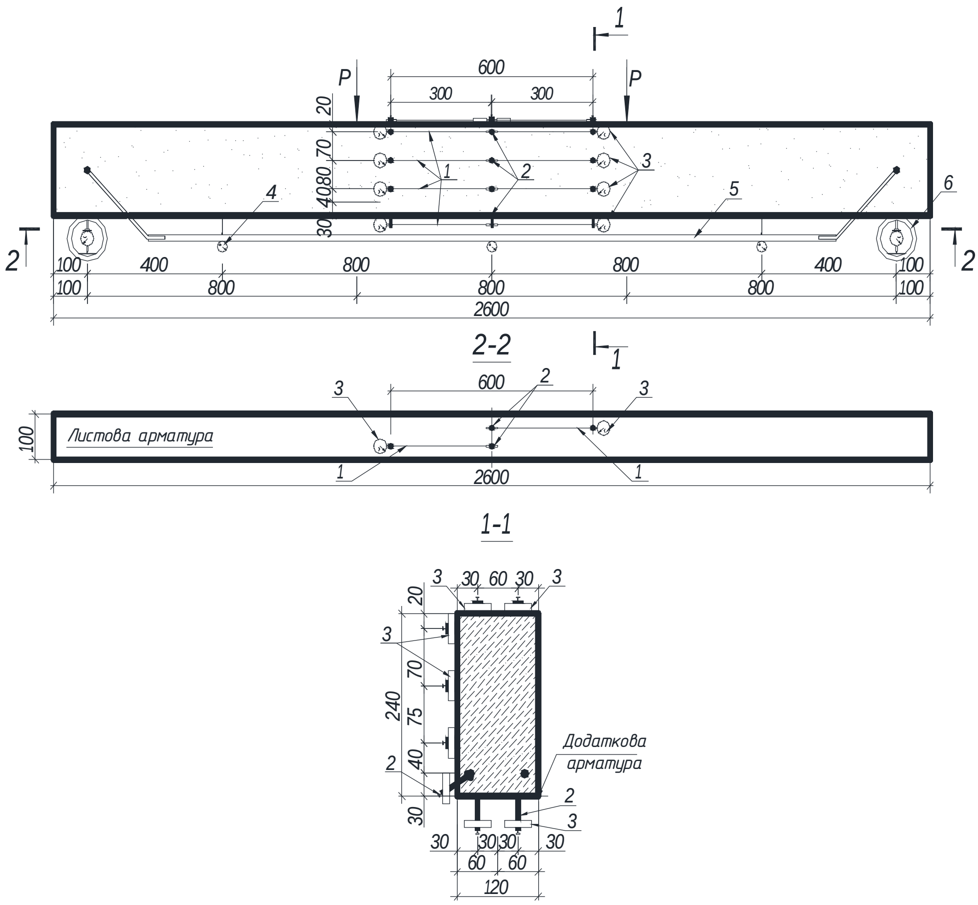


Figure 3. Layout of instrumentation
1 - unifying core, 2 - counter of microindicator 3 – microindicator division value 0.01 mm,
4 - flexure meter 5 - metal frame, 6 - ring dynamometer.

Fig. 4. Placing additional sheet reinforcement in the tension zone of the beam

*Fig. 5. test cube size 150 * 150 * 150 mm*

Fig. 6 Hard edge supports

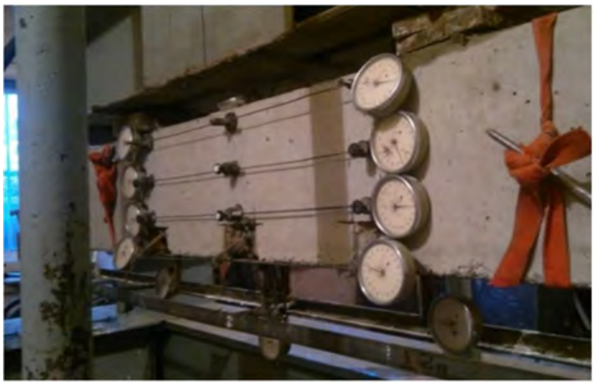


Fig. 7 The test beam. Placing instrumentation.

