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METHOD OF STRENGTH DETERMINING FOR REINFORSED CONCRETE BEAM STRUCTURES RESTORED BY INJECTION MATERIALS

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Summary. *In the work the method of bearing ability restoring by means of injectable materials for concrete structures with reinforcement which is connected by fittings crimp sleeve is proposed. The influence of stress concentration on core connection fittings characteristics load capacity, deformation and fracture of reinforced concrete beams under cycle loading are determined. Based on theoretical studies optimal requirements for injection material are found and treatment of structural materials is proposed. An experimental comparative analysis of the strength of new and restored structures by injection beams is fulfilled.*

Key words: *bearing capacity, injectable material, injector crimp sleeve, cracks, workability*.

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Introduction. Losing the performance of concrete structures caused by natural wear, deficiencies in exploitation, and technological errors in manufacturing poses to engineers the problem of partial and full restoration of structures during their operation. One method to restore the load capacity of concrete structures is the method of injecting impregnation and cracks bonding with polymer compositions for special purposes.

This work is a continuation of the research described in [1, 2, 3], which studied the work of ordinary and prestressed reinforced concrete beams with connected armature. In addition, we studied the possibility of strengthening and restoration of monolithic overlapping structures with modern injection techniques and materials.

Therefore, of relevant theoretical and practical value is the research which aims to establish the degree of restoration of the bearing capacity of concrete structures in which the valve is connected with crimping sleeves using injection technique. However, these studies need to develop a methodology for restoration of their operability.

Analysis of recent research on this issue. Recovery of bearing capacity of concrete structures of long operation by injection (filling) of damaged places with new material under the domestic [1, 2, 3] and foreign [4, 5, 6] practical experience is one of the most promising long-life extension objects of use and localization of critical growth areas of damaged construction projects. Cracks may be subject to repair by the following techniques: filling; it concerns mainly large cracks (greater than 0.6 mm) or cracks that formed as a result of corrosion of reinforcement in the initial stage, but at the same time only filling itself is not sufficient; superficial "stitching" [1, 6]; mechanical stabilization [6] and closing with injection techniques [7]. According to [4, 6] superficial "stitching" of cracks is not enough, as joint work of metal and concrete elements is poorly secured.

In [8-13] the restoration of the bearing capacity of prestressed concrete structures and conventional technologies using injectable treatment materials based on polyurethane is considered.

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Scientific and methodological approaches that have been developed in G.V. Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine (PMI) [14-21] for assessing the strength and fracture toughness of concrete did not consider their change as a result of injection technology. In [16] a developed model by the design of concrete samples with pre-deposited stress concentrators is described, and testing of recovered samples reinforced with stress concentrators in the area of steel reinforcement rods showed that the re-investigation of cracks occurred outside the compound polyurethane compositions (Fig. 1).

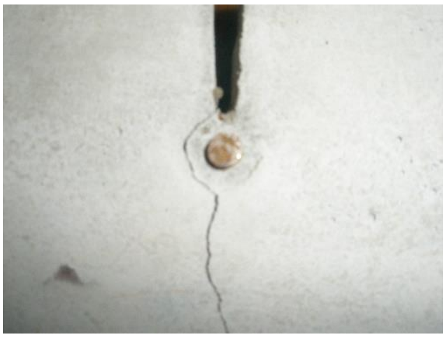


Figure 1. Line crack propagation in reinforced concrete specimen under load by bend of artificial cracks and bends around steel reinforcement

Analysis of the literature [4-7] published in our country and abroad showed:

1. The process of local treatment of concrete injection materials is not sufficiently researched.

2. There is not enough research work of concrete beam structures pretreated with injection methods, in particular, the impact of this treatment on strength, deformation and fracture toughness of structures.

3. There is not enough research work of concrete beam structures with connected armature restored with injectables. In particular, it is necessary to research the impact of stress concentration in the area of armature connection valves on such its characteristics as strength, deformation and fracture.

4. Possibility of restoring the strength characteristics of beams under cyclic loads at various levels of stress is of utmost importance.

