BUILDING STRUCTURES, BUILDINGS AND CONSTRUCTIONS

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DURABILITY AND DEFORMABILITY OF REINFORCED CONCRETE BENDING CONSTRUCTIONS STRENGTHENED BY POLYMERIC COMPOSITES

A concrete example of reinforced concrete beams operation which were needed to be additionally loaded in the process of operation with preliminarily conducting special investigations is considered. The case of strengthening constructions being described is nontraditional and connected with the impossibility of using welding process because of preparation conditions with the aim of excluding the risk of inflammation or explosion. Therefore the strengthening of normal cross sections of "sound" beams was made at the "wet" process using polymeric composites.

Keywords: asphalt concrete beams, polymeric composites.

1. Experimental research

Experimental studies were conducted at the models, the scale of which with respect to operating beams was equal approximately 1:3. The models, as well as actual construction, made of ferroconcrete and layers of polymer concrete are called layer-built composite structures (abbreviated SKIK). Influence of polymer concrete layer on the strength of SKIK has been determined experimentally during a test of beam, loaded in the thirds of span by sequentially increasing load pressure up to destruction. Experienced beams had cross-section 10x20 cm and a length of 120 cm. Concrete of class 25 was used, a working longitudinal reinforcement of class A-III in the form of two rods with diameter of 8 mm was used, and transverse beam in the form of rods with diameter of 5 mm of the same class, placed in a such way that the destruction occurred over the normal sections was used. As materials of coating layer polymer concrete (series RCIP), mastic (series RCIM) and paint-and-lacquer materials (series RCIL) were applied. All compositions are made on the basis of epoxy resin ED-20. For series RCIS glass-reinforced plastic is used, attached with epoxy glue based on ED-20. In addition, the compositions, based on liquid rubbers were used i. e. rubber concretes (cautons): concrete (series RCIRB) and mastic (series RCIRBM). Structures of polymer layers and some mechanical characteristics of them are given in the table 1.

Table 1

Composition and mechanical parameters of covering layer

Beam series	Content of components, particles on mass	Tensile strength, MPa	Modulus of deformation, MPa	Limit tensility, %	Coating thickness, mm
RCIP	ED-20-100, DBFT-20, PEPA-10	32	2780	1.15	0.15…1.2
RCIM	ED-20-100, PEPA-10, DBFT-25, arenaceous quartz — 500	9	11500	0.078	6
RCIS	Glass-Fibre plastic polyester, glued by epoxy glue	22.3	1300	1.7	2
RCIL	ED-20-100, PEPA-10, DBFT-30, crashed sand — 91, high-silica sand — 218, detritus — 450	7	9000	0.08	Variable
RCIRB	PBN-100, hardenable group — 75, filler 100, high-silica sand — 250, detritus — 500	14.5	15000	0.86	Variable
RCIRBM	PBN-100, hardenable group — 75, filler — 100, high-silica sand — 500	16	15500	0.91	5…6

Facility for test of beams allows to implement visual monitoring of the development ("germination") of cracks in the tension and the side surfaces of the beam (Fig. 1).

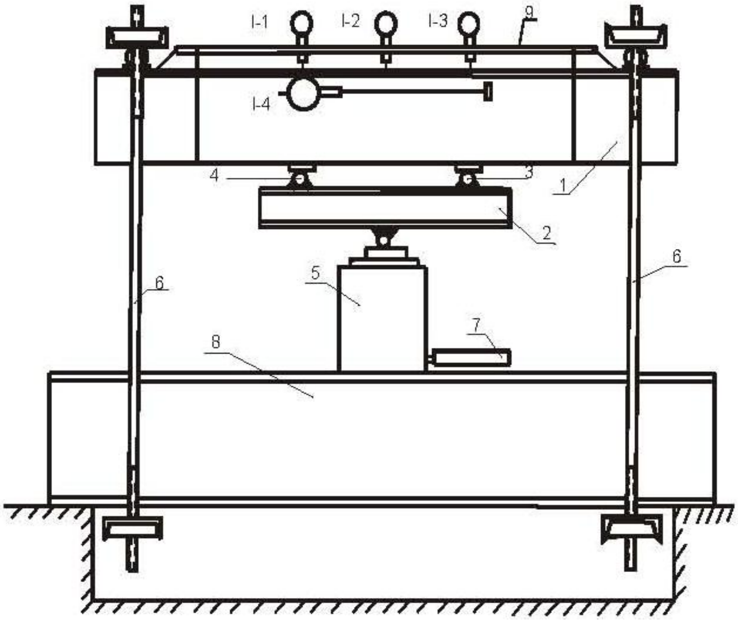

Fig. 1. Scheme of tests of composite constructions:
1 – beam; 2 – distributive cross bar; 3, 4 – hinges; 5 – jack; 6 – pulls;
7 – manometer; 8 – bracing boom; 9 – holder

During the test maximum deflection, deformations of concrete of tension surfaces, the average de-formation of the concrete over the length of beam, the local deformations of the concrete in the zone of pure bending, as well as the overall deformation of the zone of pure bending were measured.

