EXPERIMENTAL STUDIES OF THE CRACK FORMATION MOMENT OF REINFORCED CONCRETE BEAMS

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After reviewing the many reinforcement schemes, their inadequacies include the impossibility of efficiently unloading the compressed zone of the beam concrete, which significantly affects the stiffness and bearing capacity.

The work is devoted to the determination of the parameters of strength and deformability of reinforced concrete beams, reinforced by a longitudinally transverse external system and a pressed reinforced concrete element in a compressed zone. As a result of the experiments, the physical and mechanical properties of concrete and reinforcement are discovered and, based on the obtained results, their final class is determined. During the experiments, control over the moment of crack formation and the development of cracks is carried out, and also the concrete deformations and deflections of the beams are determined.

Introduction. The main task of construction is providing buildings with the property to remain operable throughout the entire life cycle. The level of bearing capacity, both of individual structures and buildings as a whole, depends on many factors.

Reconstruction, overhaul, technical re-equipment are the main types of construction, where reinforcement of supporting structures is applied in connection with superstructure, rebuilding, expansion, installation of new equipment, as well as replacement and (or) restoration of supporting building structures. Strengthening of structures also occurs due to loss of bearing capacity, which has decreased due to physical wear during operation, overload, uneven settlement of foundations, accidents, etc.

When reinforcing reinforced concrete structures, the strengthening elements, which have different physical and mechanical characteristics and have to be involved in joint work together with the reinforcing element, play a huge role. After strengthening, the structure becomes multi-component, consisting of the main section and an additional part. In this case, the main part is in a certain stress state – the deformed state, and the additional part is in the initial state.

Problem statement. One of the major problems of construction is the effective strengthening of structures with minimal costs of building materials and ensuring their reliable operation during the entire peration period.

The subject of reinforcement of reinforced concrete structures is a very topical issue. This topic was developed by many authors whose works are represented in many publications, dissertations and utility model patents. Some questions concerning the study under consideration are presented in the works of E. Babich, A. Bambura, A. Barashykov, Yu. Vitkovsky, A. Gvozdev, A. Golyshev, E. Grynevych, F. Zamaliieva, F. Klymenko, F. Leongardt, E. Lysenko, L. Murashko, N. Onufriev, S. Pichuhin, E. Rats, L. Storozhenko, A. Shahin, L. Fomytsia, E. Freisine and many others.

Experimental studies of reinforced beam structures using prestressed materials (in particular, steel reinforcement) were carried out by many authors in China, South Korea, South Africa, Canada and Spain [1-5] and showed a significant variation in strength, deformability and crack resistance.

The aim of research is experimentally determination of the effect of reinforcement parameters on strength, deformability and crack resistance of beam elements, development of a methodology for experimental studies of the strength of normal sections of reinforced concrete beams of a rectangular profile with various methods of reinforcement.

Materials and methods. In order to study the peculiarities of the work of bending reinforced concrete elements with an inhomogeneous structure of the compressed zone (concrete of different classes) and reinforced with an external metal system, experimental studies have been carried out on two series of beam samples.

To obtain real physical and mechanical characteristics of materials, samples of reinforcement are selected and concrete samples are formed. The characteristics of the reinforcing steel are determined through tests of control samples, 50 cm long, in tension [6]. The reinforcement used for reinforcement of investigated beams and for the external reinforcement system is tested using an E4S-20 tensile testing machine and the reinforcement class is determined according to the results (see Table 1).

The establishment of the physical and mechanical characteristics of concrete is carried out using standard cube samples with a size of 150x150x150 mm and prisms [7, 8]. The tests are carried out on a hydraulic press PG-250.

Experimental samples of beams, cubes and prisms are made under laboratory conditions from one batch and are stored in the laboratory room at a relative humidity of 50 ... 70% and a temperature of 10 ... 22 °C.

To determine the workability of the concrete mixture, the method according to EN 12350-2 [9], EN 12350-5 [10], DSTU B.2.7-114-2002 [11] is used. The concrete mix meets the requirements of [12,13], and the concrete obtained on its basis according to the regulatory requirements [14] refers to heavy concrete. After curing, according to the results of testing samples of concrete, it is established that concrete belongs to class C20/25 [15].