To solve these problems it is necessary to define testing techniques, the design and the number of prototypes and the impact of injection material on the characteristics of strength, fracture and deformation of beam patterns.

The purpose of the work. We aim to develop a methodology for restoring natural strength concrete structures in which valves connected with crimping sleeves, modern injection materials and investigate the extent of restoration of damaged and partially damaged beam construction elements with modern injection materials, establish the possibility of increasing the bearing capacity of new designs and the use of these methods to restore the strength of natural objects.

Determination of stress-strain state core compound using the method of strain gauges. To study the degree of restoration of damaged reinforced concrete beams with reinforcement connections using injection techniques we must first determine the effect on core connection of strength characteristics of reinforced concrete beams under low cucle loads. In order to estimate the general state of stress in the vicinity of reinforced connection in plugs there were conducted experimental trials to determine tension using strain gauges.

During experimental studies there were used load cells with the following characteristics: the base – 10 mm; resistance – R = 201,1 ± 0,3 Ohm; ratio gauge – S = 2,16; V = 1,01; CBC = 1.61; heat treatment performed at the temperature t = 160°C.

To determine the relative deformation of armature and valves in connection hub on armature and sleeve bonded we stick strain gauges at specific locations (Fig. 2).

The surface on which sensors will be pasted must be cleaned of corrosion products and fat free. This surface must be perfectly flat and smooth.

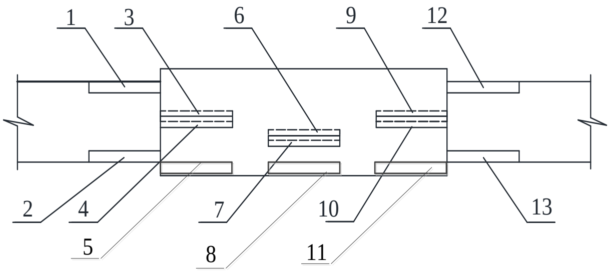


Figure 2. Location of strain sensors on bar sleeve

The results of tests armature connected with crimping sleeves were used to build graphs depicting dependence of deformation of strain reinforcing connections from incurred tensions (Fig. 3).

The results of experimental studies have shown that the stress state in length sleeve connection is uneven (Figure 3). In particular, the reinforcing rods in a neighborhood close to the hub, we observed an increase in tension between 1.8 and 2. At the same time, in the area of connection of reinforcing rods in the middle of the hub we also observed stress concentration between 1.7 and 1.9.

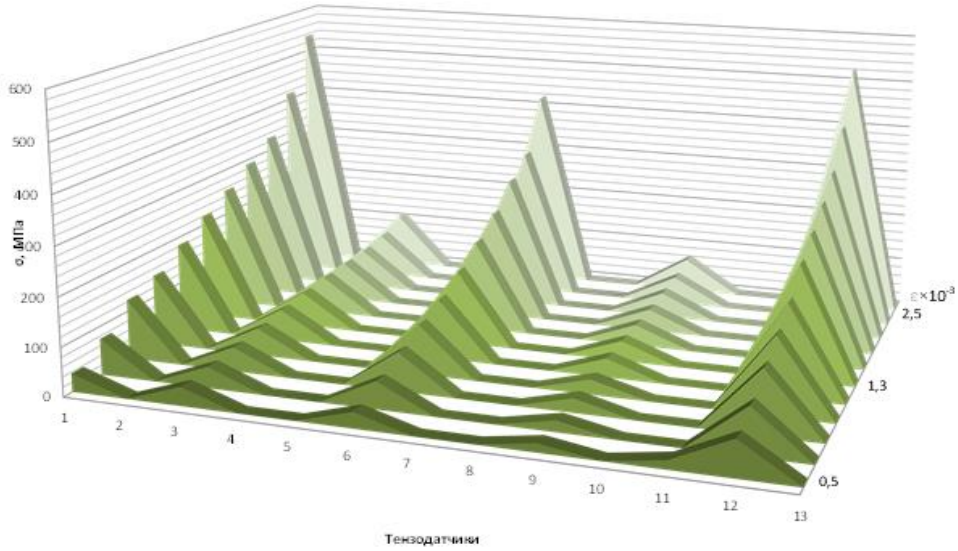


Figure 3. Graphs of stresses in new reinforcing connection

At the edges, at the points of contact of separated pieces of armature hub, there is a high concentration of stresses. From the research results it follows that the bending elements of reinforced concrete structures connecting sleeve are both optional anchor – by cutting cross-sectional area of concrete cages.