The measurements enabled to determine for each beam moment of the crack stress, bearing capacity, as well as deformability of composite beams and limit tensility of concrete.

2. Research of influence of polymer concrete layer on durability of the model

The obtained experimental data were the basis of research conducted to identify the influence of the thickness of polymer concrete coating layer on the strength of normal sections SKIK.

Fig. 2 shows that the experimental values of breaking load for the beams of a series of RCI (see Table 1, 2) are connected with the thickness of the coating layer by dependence

$$M_p = M_p^{RC} + k \cdot M_p^n, \qquad (1)$$

of where M_p is the breaking point composite beam;

$$\frac{dE}{dt} = -\int \dot{y}(x,t)F_{fr}(x,t)dx = -\sum_{lm}\int \dot{q}_m(t)\varphi_m(x)k_0\dot{q}_l EJ_z\lambda_l\varphi_l(x)dx = -k_0 EJ_z\sum_l \lambda_l\dot{q}_l(t).$$

is the moment received by ferroconcrete beam without a cover; M_p^n is the moment received by coating layer; k is the coefficient of working conditions of polymer concrete of the tension zone of composite beams, allowed for shrink stresses, the appearance of cracks in polymer concrete before destruction, and etc.

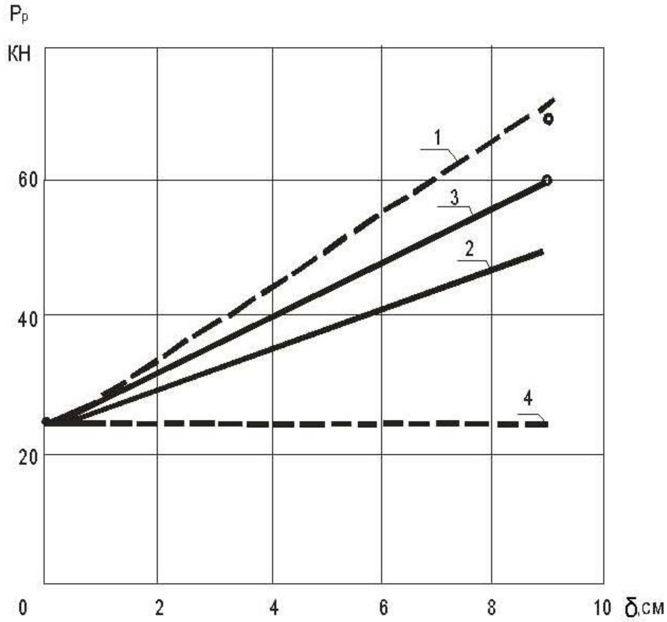

Fig. 2. Influence of thickness of coating on bearing capacity of composite beams:
1 – dependence at κ = 1; 2 – the same, at κ = 0.65; 3 – experimental dependence for coated beams; 4 – the same, for beam without coating

Table 2

Beam code	Height of polymer concrete layer, mm	Destructive load P, кN	M_p^0, кН·см	M_p^T, кН·см	M_p^{RCI}, кН·см	M_p^n, кН·см	$\frac{M_p^m}{M_p^0}100$, %
RCI	0	26	430	415	415	–	97
RCI-6	6	27	446	468	415	53	105
RCI-20	20	30.5	505	550	384	166	109
RCI-50	50	43.7	720	730	360	370	102
RCI-90	90	62.3	1030	901	336	565	88
RCRC	20	34.1	543	601	408	174	108

After analyzing fig. 3 and decoding of the formula (1), this expression can be written as

$$M_p = R_s \cdot A_s\left(h_0 - \frac{x}{2}\right) + k \cdot R_n \cdot A_n\left(h - \frac{x}{2} - \frac{\delta_n}{2}\right). \qquad (2)$$