Table 1

Physical and characteristics of reinforced beams

Main section					Additional elements				
Reinforcement			Concrete		Reinforcement			Concrete	
Yield strength f_y, MPa	Tensile strength *fu*,, MPa	Elasticity modulus E_s, MPa	Cubic strength f_{cd}, MPa	Deformation modulus E_c, MPa	Yield strength f_y, MPa	Tensile strength *fu*,, MPa	Elasticity modulus E_s, MPa	Cubic strength f_{cd}, MPa	Deformation modulus E_c, MPa
235	441,15	$2{,}1x10^5$	32,16	23	363,6	608,8	$2{,}31x10^5$	C50/60	34

The beams are concreted in series, depending on the design. Concreting of the beams is carried out by manually inserting the concrete mix (mobility of 4 cm) into a rigid metal formwork, followed by compaction using a vibration machine. The joint work of concrete and high-strength liner from reinforced concrete is ensured by the joint laying and compacting of the contained mixture without a technological break. The dismantling of the samples is carried out after 8-10 days after formation.

Prototypes – reinforced concrete beams with a length of 2100 mm with a cross-sectional rectangular cross-section of 200 x 100 mm. All reinforced concrete beams are made of identical geometric dimensions, the deviation is less than 2%.

First of all, reinforced concrete insert is made. The concrete mix, encased in a uniform and uniformly compacted, is pressed by pressure, provides further compulsory compaction by squeezing some of the free water out of it. Seals of the concrete mix ware performed on a hydraulic press R-

125. The degree of pressure is 0.5 MPa. Taking into account the technological capabilities of the equipment, the time range for application of the pressing load from 2 to 20 seconds is chosen.

The pressed element is reinforced with two reinforcement rods with a diameter of 6 mm of class A240C. The size of the extruded element with reinforcement is shown in Fig. 1.

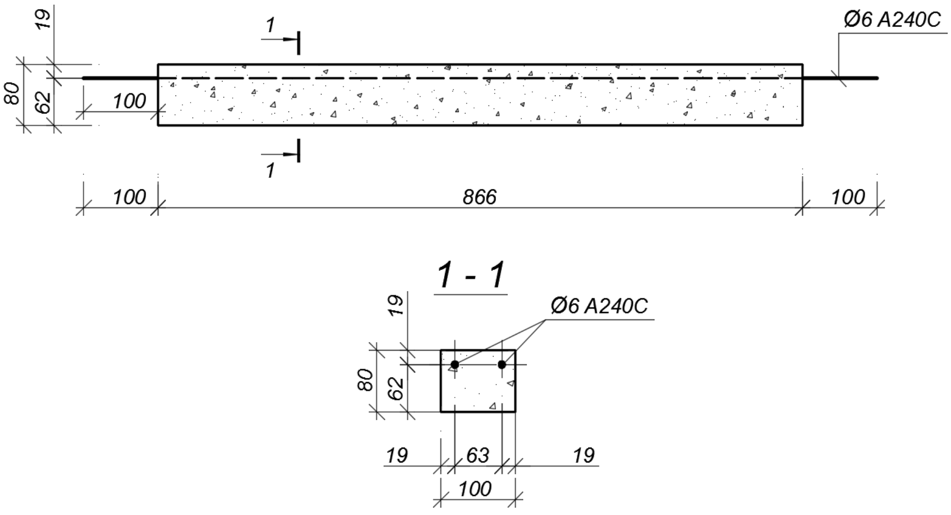


Fig. 1 Formwork drawings for reinforced concrete insert

The compressive strength class of the pressed element is determined after 28 days with an ultrasonic device “Pulsar-1.1” according to DSTU B.V. 2.7-226:209. The compressive strength class of concrete is C50/60.