On the basis of these studies we found optimal geometric characteristics of connecting sleeves. Gage method found that stress concentration in specific areas of the connection is between 1,8-2,0.

Testing of reinforced concrete beams. The design of prototypes and experimental program is described in detail in the works [1,2,3]. Tests were carried out after 28 days after concreting. Two concentrated forces were applied to the upper face in the run-thirds (Fig. 4) to download the beams. The applied degrees load $\Delta F = 0.05F_{max}$ was used until cracking and then $\Delta F = 0.1F_{max}$ with exposure after each level for 30 minutes, namely 10 minutes to capture impressions devices and 20 minutes during the data taking. Application of concentrated forces took place using hydraulic jacks of 200 kN and distribution arms. The value of efforts was determined with two ring dynamometers located on support beams. One dynamometer was a resistance movement and was able to move in a horizontal direction, and the second was stationary.

The devices are located on the same height so as to cover all the key points: upper bound beams (compression); side faces beam at a distance of 20 mm from the upper face (compression) and at a distance of 70 mm from the upper face (neutral axis); at the center of gravity of internal steel reinforcement (tension). For measuring strain fittings we used watch-type microindicators with point value 0.001 mm, fixed on special holders that had been stuck on the concrete surface.

Stand for testing beams on bending with static load is shown in Fig. 5. During conducted testing we observed point of cracking and crack propagation. Crack moment was determined visually using a microscope MPB-3. Using a microscope we measured opening width of cracks. We fixed fractures after each stage and entered the data into the tests register.

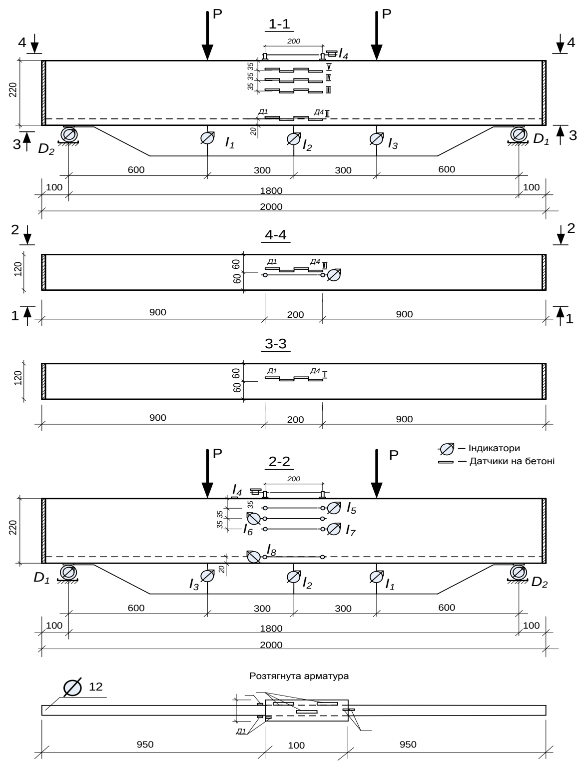


Figure 4. The scheme of testing and location of sensors on experimental beams

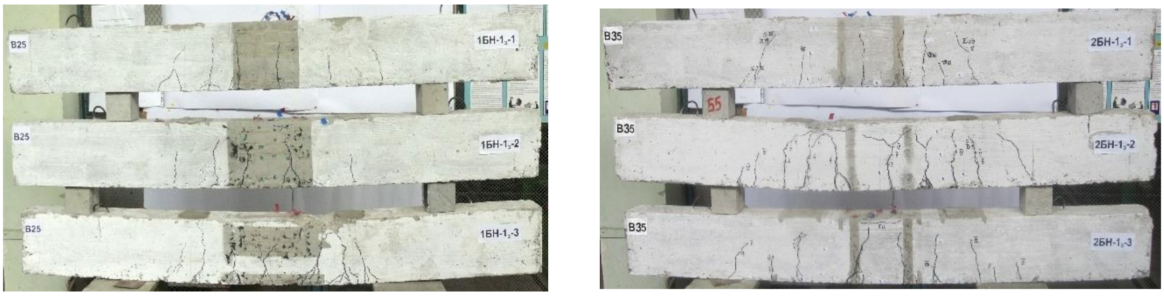
Figure 5. General view of the stand for testing of beams under bending loading