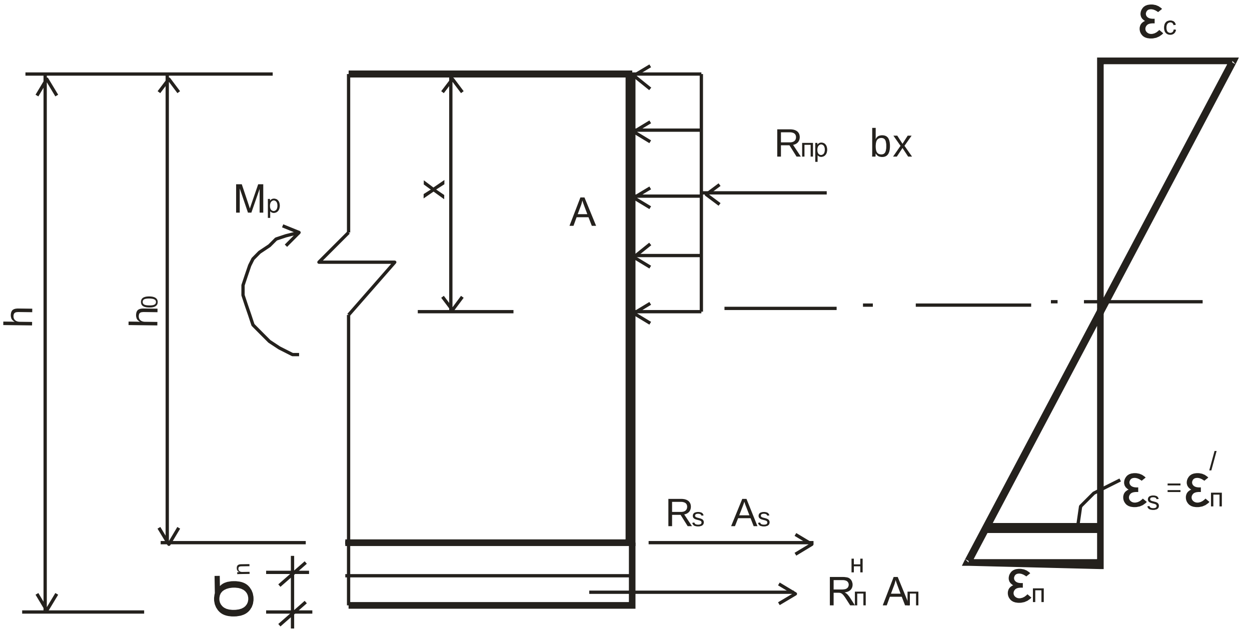

Fig. 3. Stress diagrams and deformations
in the section of composite beams in the calculation of the strength

Analyzing the dependence (2), we obtain an expression for determining the height of the compressed zone in the beam with layer polymer concrete layer:

$$x = \frac{R_s A_s + R_n A_n}{R_{np}^{в}}, \qquad (3)$$

where R_n - $R_{np}^{в}$ is the strength of polymer concrete on tension and compression; R_s is the strength of reinforcement; A_s and A_n is the cross-sectional area of reinforcement and polymer concrete.

Comparison experimental values M_p^o with values calculated M_p^m by the formula (2) shows that the difference between them when changing the coating thickness from 0 to 90 mm does not exceed 14 % (see Table. 2).

In addition, analysis of experimental data and formula (4) indicates that the bearing capacity of composite beams increases with increasing of thickness of layer of polymer concrete and its tensile strength. A further increase of bearing capacity of beams can be achieved by increasing the coefficient *k*, that is possible while reducing shrink stresses in polymer concrete and reinforcement of coating layer to prevent the cracks formation in the tension zone up to the moment of destruction.

In the joint decision of equations (2) and (3) with replacement A_n by the product $b \cdot \delta_n$, studying obtained the expression on extremum by δ_n evaluate optimal height of polymer concrete layer from the condition of strength:

$$\delta_n = \frac{R_{np} h - (1+k)\dfrac{R_S A_S}{2bk}}{R_{np} + R_n}. \qquad (4)$$

Optimal value height of polymer concrete layer, calculated by the formula (4), is within 12… 16 cm, and the height of the compressed zone of concrete, determined by the formula (3), is equal to 3.5… 5.5 cm. In our case, the sum of the thickness of polymer concrete layer and the height of the compressed zone of concrete (17… 20 cm) are approximately equal to the total height of the beam (20 cm).

All of this suggests that the maximum effect when using polymer concrete as amplification of reinforced concrete beams and at the same time for further corrosion protection is achieved when the tension part of the beam section is made of polymer concrete and compressed part is made of concrete. Dividing the right and left side of the equation (4) on h and introducing the symbols $\alpha_n = \delta_n / h$, $\mu = A_s / F_\delta$, we get:

$$\alpha_n = \frac{R_{np} - \mu A_S k'}{R_{np} + R_n}, \qquad (5)$$

where $k' = \dfrac{1+k}{2k}$.

At certain values R_{np}, R_s, μ as it is shown in (5), polymer concrete surface does not affect the carrying capacity of composite beams, and serves only to protect it from corrosion. This happens in the case

$$R_{np} - R_S \mu k' = 0. \qquad (6)$$

Tests show that polymer concrete surfaces amplify reinforced concrete beams, regardless of the type of destruction, and the most favorable results are obtained for the beams with polymer concrete layer on three sides.

Data of table 3 show that the carrying ability of SKIK depends on the strength of the material of surface and the conditions of its work.