The reinforcement of prototype beams is made in the form of two flat frames made of smooth reinforcement Ø6 A240C, which are combined into spatial reinforcement with the help of connecting rods. In the extreme thirds of the beam span, transverse reinforcement with Ø6 A240C reinforcement with a pitch of 110 mm is made. In the lower stretched zone, the beams are additionally placed in the center of the section 2 reinforcement bars Ø16 A400C. The percentage of reinforcement is 1.95%

Section of reinforced concrete beams (formwork drawings) and the design of the reinforcement cage is shown in Fig. 2

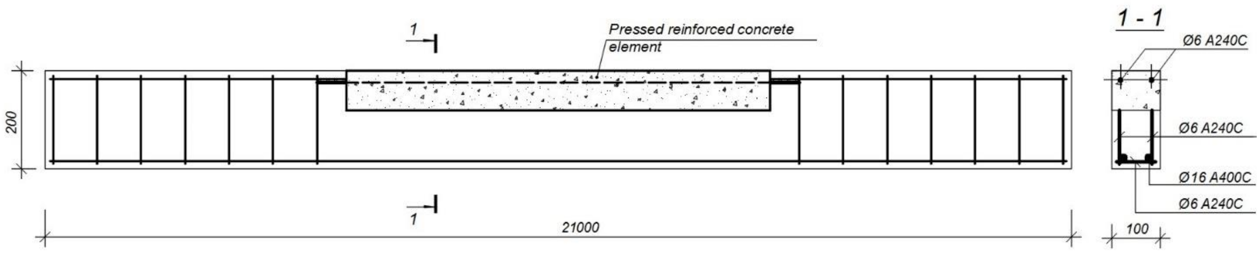


Fig. 2 Reinforcement of investigated beams

The reinforcement element of investigated beams consists of two components: a pressed reinforced concrete insert of high-strength concrete and an external reinforcement system. The external reinforcement system contains a tightening fixed at the ends on the beams, interacting in the middle with the tensioning element, rests on the lower edge of the beam, and transverse external reinforcement interacting in the near-bottom zones of the beam with the upper and lower edges, and in the middle part interacting with tightening. The transverse reinforcement rods are inclined toward the center of the beam at an angle of 65˚. Tightening is made of reinforcement periodic profile Ø8 A400C. The diameter of the roller in the middle of the span is calculated, experimentally investigated and taken d_k= 55 mm. The external reinforcement system is fastened by welding to the embedded parts installed during the concreting of the beam. The tension of the reinforcement is performed manually.

Strengthening of the compressed zone is made using extruded reinforced concrete insert of high-strength concrete in the center of the investigated beam.

The following symbols are used in marking of beams: the first letter B denotes a reinforced concrete beam element; the second letter P designates the beam is overreinforced, and the letter O – the usual one not reinforced by the external system: the next letter P – reinforced; numbers I or VIII denote a series of beams manufacturing. The last figure 1, 2 showed the sequence number of twin beams.

Series I – reinforced concrete beam BOP-I overreinforced and reinforced concrete insert made of pressed concrete (Fig. 3).

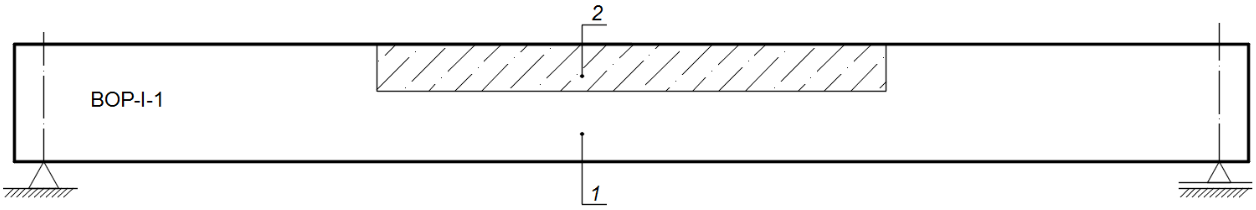


Fig. 3 BOP-I beam reinforcement schemes: 1- investigated beam; 2– reinforced concrete insert made of pressed concrete

Series II - BPP-VIII-1 –concrete overreinforced beam, reinforced by the external system according to the patent [16] and reinforced concrete insert made of pressed concrete (Fig. 4).

