Strengthening prefabricated reinforced concrete roof beams that are damaged by corrosion of concrete and reinforcement

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Abstract. In this article are analyzed different methods of strengthening reinforced concrete structures as ceilings and coverage. And there are also structured methods and the principles of their execution. In this article are described in detail and are shown graphically the methods of strengthening prefabricated reinforced concrete I-beams of coverage (its span is 12 m), which were in accident technical state at the moment of examination. The compression and tensile areas of concrete in structures were completely destroyed by corrosion, and furthermore the joint work of normal concrete and pre-stressed reinforcement was not ensured. In general, the examined methods of strengthening concern the reinforced concrete structures, where the strengthening elements come to work in conjunction with the existing concrete and reinforcement. Presented method consists in total forces transfer on strengthening elements, i.e. concrete and reinforcement of the existing reinforced concrete structures of floorings are completely excluded from work.

1. Introduction
The necessity to strengthen bearing structures (ceilings and roof) during the operation happens not only during renovation, but as a result of negligent operation and impact of corrosive medium on these structures. Long operation of structures in variable thermal and humidity conditions reduces its operational reliability and presence of corrosive medium greatly accelerates loss of the bearing capacity of the structures. Therefore, reinforced concrete ceilings and roofs are strengthened not only to ensure the necessary serviceability for structures at change the active loadings on them, but when defects and destructions occur as a result of negligent exploitation [1-4].

There are such factors, which need necessity of execute the strengthening of bending elements during all the operational time of building structures and constructions [5-8]:

a) the renovation with modernization of technological processes that cause to the increase the loading on the ceiling and change of its constructional scheme;
b) the loss of operational integrity with physical ageing of structures' materials during its intensive and long exploitation;

c) the change of initial designed temperature-humidity parameters of environment at its aggressive action to normal concrete and reinforcement;

d) the appearance of extreme situations on enterprises, which cause to hazardous technical state of building structures;

e) the negligent execution of design documentation, unsatisfactory production and assembling of structures, the changes in normative documents.

Strengthened of the reinforced concrete structures have been performed since the beginning of the 20th century. At first, the scientists used even layer of plaster and stowage of strengthened layer of normal concrete as kind of reinforcement [9, 10]. In 1936 Henri Lossier used stirrups with pre-stress for structures which were inclined to cracking. He also recommended using additional longitudinal reinforcement at insufficient area of existent reinforcement [1]. In 1938, in Britain, were executed pre-stressing of subdiagonals by mechanical method with the help of adjuster bolts. This method was used for strengthening of reinforced concrete beams. In 1930-40, adhesion of ‘new’ concrete to ‘old’ concrete was used for reinforcement, one-sided joint of reinforced concrete structures and the filling method of jackets and strips with addition longitudinal reinforcement and stirrups. The solution of these questions was searched for by A.A. Gvozdev, I.M. Litvinov, I.F. Sharov, A.A. Sudarikov [1-3]. From 1949, Lozovyy Y.I. executed the strengthening of reinforced concrete structures under the loading. For existent structures, which were needed the strengthening; he inputted new elements in the form of additional reinforcement, spatial ties of squeezing and systems of one-sided bonds. At that the stressed state of strengthened elements were executed by thermal, thermal-electric and thermomechanical methods. Also it was interesting the method of strengthening bending elements by means of local stress for tensile and compressed areas and creation in its stress, which is reverse of the sign from stresses that create working load [1]. These investigations were continued by other scientists of Lviv Polytechnic National University, in particular E.R. Khilo and B.S. Popovych. They investigated the strengthening of reinforced concrete beams by means of prestressed articulate and bar chains [11, 12]. These investigations were introduced in many enterprises of Ukraine and Russia.