Table 3

The results of the beams test

Code of series	Components of constructions	P_p, кN	Load received by polymer concrete layer, кN	$\frac{P_p}{RC} \cdot 100\%$
RC2E1	ED-20, PEPA, DBTF	87.5	–	100
RC2E3	ED-20, PEPA, butanol, glass cloth	100	4.5	114
RC2E1S	ED-20, PEPA, butanol, glass cloth	95	10	108
RC2E3S	ED-20, PEPA, butanol	112.5	17	128
RCR1	PBN, hardening group	89.5	–	100
RCR3	PBN, hardening group, glass cloth	102.5	5	115

3. Researches on influence of polymer concrete coating on deformability of the model

Influence polymer concrete layer on deformability of SKIK was researched on the same beams as in case with strength. Deflection in the middle of span was taken as criteria of deformability. In loading beams with coating three stages of deformation are specificated: the first — from the beginning of loading until the moment of cracks formation in concrete, the second — from the moment the appearance of formation in the concrete to the rupture of coating, the third one ended by the destruction of the beam. The most important value of deformability is the deflection at the boundary of the first and second stages, as in this case polymer concrete layer is not destructed yet, and performs its basic function: isolates concrete and reinforcement from the corrosive environment. It is necessary and important to know deformability on the border of the second and third stages of deflected mode, since coating while also protecting concrete, but in the zone of cracks it overstretched and under long-term load storage it can break.

In table 4 quantitative characterization of deformability of deflections of beams under bending stress is given. To do this, reinforced concrete beams with a length 140 cm and a cross-section 20x10 cm of the class 15 concrete, reinforced with one core with working reinforcement with diameter of 20 mm of class A III, transverse rod of diameter of 6 mm of class A-II were tested.

The first series of beams RCR are control beams without coating. Beams of series RC2E1 were coated with epoxy composition only over tension side. This composition was applied at coating of three sides (lateral and tensile) on the beam of series RC2E3. Stretched sides of beams of series RC2ESF were covered with epoxy polymer glasslinen. In beams of series RC2IS and RC2E3S only stretched sides and stretched plus flat sides were covered with epoxy composition, reinforced by glass cloth.

Table 4

Code of series	Deflection at *P*-40 кN, mm	$\frac{f\ at\ P = 40\ kN}{f^{zhb}\ at\ P = 40\ kN}$
RCR	1.2	1
RC2E1	1.07	0.89
RC2E3	1.06	0.89
RC2ESF	1.1	0.82
RC2ESI	1.13	0.94
RC2ES3	0.9	0.75

In all cases, with loads of 40 kN over deflections deformability was registered (in the last column the relative size of deformability are shown). As it can be seen from the table 4, one or another SKIKs have less deflection compared with ferroconcrete.

Researches have shown (Fig. 4) that polymer concrete coverings reduces deformability of the product, especially before the emergence of cracks in concrete, that is, on the border of the first and second stages of deformation.

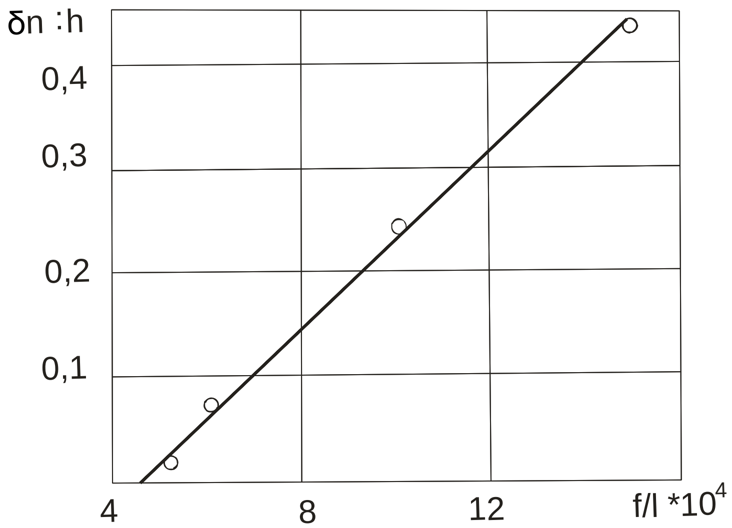

Fig. 4. Influence of thickness of polymer concrete layer on deformability of bending composite beams

The greatest effect of reducing of deformability is observed at the coating on three sides. Deflection of beams with a polymer concrete layer increases sharply and approximates to deflection of control samples at the formation of cracks in the concrete (the second stage of deformation). Reduction of deformability of beams with polymer concrete layer of small thickness is explained by the redistribution of stresses between and of polymer concrete in concrete in the process of loading, resulting in smoothing of the peak deformations of tension side of concrete and reinforcement. When the tension side of products completely consists of a polymer (more flexible than concrete) composite deformability increases with increasing of thickness of polymer concrete layer (see Fig. 4, Table. 4).