Special materials and technology of their use. Concrete beams of cross-section of 120 to 220 mm., span of 200 cm. were used in the first phase of testing. Three series beams were used.

The first series – concrete C20/25 with prestressed reinforcement, the second series – concrete C12/15 previously hard fixture, the third series - concrete C12/15 stress-free fittings.

Beams of first and second series were rebuilt after the loss of the bearing capacity (Fig. 6). Third series beams seeped applying them to load to full hardening of the injection material.

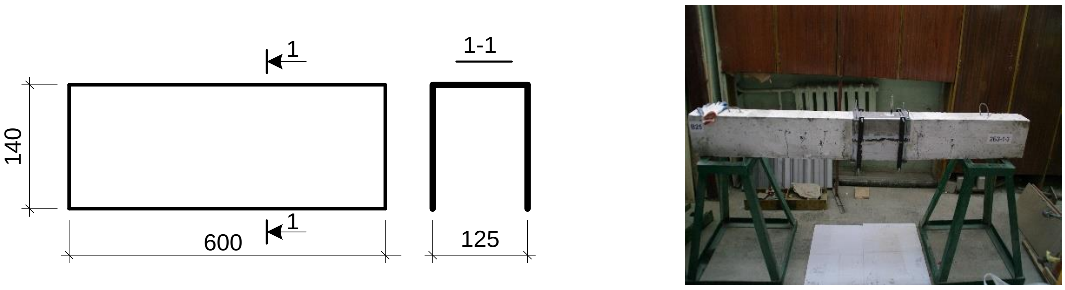
For the first and second series using bills of metal casings we impregnated three top central beams, for the next three beams we impregnated upper and lower central zone beams.



a *b*

Figure 6. The character of destruction and cracks location in previously destroyed beams:
a – concrete C12/15, *b* – concrete C20/25

For the third series using bills of metal casings we impregnated three top central beams, for the next three beams we impregnated upper and lower central zone beams. Metal housings were made from steel thickness of 1 mm. (Fig. 7, a). The guard was mounted on a beam using fixing clamps. Sealing casing was enforced with rubber gasket and epoxy glue SP RESIN 220 (Figure 8, a), which provided treatment to the pressure of 0.4 MPa for the period prior to the polymerization of the injecting material. The top of the casing is welded an injection nozzle - packer with a ball valve at the end.



a *b*

c *d*

Figure 7. The beam with fixed metallic casing: *a* – metalic casing;
b – general view of the beam with casing in the upper area of the beam; *c* – packer on the top of the casing;
d – general view of the mechanical pump Desoi HP 30-LD

Ball valve allows using a discharge device apply pressure to the injection casing material and prevents leakage and pressure loss of injection material after injection (Fig. 7, c). As the discharge device is used mechanical pump mark Desoi type HP 30-LD. This device is designed to create and maintain pressure in the range of 0.2 to 8.0 MPa (Fig. 7, d).

As an injectable material was selected two-component polyurethane resin KÖSTER KB-PUR IN III specifically designed to restore the bearing capacity of structures. This resin-elastomer is of low viscosity polyurethane-based, solvent-free, with extended setting time. After curing the resin is solid, tight-plastic. It increases in volume after contact with water. Technical characteristics of the injection material are presented in Table. 1.

Technology of beams treatment and recovery. Research beams mounted on temporary supports. In the upper area of the beam there was metallic casing gaskets on epoxy adhesive SP RESIN 220 and fixing vertical and horizontal clamps (Fig. 7, *a*, *b*). We attached to the top of the casing packer mechanical pump hose trailer Desoi type HP 30-LD make. In the mouth of the pump we poured the prepared injectable material.