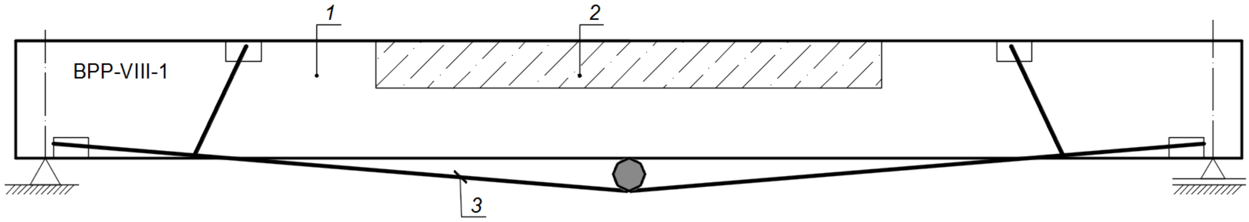


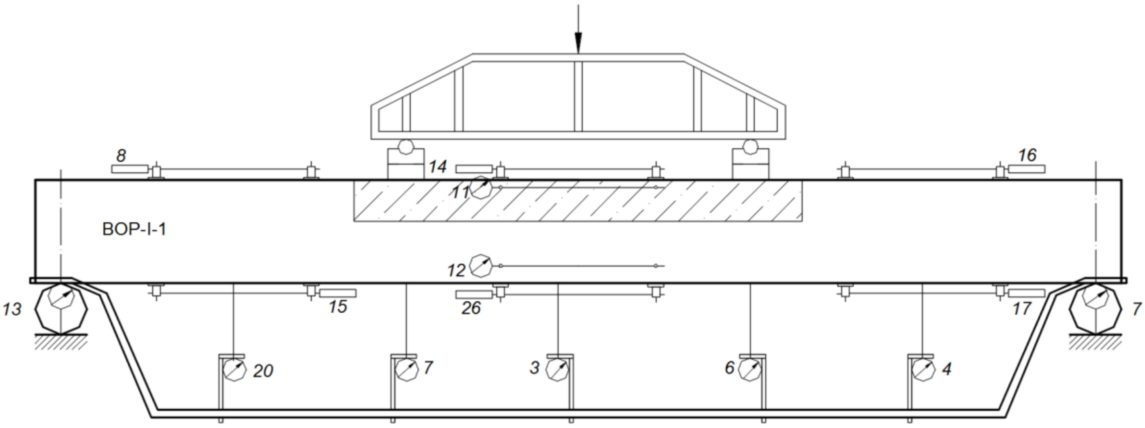
Fig. 4 Schemes for reinforcement of BPP-VIII-1beams: 1– investigated beam; 2 – pressed reinforced concrete insert; 3 – external reinforcement system

Tests of prototypes are carried out according to the scheme, equal to the single-span beam on two supports, loaded with two forces, at the same distance from the supports [17]. Estimated span is 2000 mm. The pressure of the press is transmitted to the beam through the traverse and the rollers in the form of two concentrated forces in the thirds of the span. The effort is created by the jack, and the load is recorded by ring dynamometers.

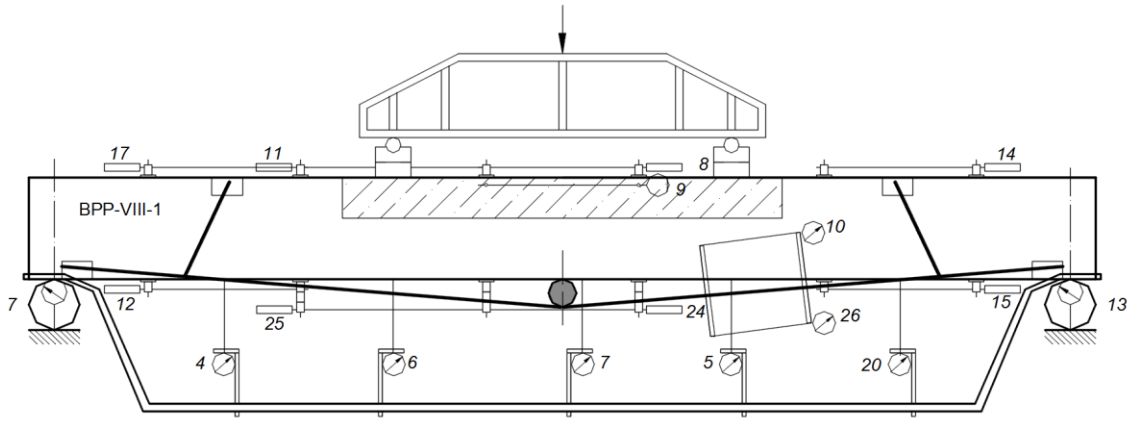
A metal frame is attached to the tie, it serves as an attachment of instruments for measuring the deformations of the reinforcement during the tests.