Effect of coatings on deformability of concrete and reinforced concrete under long-term exposure of bending load (on creep) was studied on samples-beams: three series of unreinforced samples (B, B1 and BZ), and two series of reinforced concrete beams (BO and BP). Unreinforced beams with size 3x6x64 cm; reinforced concrete beams — 10x20x160 cm. Characteristics of elements are given in the table. 5.

Table 5

Characteristics of elements and the results of their tests

Code of series	Sort of concrete	Thickness of coating, mm	Durability of coating at rupture, MPa	E_n, MPa	σ_{nr}, MPa	M_p, Nm	M_T, Nm
B	B20	–	–	–	2.7	8.33	–
B1	B20	1…1.5	13	$35x10^2$	6.1	192	–
B3	B20	1…1.5	13	$35x10^2$	10.5	326	–
B0	B12.5	–	–	–	–	14000	1800
BP	B12.5	1…1.5	13	$35x10^2$	–	16500	4000

Polymer coating were brought with the usy of “wet” method. The composition of the coating (in parts by weight): ED-20-100-PEPA 10, andesite-100. After the ending the process of the polymerization tests were carried out. In order to identify the impact of the coating position and the percentage of the covered surface on work of element unreinforced samples with two types of coverage were used: on the lower bound and on three sides (flat and lower bound). Reinforced elements are coated only on three sides.

Basic mechanical properties of material were determined in a test of samples of all series at short-term load. At that such characteristics as strength of coating at rupture, its module of deformation, tensile flexural strength of composite were calculated as the arithmetical mean value in a test of samples. Determining the strength of the elements the following formula were used for concrete:

$$\sigma_{nr} = \frac{3.5M}{bh^2}, \tag{7}$$

for composite with a polymer coating on the lower bound:

$$\sigma_{nr} = \frac{7M}{2bh^2 + 3.5\delta bh \dfrac{E_n}{E_\delta}}, \tag{8}$$

for the composite with polymer concrete coating on three sides:

$$\sigma_{nr} = \frac{49M}{14bh^2 + \delta h(24.5b + 28h)\dfrac{E_n}{E_\delta}}. \tag{9}$$

Using formulas (7)—(9) calculated diagrams of stresses shown in Fig. 5 were taken into account. Note that the strength of the composite element significantly increases compared with concrete. Thus, for a series of BI, it has increased in 2.3 times and for BZ in more than 3.8 times.

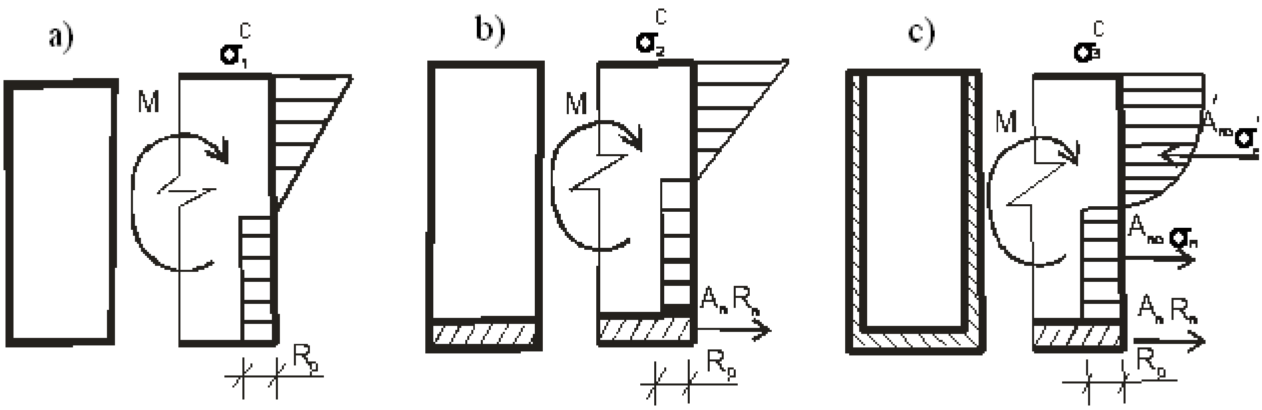

Fig. 5. Calculated diagram of stresses for the composite elements:
a) concrete, b) coated on the lower bound, c) coated on three sides

As it can be seen on the creep curves (Fig. 6—9), the nature of deformation in time under constant load for different elements varies. This is reflected in the coefficients of duration, which for series B, BI and BZ, respectively, were equal to 0.75-mi, 0.6, 0.61. Reduction of value κ_{dl} for compositional elements indicates their approximation to polymer concrete with pronounced deformations of viscous and viscoelastic phases. Quantitative side of limit of long-term strength, as it can be seen from these graphs increases. Compared with the concrete long-term strength of samples of series of BI is higher at 80 %, while of samples of BZ series at 317 %.