Figure 7 presents the layout of devices in short-term load. Strains of stretched and compressed zone of concrete strain sheet and rod reinforcement were measured by microindicators with division value 0,001 mm 300 mm. Elements for devices installation were stuck to the concrete beams using epoxy glue, transition elements were welded to the sheet and rod reinforcement. Location of the devices along the beam height makes it possible to obtain distribution of strains along height of beams with full and partial unloading and use these data to establish the design scheme of effort in the process of unloading. Flexures of beams were measured by three indicators of watch -type scale division of 0.01 mm, which are fixed to a metal frame. At each stage appearance of cracking was recorded and on the side surface their character development was displayed. Thus crack opening width was measured at a height of 30-40 mm from the bottom of the beam height and penetration of cracks in higher section of the beam . Width of opening was measured by microscope MPB -2M with a scale division of 0.005 mm and height of development - a ruler with millimeter divisions.

Load steps before the formation of cracks had 0.05P and after the formation of cracks – 0.1P, from exposure to stress levels . After holding the load for 10 minutes all data of microindicators , flexure meters was recorded, each load at which a crack appeared was recorded as well as the width of opening.

For H- beams and the percentage of the main reinforcement rebar 0.78% and the percentage of reinforcement rebar additional 0.69% of experimental values determined strength concrete and reinforcement strains and deflections of beams at short test at load levels up to 70 % of the devastating not reinforced beams and full unloaded before installing additional reinforcement. After installing additional reinforcement beams were tested again. For beams of H -II with primary reinforcement percentage of 0.78% and the percentage of additional reinforcement armature 0.69% experimental values determined strength concrete and reinforcement strains and deflections of beams at short test at load levels up to 70 % of the devastating unstrengthen beams and equal discharge to 30% of the damaging before installing additional valves. After installing additional reinforcement beams were tested again.

Experimental studies . Unloading of the tested samples was carried out from a 70% level of the damaging bending moment for beams and also without additional reinforcement. For sample H- I a complete discharge was performed, and sample H- II - partial, up to 30 % of damaging moment. When unloading tested samples of reinforced concrete beams with load level of $M = 0.7M_p$ gradual decrease of deflections of beams was observed, but not a full return to their initial indicators. This is due to the fact that the test items developed residual inelastic strains. Observing strains of concrete and reinforcement (Fig. 8) the impact of residual inelastic strains during unloading items that affected the value of their return to the initial landings experimental beams can also be noted. During unloading a gradual closing of formed cracks was observed.

In the process of strengthening of reinforced concrete beams reinforced steel was pulled to stress slightly below the working rod reinforcement, in order to simultaneously achieve fluidity of armatures. This is due to the fact that sheet reinforcement has a smaller estimated resistance to stretching and is further positioned relatively to the neutral axis than the main reinforcement. Accordingly, the sheet reinforcement rather reaches the elastic- plastic state than the rod reinforcement. The tested reinforced-concrete beams were reinforced with sheet reinforcement without bonding with the anchoring of the ends with pre- welded studs. Tension of sheet reinforcement occurred via edge resistance. While tension extra sheet reinforcement decreased deflections of beams D and return deformation of concrete and reinforcement (Fig. 8) , the closure and reduction of the width of the crack openings which were formed before unloading the researched beams.

With further load deformation of concrete and reinforcement, deflections enhanced research items increased much less than the last load levels to gain. This suggests that additional sheet reinforcement was involved in the work. And the smaller the deformation of the beam in the initial stages of loading after amplification, the better additional reinforcement included in the work was. It can be concluded that an additional sheet reinforcement bar included in the work of the first level loads after amplification. In this case, higher levels of loading additional sheet beam fixture does not use all of its characteristics of strength through the main achievements of the yield strength of reinforcement rods in cases no fully using sheet reinforcement.