Today, the Department of Building Constructions and Bridges of Lviv Polytechnic National University actively execute the investigations and give practical guidelines of the strengthening for flexural members, which were lost its bearing capacity under influence of different factors, which are described earlier. In [13] are shown the investigations of the strengthening for structures by reinforced concrete casing. The feature of this strengthening is accounting of existent deflected mode. The important aspect of strengthened structures is its durability and reliability of exploitation, inasmuch as these parameters can change after the strengthening [14]. Fairly often during the strengthening of bending structures are strengthened only normal sections, because it appears necessity to increase quickly and safely the bearing capacity of oblique sections [15]. The most of scientists note that for economical decision of strengthening with predicatable estimation stress condition after strengthening, it is necessary to take into account the stress condition of structures before the use of strengthening with ensuring of joint work of principal and additional reinforcement. Strengthening of steel concrete structures (we can use these methods for reinforced concrete structures) with unloading of beams, which are strengthened, to any level, was described in [1-3]. These investigations enable to use derived experimental values of the strength for estimation of technical state, bearing capacity and operational integrity of structures. The experiments proved that the unloading of bearing structures to any levels decreases the quantity of reinforcement for strengthening and ensures considerable economy of building materials. For use of strengthening with unloading, it is necessary that in structures, which are subject to strengthening, are not considerable loss of physical-mechanical properties of normal concrete and reinforcement with ensuring of its joint work.
Our scientific work shows how possible to do the strengthening of precast reinforced concrete I-beams without unloading with the help of steel casting with prestressing of reinforcement rods. At the moment of the strengthening, the structures were in accident operational conditions (class ‘4’ [16]), they had considerable physical-mechanical damages of normal concrete and reinforcement as a result of influence of corrosive medium for its (fig. 1, 2). These structures were not subject to unloading, i.e. the ensuring of joint work of principal and additional reinforcement is not possible [17, 18].

Figure 1. The parts of building with two spans, which are equal to 12 m. The destruction of compression and tensile areas of normal concrete of supporting part of precast reinforced concrete beam. The uncovering of reinforcement from cold drawn wire

Figure 2. The parts of building with two spans, which are equal to 12 m. The destruction of compression and tensile areas of normal concrete with falling away its separate parts in middle of span of prefabricated reinforced concrete beam. The uncovering of reinforcement from cold drawn wire

2. Materials and methods
The prefabricated reinforced concrete I-roof beams (its spans were accordingly 12 m and 24 m) are in storage rooms, where preserve dairy products. Formerly, the investigated building was a former dairy factory, which located in Drogobych, Lviv region, Ukraine. This building is two-aisle building, which are conditionally divided on two parts by deformation joint. Each of these parts has two different spans – 12 m and 24 m. The constructional scheme of structure is full reinforced concrete frame with wall reinforced concrete cladding panels. The column spacing is 6 m in longitudinal direction. The main vertical bearing structures of two parts of building are reinforced concrete frames, the columns of which are rigidly jointed with foundations and they are hingedly jointed with girders. The frameworks dispose along numerical axes. The geometrical invariability of building’s parts ensures by rigid connection of columns in foundations and by disc of reinforced concrete slab roofs. In building with two spans, which are equal to 24 m, are present brick walls (its thickness is 380 mm) with strip foundations. The separate walls were used as supports for independent steel trusses in places, where disposed destroyed precast reinforced concrete roof beams (fig. 3). It was not able to executed the bearing of independent steel trusses, inasmuch as protective brick walls, which were used as bearing, were absent in part of two-aisle building with two spans that were equal to 12 m. As a consequence of we made a decision to do characteristic strengthening of reinforced concrete I-beams (its span was 12 m), i.e. we took in casing each of beams, which were need the strengthening (fig. 1, 2). The strengthening method was chosen on the basis of information, which is described earlier.
Figure 3. The part of building with two spans (span was 24 m). The strengthening of destroyed precast reinforced concrete beams by means of establishment of independent steel truss of angle bars

3. Results and discussions

The constant loads for roof beam were determined as a result of roof's opening. Total thickness of roof was 480 mm, including the thickness of prefabricated ribbed slab roof was 300 mm, and the thickness of layer on top prefabricated ribbed slab roof was 180 mm. The layer on top prefabricated ribbed slab roof were formed of eight-six layers of asphalt felt, asphaltic concrete covering (30-40 mm), foamed concrete as heat insulation (100 mm), vapour seal. Also there was not long ago carried out renovation, which consisted in gluing on new layers of asphalt felt. The temporary load was accepted by [19], as for framed building, which was built in urban zone of fourth snow region with characteristic snowy loading 131 kgf/m² and in urban zone of fourth wind region with characteristic wind loading 52 kgf/m².