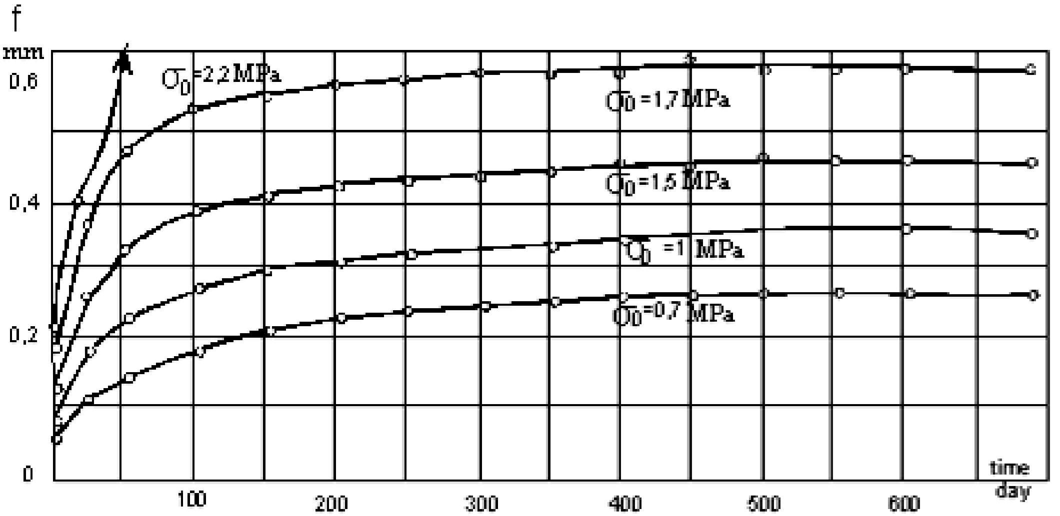

Fig. 6. Creep of concrete of bending elements

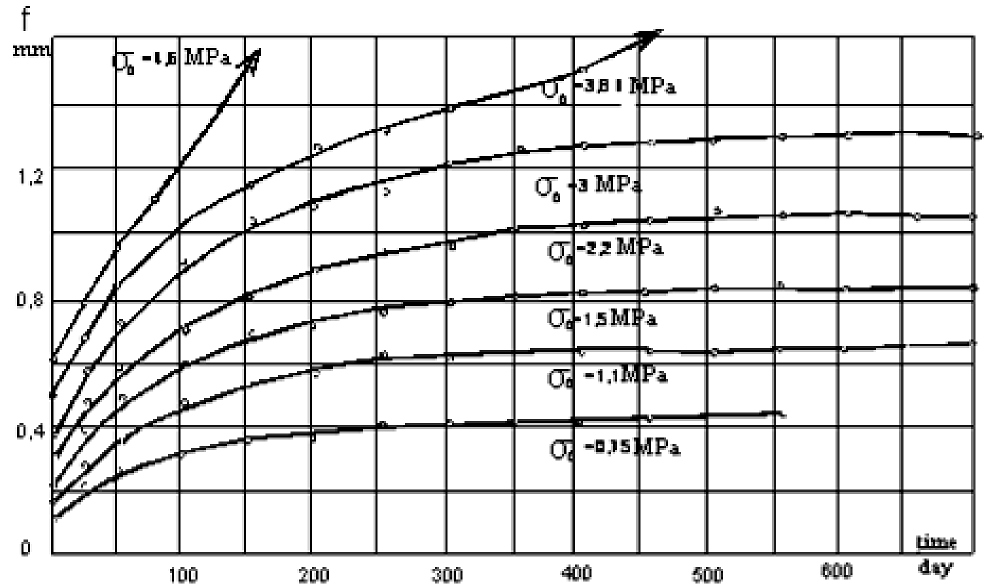

Fig. 7. Creep curves of composite elements coated on the lower bound

Deformability of composite elements (Fig. 9) is much lower than of concrete one. For example, at stress 1.9 MPa deflections of concrete samples, composite beams of series BI and BZ series, respectively, are equal to 0.19, 0.13 and 0.1 mm. As a result of a creep of samples their deflection increases. As at short-term load, long-term effect of load results in an increase of deformability of composite beams, however in significantly less degree than that of concrete. Interestingly, that with the increase of the percentage of covered surface compositional elements in respect of deformation begin to approach to polymer concrete. For example, if coating on one border imparts a number of properties to concrete, quantitatively improving its strength and deformation characteristics, covering on the three sides qualitatively changes the concrete.