With increasing stress and rising tensions in the compressed zone of concrete and normal development of cracks in beams where they are formed , there comes a time when the item is no longer resistant to these efforts. This defines the end of the second stage of the stress- strain state of the beams , characterized by the beginning of significant inelastic deformation in the main reinforcement. There comes a stage destruction of reinforced concrete elements.

Tension in the stretched zone reinforcement reaches liquid limit before the concrete compressed zone reached a voltage equal to the resistance of concrete in compression. In this fast growing deflection element and the height decreases rapidly compressed zone of concrete due to the development of cracks in height and display of inelastic deformation of concrete compressed zone of the crack. In conducting tests of samples strength calculation without experimental beam amplification was performed according to current standards with the main physical and mechanical properties of concrete and rebar, which was determining by testing standard specimens. Estimated time of experimental beams without reinforcement is to establish the effect of the discharge on the strength and deformability of concrete reinforced prototype was tested in experimental and H- beam , which loaded the level of stress then unloading to gain and was downloading pilot beam until the loss of bearing capacity , which corresponds to the crack occurred for the not reinforced H- beam. And when bending moments . The height of the first crack was formed 0,13-0,3 out of the total height of the beam.

If the operating load ($M = 12.48 кНм$) crack opening width was 0.15 mm, up to a height of 0.6-0.7 beams. And for enhanced H- I beams and a maximum width of cracks was 0.4 mm at $M_p^e = 30.68 кНм$. Upon reaching the limit load crack in the middle of the beam spread to a height 0,7-0,73 height of the beam. To determine the effect of unloading on the strength and deformability amp prototype beam H- II loaded to the load level $M = 0.7M_p^{norm}$, then unloaded up $M = 0.3M_p^{norm}$ and brought to destruction.