Preparation KB PUR IN III. Both components are thoroughly mixed using slow-drills, then there is the expectation interval 1 min. After it is stirred once again. After kneading the mixture can be injected into the crack using injection pumps of various types, including manual, carrying upward injection process. To further reduce the viscosity of the injection material 5% of the solvent was applied. It consumed about 1.1 kg/l of void. Injecting material into the casing is fed gradually with smooth jumps of pump pressure to 0.2 MPa. Feeding continues until injectable material does not appear in the top control hole (Fig. 7, *c*) then this hole is closed with a special screw.

Table № 1

Characteristics of injection material

1	Mixing ratio (weight)	5 до 3
2	Open time (at 20^0C, 1)	40 min.
3	Application temperature	above $+5^0$C
4	Mixture density	1,1 kg/l
5	Compressive strength	≥60 H/mm^2
6	Adhesion to concrete	≥2,5 H/mm^2

Pumping of injection material continues if necessary for an hour to maintain the pressure at 0.2-0.4 MPa. Then the trailer of the hose of the mechanical pump is disconnected and the beam is left for two days. In two days the casing is removed and the beam deemed ready for further testing. Restoring the lower zone of the beams, beams were overturned the lower zone up. Further operations of impregnation and recovery are the same as described above.

Requirements for selection of the injecting material at closing (gluing) cracks in reinforced concrete beams with injection method. In choosing the material and the method of injecting adhesive fractures significant factors are the width opening of cracks, its change in height (split-mobility), the degree of moisture. The injection method is influenced by: one or versatile access to cracks, temperature and humidity conditions, proper selection pressure for pumping injection material.

The injectable material should have the following properties: good fluidity and penetration without cork creation, moisture and involvement (adhesion to concrete surfaces and cracks of the walls). Injection materials should not contain ingredients harmful to concrete and rebar and must be resistible to the action of an alkaline environment that creates concrete, and have a low density for deep penetration in the cracks. Reducing the density of injectable material with solvents is not permitted, because it decreases the strength, surface tension, which should be negligible for movement in damp pores. Time validation of injecting material should be sufficient to complete filling of cracks, but not too large to prevent leakage of some capillaries and formation of air "bags" (cork), especially in cases where we have limited ability to cover surface cracks. Shrinkage injecting material should be minimal so as not to reduce adhesion, to avoid the appearance of internal stresses in the material injection during its crystallization. A slight swelling of the injection material is desirable.

An important parameter is the elasticity of the material for injection perception of cracks in time. Suitability of the injection of the crystallized material decreases with the increase of its modulus of elasticity. According to German regulations «ZTV-Riss-93» for the cracks to the disclosure of more than 0.3 mm., polyurethane-filled injectors changes of the disclosure of cracks may reach 5%, and in the disclosure of cracks over 0.5 mm to 10%. For crack disclosure of more than 0.1 mm filled with epoxy compositions crack width change on its length to 0.03 mm is allowed. This is due to their elasticity polyurethane injection materials ensure compliance with the above requirements.

When drilling packers it is necessary to pay attention not to damage the existing rebar construction which is being repaired. Drilled holes must be cleaned of dust by exhaustion (vacuum). Frequently used structure blowing with compressed air may cause cracks dust filling. Depending on the type of cracks and injection material we close the crack partially or leave open. Surface closure is done with epoxy or polymer-cement putty to avoid loss of injection material during its injection.

Based on the above, for injecting bonding cracks we used two-tiered polyurethane composition KOSTER KB-PUR IN III (Germany), thanks to its ability to take considerable effort on compression (60 N/mm^2) while providing adhesion to concrete (over 2,5 N/mm^2). Injection material was carried out by injection molding using a hand piston pump Desoi “HP-30LD” through drilled socket (packer) using advanced injector (Figure 8).