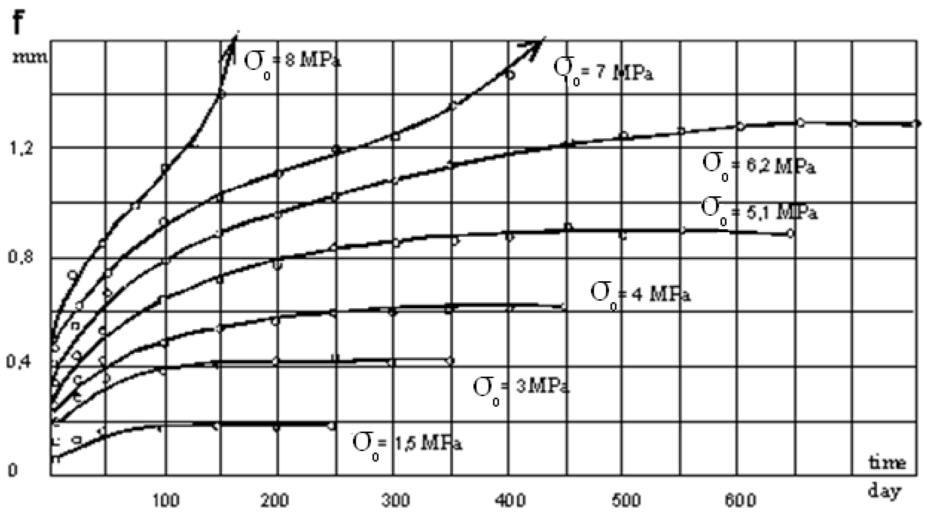

Fig. 8. Creep curves of the composite elements coated on three sides

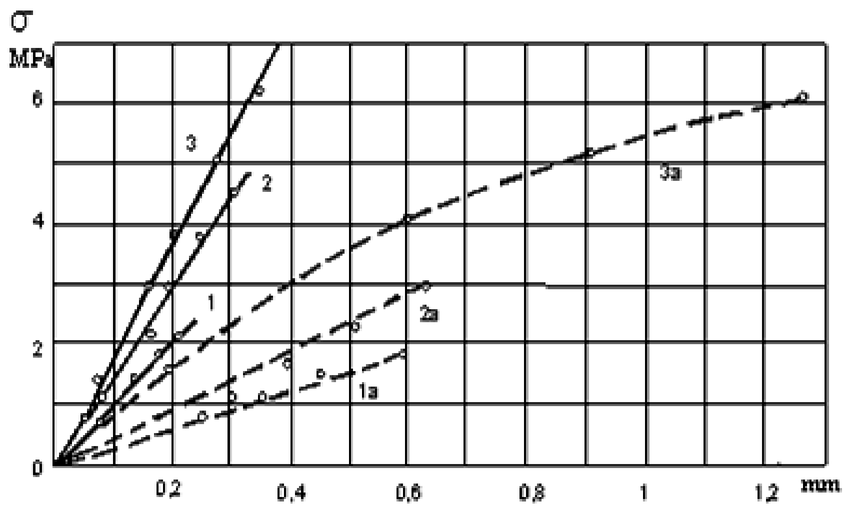

Fig. 9. Dependence of deflection on stresses at short-term impact of loads for the following elements:
1 — concrete, 2 — coated on the lower bound,
3 — coated on three sides; with long-term load of these elements: 1a, 2a, 3a — respectively

Tests of reinforced elements on the long-term exposure of load are performed at the specially constructed facilities (the general view of tests is shown in Fig. 3), which allow both to test two beams: one control, another with covering. Loading was produced by equal concentrated forces in the thirds of span, a deflection of beams were measured in the middle of the beam and on the borders of the zone of pure bending. Facilities also allow conducting visual observation for the formation and development of cracks in both beams.

Loading steps were performed at 5 kN to extract at each step for 10 minutes with the mandatory registration of indications of measuring instruments. According to the above scheme an was experiment carried out, in which two series of beams were tested, two beams of series (control and coated). Beams Bo-4 and BP-4 were loaded with load equal to P = 18 kN, which corresponds to the load, in which the cracks forms during short-term tests for beams without coating. In the reference beam Bo-4 in the zone of the pure bending there were two hair cracks; in the beam with the same surface there were not cracks. Indicator readings and tension resistors at the time of complete transfer of the load corresponded to the initial (elastic) deflection and the initial deformation. The curves of creeping of beams are shown in Fig. 10, a graphics of change deformations of tensile side and over section height in time, and graphics of dependence of deflections of the load both at the short-time effects of the load, and in its long-term effects are shown in Fig. 11.