The beams, which were necessary to strengthen immediately, were determined by means of visual and instrumental investigations (fig. 1, 2). Furthermore, the quantity of beams was adjusted with plant management. Unfortunately, the present investigation of beams and slab roofs (February 2019) noted considerable impairment condition of bearing structures of workshop from 1997, i.e. from last investigation of structures. Some beams and detached ribbed plates were in accident conditions and in technical state by paragraph 5.3 [16] (fig. 1-3).

For the purpose of reliable inclusion of strengthened systems in joint work with existent structures and creation the forces of prestress in these structures; the strengthened rods (items 8-13) were heated to temperature 225-250°C before welding. The control of heating temperature was executed at colour of oxidative thin layers on purified areas of surfaces from oxidations (items 8-13). Besides that, the clean sections were evenly situated with spacing 300-400 mm along rod. The welding of rods, which are prestressed, was executed in hot condition [20]. The strengthened rods were supported in heated condition till end of welding each of four pair of rods, which were symmetrically, arranged relatively middle of beam.

The order of execution of works for strengthening of prefabricated reinforced concrete I-beams (fig. 4-8):  
1. To establish temporary fixing of beam (for time of a strengthening).  
2. To clean the surface of beam that is subject to strengthening, from stratification of plaster, paint mortar and soiling. Full cleaning of beam’s surface has to execute by stream of water.  
3. To prepare necessary elements of strengthening, to compare its sizes with actual sizes of reinforced concrete beams.  
4. To clean the surface of strengthened details (as stated above), to apply one layer of paint-and-lacquer coating (with the exception of weld zones).  
5. To establish lower longitudinal angle bars (item 1) on overhead flange of beam using transversal short angle bars. Verify the position of indicated strengthened elements, to fuller densely all openings between surface of beam and angle bars by the cement-sand grout.  
6. To establish vertical angle bars (item 7) in design position and to fix angle bars by erection welds to item 1.
**Figure 4.** The general view of prefabricated concrete beam of strengthening:

1 - upper band of angle bar (angle bar 160x10 mm, L=11967 mm); 2 - lower band of angle bar (angle bar 160x10 mm, L=11967 mm); 4 - connection element of upper band of angle bar (angle bar 80x7 mm, L=480 mm); 5 - connection element of lower band of angle bar (angle bar 80x7 mm, L=300 mm); 6 – supporting connection element of lower band of angle bar (angle bar 80x7 mm, L=360 mm); 7 – support (angle bar 80x7 mm, L=811 mm); 8, 9, 10, 11, 12, 13 – braces (reinforcement tension bars 2Ø28 А400С, accordingly L=1761 mm; L=1724 mm, L=1647 mm, L=1603 mm; L=1518 mm, L=1650 mm)

7. To establish lower longitudinal angle bars (item 2) in design position and to join angle bars by erection welds with items 5-7.

**Figure 5.** Sections 1-1, 2-2, unit A

1 - upper band of angle bar (angle bar 160x10 mm, L=11967 mm); 2 - lower band of angle bar (angle bar 160x10 mm, L=11967 mm); 4 - connection element of upper band of angle bar (angle bar 80x7 mm, L=480 mm); 5 - connection element of lower band of angle bar (angle bar 80x7 mm, L=300 mm); 6 – supporting connection element of lower band of angle bar (angle bar 80x7 mm, L=360 mm); 7 - support (angle bar 80x7 mm, L=811 mm)
8. To verify the position of indicated strengthened elements and to fuller densely all openings between beam and angle bars by the cement-sand grout (items 2, 5, 6).
9. To apply the designed seams between items 1-7.