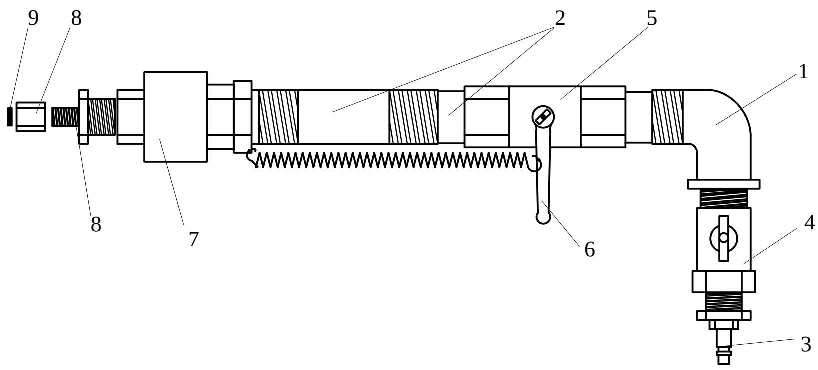


Figure 8. Injectors for treatment of structural materials

To calculate the amount of injection material we assumed the following: total length of all cracks of 920 m, the average crack opening – 0.2 mm, the depth of cracks – 0.14 m. The total amount of cracks (void) – 60 liters. Estimated consumption of injectable material KOSTER KB-PUR IN III is about 1.1 kg/liter of the cavity. Thanks to improved injector design (see. Figure 8.) we managed to save 10% of the injecting material.

Calculated strength characteristics of concrete and beams destroying moments, restored with the injection method. In order to compare the characteristics of strength and deformability of concrete impregnated polymer, and the relevant characteristics of conventional concrete we calculate with f_{cdp}, E_{cdp} for concrete class C12/15 and C20/25. The obtained results we compare with strength and modulus of elasticity of conventional concrete classes. The calculation results are shown in Table 2.

Table № 2

Comparison of strength and elasticity modulus for concrete impregnated with a polymer to conventional concrete

№ з/п	f_{cd}, МПа	f_{cdp}, МПа	$\frac{f_{cp}}{f_c}$	$E_{cd} \cdot 10^3$, МПа	$E_{cdp} \cdot 10^3$, МПа	$\frac{E_{cp}}{E_c}$
C12/15	11,5	11,85	0,97	17,6	17,9	0,98
C20/25	14,5	14,96	0,96	23,1	23,4	0,99

Table № 3

Calculated destroying moments

№	Code series of beams	$M_1^{\exp}$ $кН \cdot м$	M^{theor} $кН \cdot м$	$M^{theor} / M_1^{\exp}$
Concrete C12/15 (B15) New beams without stress				
1	0БЗ-1		9,35	
Concrete C12/15 **(**B15) New beams without tension impregnated upper zone				
2	0БЗ-1	9,8	10,42	0,94
Concrete C12/15 **(**B15) Predamaged beams without stress				
3	1БЗ-1	10,36	10,89	0,95
Concrete C12/15 **(**B15) Prestressed beams previously destroyed				
4	1БН-1з	10,02	10,82	0,93
Concrete C20/25 **(**B25) Predamaged beams without stress				
5	2БЗ-1	11,22	12,03	0,93
Concrete C20/25 **(**B25) Prestressed beams previously destroyed				
6	2БН-1з	11,55	11,93	0,97
Concrete C20/25 **(**B25) Prestressed beams previously destroyed with partial impregnation zone of pure bending				
7	2БН-1з	11,56	12,35	0,94

Примітки: $M_1^{\exp}$ – destructive experimental point of reconstituted (soaked) beams; M^{theor}, – calculated devastating moments scores of polymer impregnated concrete, designed by ISO.

On the basis of comparisons of the strength of concrete and polymer impregnated normal concrete we concluded that impregnated concrete strength increases to 3%. The modulus of elasticity of concrete soaked polymer is 1-2% higher than the module of elasticity of conventional concrete. Characteristics of concrete strength increased by filling pores polymer concrete and polymer concrete matrix formation. Then according to ISO B V.2.6-156:2010 requirements, taking into account the concrete characteristics listed in Table 2, we calculate the devastating moments of reinforced concrete beams made of concrete, impregnated with polymer. The resulting devastating moments we compare to the devastating moments obtained experimentally. The results are listed in table 3.