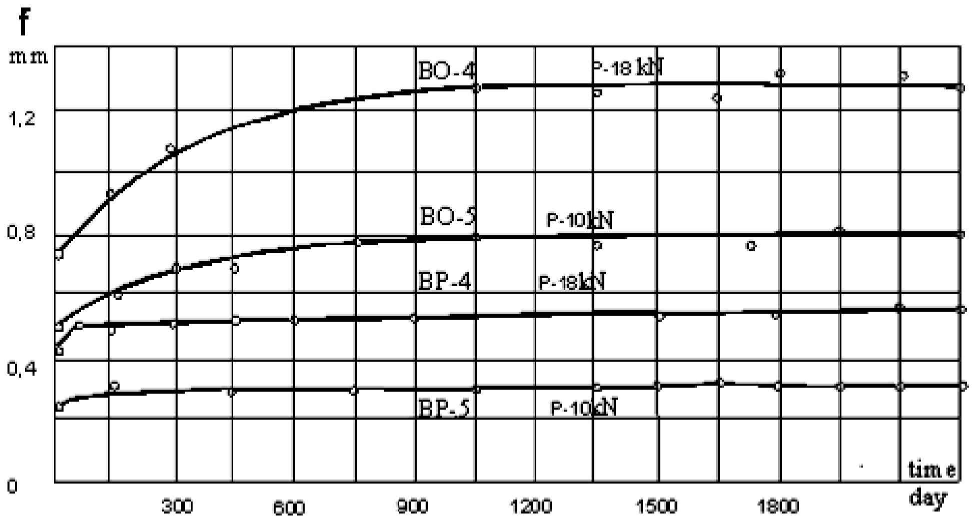

Fig. 10. Creep curves of reinforced composite beams

Readings in the test were taken regularly, also the emergence and development of cracks were visually observed. Observed in the early test on the reference beam Bo-4 cracks developed in time, and the breadth of their opening through the year amounted to 0.3… 0.35 mm, in addition, a further few minor cracks formation was noted. On the ninth day of tests hair cracks in concrete of beams with the surface were emerged. The cracks were formed under the coating; the same coating retains its integrity until the end of testing.

Beams Bo-5 and BP-5 were tested by load 10 kN. At the beginning of lengthy research both on a beam with surface BP-5, and on the control BO-5 there were not cracks. During the tests in a month, at first one appeared, then another crack at the Bo-5, which opened a year later on the amount of 0.1… 0.15 mm. At the BP-5 crack is not observed.

These studies indicate that the coating of concrete and reinforced by polymer concrete layer provides a sharp decline of elements deformability. Together with the decrease of creep the rate of rise of sagging of deflections over time reduce. Increased elongation of concrete means an increase in crack resistance of reinforced concrete, and greatly enhances the durability of structures and facilities in general. Limit elongation of concrete at the coating of the surface of tensile side increases in 1.5…2 times. It can be increased in 2—3 times applying as a coating composites with higher elastic characteristics (table 6).

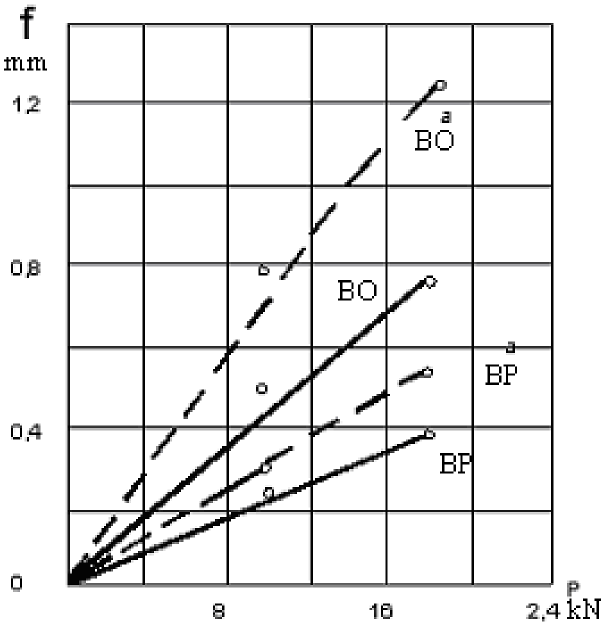

Fig. 11. Dependence of deflection of the load for the reinforced structures at short-time load (BO, BP, and long-term load (BO^a, BP^a)

Table 6

Tensility of concrete on the contact with coating

Maximum tensility	RCR	RC2E3	RC2ЭSI	RC2ES3
$\varepsilon_\delta \times 10^{-6}$	2.5	7	7.6	15.3
$\frac{\varepsilon_\delta}{\varepsilon_\delta^{BK}} \times 100\%$	100	280	304	610

Testing of reinforced elements shows that for beams with surface deformations of creep reduce compared with control in 2… 2.4 times, the time of the of cracks formation in beams with coating is observed later than in control ones. In the case of the occurrence of cracks in concrete under coating their opening value remains in the 3…4 times less and coating retains its integrity, preventing the further development of cracks and continuing to protect the structure.

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