Figure 6. The units B, C, J, section a-a, the joining of diagonals (items 8...13) to bands of angle bars (items 1, 2): 1 - upper band of angle bar (angle bar 160x10 mm, L=11967 mm); 2 - lower band of angle bar (angle bar 160x10 mm, L=11967 mm); 4 - connection element of upper band of angle bar (angle bar 80x7 mm, L=480 mm); 7 - support (angle bar 80x7 mm, L=811 mm); 10, 12 - diagonals (reinforcement tension bars 2Ø28A400C, accordingly L=1647 mm; L=1518 mm); 14 - erection weld

10. To heat (as stated above) and to establish diagonal bars (items 8-13) in design position and apply designed seams. The reinforcement rods are necessary to establish symmetrically beginning at the middle of beam.

11. Additionally to clean weld zone, and in case of need to clean the other surfaces of steel elements.
12. To apply required quantity of anticorrosive coat’s layers.

Figure 7. The units F, G, K: 2 - lower band of angle bar (angle bar 160x10 mm, L=11967 mm); 3 - plate 10x140x140 mm; 5 - connection element of lower band of angle bar (angle bar 80x7 mm, L=300 mm); 6 - strong connection element of lower band of angle bar (angle bar 80x7 mm, L=360 mm); 7 - support (angle bar 80x7 mm, L=811 mm); 8 - diagonal (reinforcement tension bar 2Ø28A400C, L=1761 mm); 15 - plate 10x140x900; 16 - plate 14x90x300

13. It is necessary to prepare the cement-sand grout for calking of seams between strengthened elements and reinforced concrete beam a harsh consistency with activity of Portland cement not less than
400. During calking of seams, the concrete surface of prefabricated reinforced concrete beam should be moist [21, 22].

14. The details of strengthened elements were accepted of carbon steel C245 [19] and reinforcement rod A400C [23]. The design resistance of strengthened reinforcement was \( f_{yd} = 365 \text{ MPa} \). The welding was executed by electrodes E46 by GOST 9467-75*. It is significant that the legs of fillet weld, which weren’t shown in figures, were not less than 8 mm [20].

15. The rods of diagonal (items 8-13) are necessary to weld in joints (fig. 6).

![Figure 8](image_url)

**Figure 8.** The units H, E, D: 1 – upper band of angle bar (angle bar 160x10 mm, L=11967 mm); 2 - lower band of angle bar (angle bar 160x10 mm, L=11967 mm); 4 - connection element of upper band of angle bar (angle bar 80x7 mm, L=480 mm); 5 - connection element of lower band of angle bar (angle bar 80x7 mm, L=300 mm); 7 – support (angle bar 80x7 mm, L=811 mm); 8, 9, 11, 13 – diagonals (reinforcement tension bars 2Ø28А400С, accordingly L=1761 mm; L=1724 mm, L=1603 mm; L=1650 mm)

4. Conclusions

The bearing roof structures of former dairy factory (nowadays storage room was used for storage of dairy products) were greatly injured as a result of influence corrosive medium on them. The separate structures (its span is 24 m) were completely injured and they were strengthened by independent steel trusses earlier. The damage of beams (its span is 12 m) was not greatly, however now its bearing capacity was not ensured. During the investigation of beams were discovered physical-mechanical destructions of normal concrete and reinforcement and this situation did not permit to use methods of strengthening with application physical-mechanical properties of normal concrete for perception of outer loadings. The scientific studies [6, 7, 9, 11, 12, 14, and 15] foresee partial or full inclusion in work existent materials of structures with elements of strengthening. Therefore were made decision to execute strengthening for experimental beams without unloading and to transmit forces on existent structure because physical destruction of normal concrete of flexural element was disclosed. The strengthening was used using steel rolled elements with prestressing of reinforcement rods by means of heating. This solution made possible to exclude of work reinforced concrete structure and to avoid its dismantling.

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