As can be seen from Table 3 calculation devastating moments of reinforced concrete beams made of concrete class C12/15 without stress and without treatment is 11% lower than the estimated destructive aspects of the same beams, but with impregnation of the upper beams zone. This is due primarily to the impact on the characteristics of the polymer concrete. The devastating moments of the previously destroyed beams without tension made of concrete class C12/15 were 10% lower than the corresponding devastating moments previously destroyed without tension beams made of concrete class C20/25.

The devastating moments of the previously damaged beams with prestressing, made of concrete class C12/15 were 9% lower than the corresponding devastating moments of the previously damaged beams with prestressing, made of concrete class C20/25.

Partial impregnation of pure bending beams zone led to the conclusion that devastating moments of the previously destroyed by intense beams of our experiments were 3% higher than the corresponding beams without impregnation. In general, experimental data showed that recovered by treatement beams can withstand the destructive points to 10% less than the theoretically calculated the same floor of polymer impregnated concrete. In this regard, it is proposed to calculate the devastating moments of beam structures under the DBN, including creep factor.

The mentioned above confirms the effectiveness of the injection technology for repairing defective concrete and reinforced concrete structures and buildings.

Conclusions and prospects of research in this area:

1. It is established that strengthening composite systems have a number of technological and design advantages over conventional methods of strengthening metal. In some cases enhance through injection is indispensable and the only possible way to strengthen and protect concrete structures.

2. Shrinkage of the injecting material should be minimal so as not to reduce the adhesion and thus avoid local leaks and unwanted occurrence of stresses in the injection material during its crystallization. A slight swelling of the injection material is rather useful. In case of strength bonding of reinforced concrete structures by injection of polyurethane composition it is necessary to create pressure for injection of P> 0,8 MPa.

3. The injectable material that fills the crack will be useful only if secured on adhesion to concrete and reinforcement, as well as on strength. It concerns, above all, the strength of bonding and sealing cracks in concrete with variable width along the length of the disclosure.

4. On the basis of the experimental studies we found that it is possible to restore strength of the reinforced concrete beam structures to 85-92% using modern impregnation injection materials. The depth of concrete beams body impregnation was within 2-5 mm. Filling and bonding of existing cracks and defects was done in the lower and upper beams areas.

5. By means of experimental testing of impregnated and nonimpregnated reinforced concrete beams which were not exposed to preliminary loading and destruction, it was found that a significant increase in the strength of impregnated beams was not observed.

6. Based on statistical analysis of experimental results, it is offered in the calculation of the strength of reinforced concrete beam structures, restored by modern impregnation injection polyurethane materials, consider durability as for conventional beams with downward coefficient K = 0.9.

7. The influence of stress concentration in reinforcement joints on strength of restored beams in experiments was low (1%), because stiffness in the joints of fittings is greatly increased by increasing the cross-section of the hub.

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МЕТОДИКА ВИЗНАЧЕННЯ МІЦНОСТІ ЗАЛІЗОБЕТОННИХ БАЛКОВИХ КОНСТРУКЦІЙ, ВІДНОВЛЕНИХ ІН'ЄКЦІЙНИМИ МАТЕРІАЛАМИ

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Резюме. *Запропоновано методику відновлення роботоздатності залізобетонних конструкцій ін'єкційними матеріалами, в яких арматура з'єднана обтискними втулками. Встановлено вплив концентрації напружень втулкового з'єднання арматури на характеристики несучої здатності, деформативності та тріщиностійкості залізобетонних балок при малоциклових навантаженнях. На основі теоретичних досліджень встановлено оптимальні вимоги до ін'єкційного матеріалу та запропоновано ін'єктор для просочення конструкційних матеріалів. Проведено порівняльний аналіз міцності нових та відновлених ін'єкційним методом зруйнованих залізобетонних балок.*

Ключові слова: *несуча здатність,залізобетонні балки, ін'єкційний матеріал, ін'єктор, обтискна втулка, тріщини, роботоздатність.*

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