Beam H-I *Beam H-II*

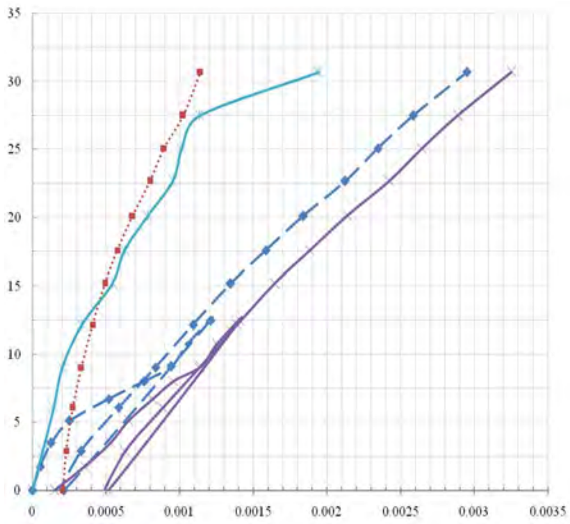


Figure fixture deformation of rod and rebar reinforcement beams and H-I

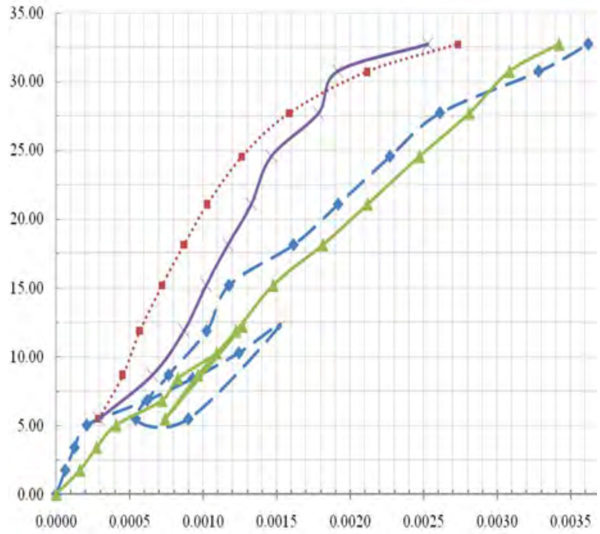


Figure fixture deformation of rod and rebar reinforcement beams and H-II

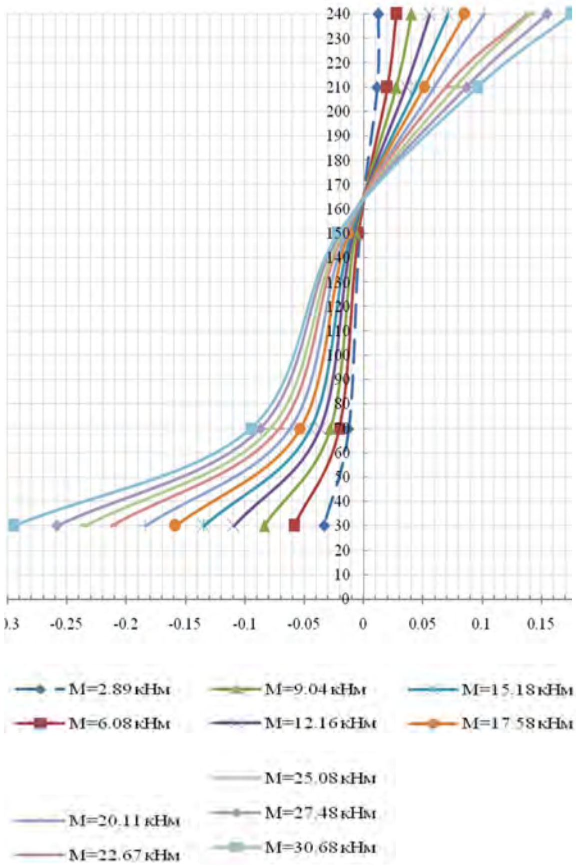


Figure deformations of concrete beams, height-H-I

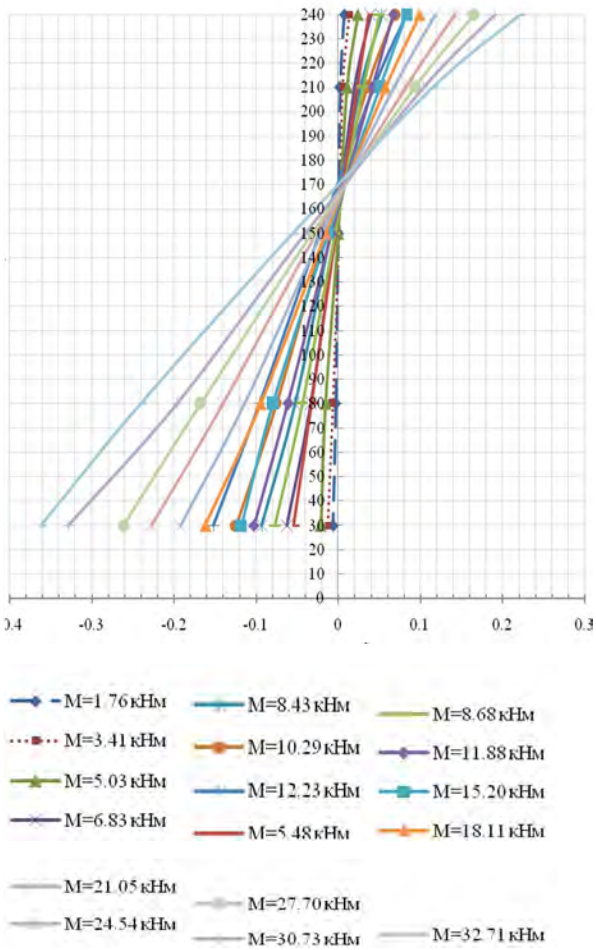
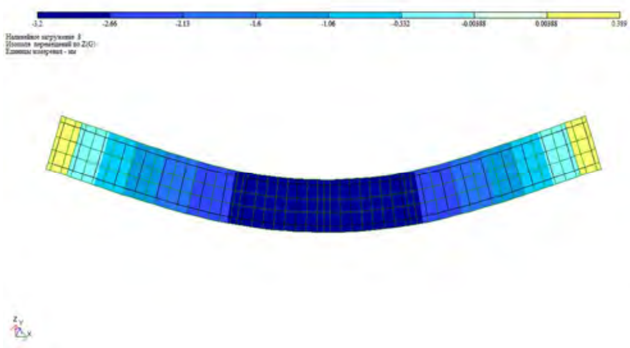


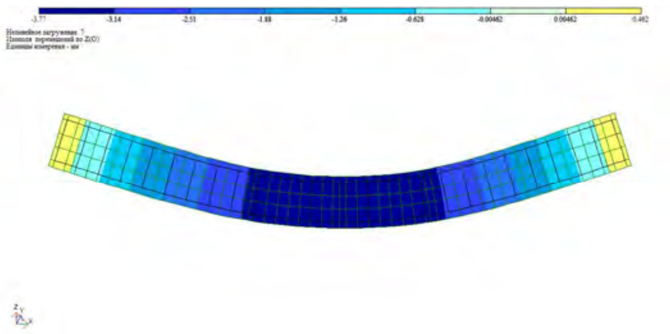
Figure deformations of concrete beams, height-H-II

Fig. 8.Graphics deflection strains, sheet and rod reinforcement, concrete beam height.

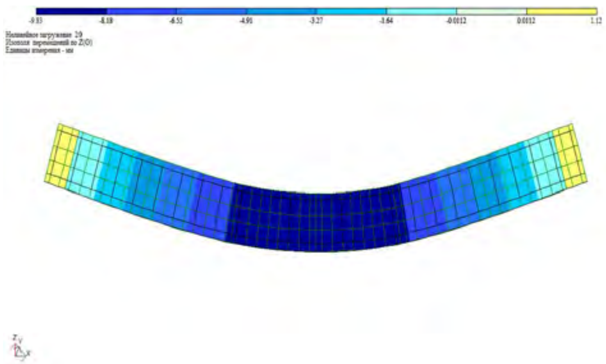
Beam H-I *Beam H-II*



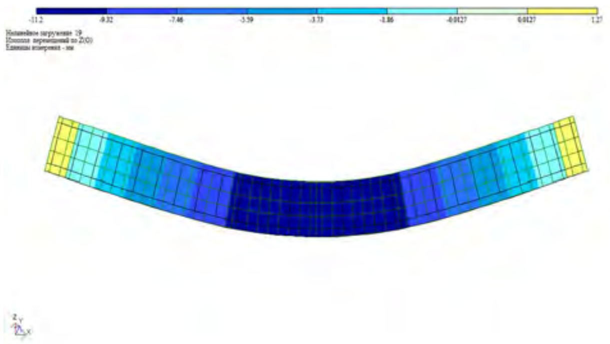
Isofields of displacement along the axis Z (model H-I beams and to reinforce).



Isofields of displacement along the axis Z (model H-II beams and to reinforce).



Isofields of displacement along the axis Z (model H-I beams, and after amplification).



Isofields displacement along the axis Z (model H-II beams, and after amplification).

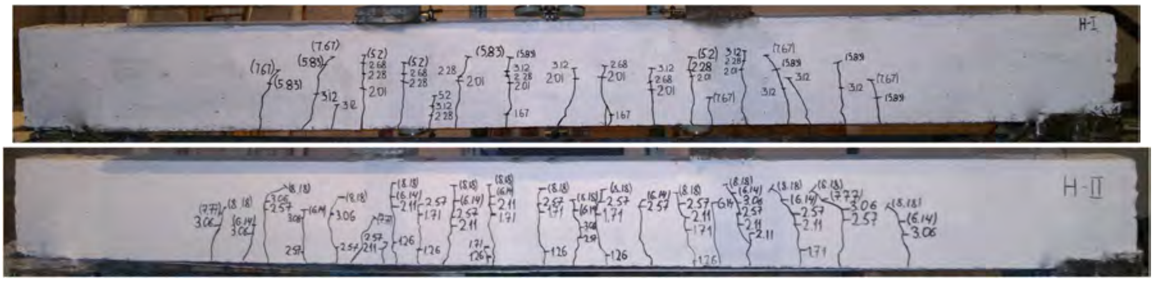


Fig 9. Nonlinear calculation of test samples in the software sector Lear 9.6. Crack spreading along the beam height depending on the load.

The experimental value destroying moment in this case was $M_p^e = 24.54kH\text{м}$. Cracking occurred for not reinforced beam H- II in bending moment $M = 5{,}03\kappa H\text{м}$,up 0.12 of the total height of the beam. In the case of operational stress crack opening width was 0.15 mm, their height - the height 0.5-0.6 overall beam. And for reinforced beam H- II maximum width of cracks was 0.3 mm at $M_p^e = 24.54kH\text{м}$. Compared with H-I beam the number of cracks increased by 20 %. In the H-I beam and fluidity of the basic and additional reinforcement occurred simultaneously. This is primarily due to the full discharge of a sample, allowing us to eliminate the elastic strain in the elements of design. $\varepsilon_{s,\ letter}$. = 21 * 10^{-5}. Sheet reinforcement that worked without adhesion to the concrete and deformed almost uniformly along the length and reaches the yield stress at the site of action at the moment of greatest δ is possible plastic strain offset tension reinforcement sheet that corresponds to the relative elongation. $\varepsilon_{s,\ letter}$ = 114 * 10^{-5}. Relative elongation $\varepsilon_{s,sterzh}$ = 295 * 10^{-5}.εFluidity came the reinforcement rod with a relative elongation In the beam of H II fluidity sheet reinforcement occurred before rod . The load that meets this condition was taken as devastating. Bending moment , which corresponds to the load is $\varepsilon_{s,\ letter}$ = 127 * 10^{-5}, which correspond to its yield point. Thus the relative elongation of leaf -laden fixtures $\varepsilon_{s,sterzh}$ = 227 * 10^{-5} intension reinforcement sheet corresponds to a relative elongation relative deformation of rod reinforcement.

To compare the results obtained by the experimental method was the calculation of the LIRA 9.6. The calculation is based on the method of finite elements in the movements. The main unknown were taken moving units: linear along the axes X and Z and the angle around the axis Y. In the design scheme included 210 type (physically nonlinear spatial versatile rod finite elements) and type 230 (physically non-linear finite element four-angled dimensional problem (beam wall). Finite number of steps the load model consistent with the number of stages in beams investigated experimentally. in fig.9 shows the estimated finite model beams.

Conclusions

1. Data obtained from the experiment allow to assess the nature of crack formation and destruction of tested items, namely the development of deformations of sheet and rod reinforcement, time of formation, the maximum height and width of the crack opening.

2. Maximal load carrying capacity and deformability of researched beams is experimentally determined.

3. Strengthening of reinforced-concrete flexing members with sheet reinforcement without bond and previous prestressing that were not subject to full unloading is not fully effective because of residual permanent deformation of primary reinforcement and concrete deformations.

4. To increase the effect of amplification in order to gain full use of the reinforcement it is necessary to carry out the tension of sheet reinforcement.

5. Previous tension of sheet reinforcement provides a quick and full inclusion of additional reinforcement in the work of the reinforced construction.

6 Level of unloading determines the amount of residual strains of concrete and main reinforcement as a whole, which has a direct impact on common work of initial and additional reinforcement of beams after strengthening.

7. To increase the carrying capacity of elements with a high level of stress in the initial rod reinforcement, the factor of additional reinforcement armature should approach or have higher value than the factor of the main rod reinforcement .

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