Measurements of deformations of concrete and reinforcement are performed using hour-type indicators ICH-01-0.001, with a scale value of 0.001 mm, accuracy class – 1 and installed with a base of 30 cm and strain indicators. To determine the deflections and curvature of the beam, deflectometer are used, with a scale value of 0.01, accuracy class – 1 and hour-type indicators ICH-10-0.01, with a scale value of 0.01, accuracy class – 1.

The location of the instruments on an experienced beam is shown in Fig. 5.



a)



b)

Fig. 5 Scheme for testing a series of beams: a -– reinforced concrete beam BOP-I-1; b – reinforced concrete beam BPP-VIII-1

Research results. The first stage of the research is the testing of the BOP-I beams (photo 1) and bringing them to the load, according to which normal operation would be impossible. A sign of such a state is the opening of normal cracks in the lower stretched zone of concrete, the width greater than $a_{crc} = 0{,}4$ мм, or exceeding the value of the relative deflection [18].

Photo 1. General view of the BOP-I-1 investigated beam at the test stand

The destruction of the reinforced concrete beam BOP - I begins with a stretched zone with a load of 14.75 kN the first cracks visually formed. The devices record an increase in relative deformations, and as the load increases, new cracks appears and the development and growth of the crack opening width is observed. In the compressed zone of concrete, a system of horizontal cracks along the height of the cross section is created, which is called a split. After this, the process of destruction occurs due to the development of the split cracks and the subsequent cleavage of individual layers of concrete along these cracks (photo 2).

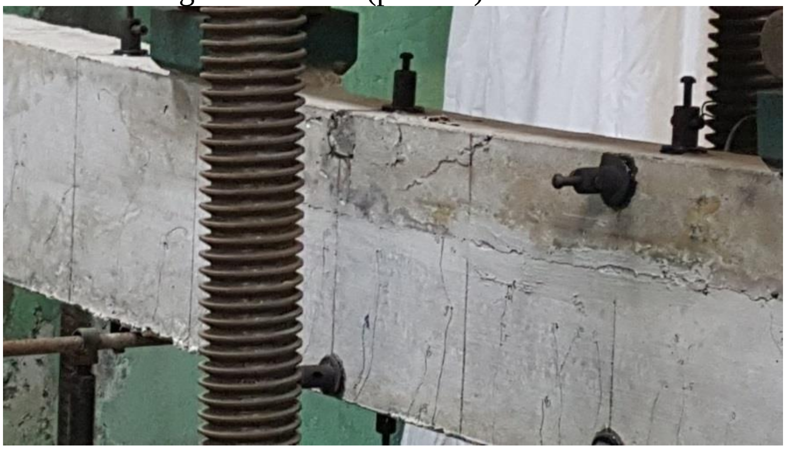


Photo 2. Partial destruction of the compressed zone of a reinforced concrete beam BOP-I-1

The destruction occurred in the zone of pure bending when the reinforcement reaches the yield strength and concrete of the compressed zone of ultimate deformations with the grinding of the concrete of the compressed zone under a load of 33.2 kN.

In the process of testing beams contact cracks on the boundary between the two layers does not occur. The maximum deflection values are fixed in the middle of the beam span.

The second stage of research is testing of beams, reinforcement with two components: a pressed reinforced concrete insert made of high-strength concrete and an external reinforcement system (photo 3). The formation of the first normal cracks in the lower (stretched) zone of the reinforced beam is recorded with a load of 21.5 kN. The bending moment at the crack resistance moment of the reinforced beam is M = 14.3 kN·m.

Photo 3. General view of the investigated beam at the test stand

In accordance with the method of experimental testing of beams before and after reinforcement with an external longitudinal-transverse system, concrete deformations and deflections of beams are determined. Under the action of a concentrated load, the intensity of growth of the deflections is observed, as well as the distribution of deformations both in height and in length of the test specimen.

After processing the results obtained using the established dial indicators, graphs of the deformations of the concrete on the bending moment for the beams are plotted. Fig. 6 shows a general diagram of comparison of concrete deformations in the middle of the span of the beams.

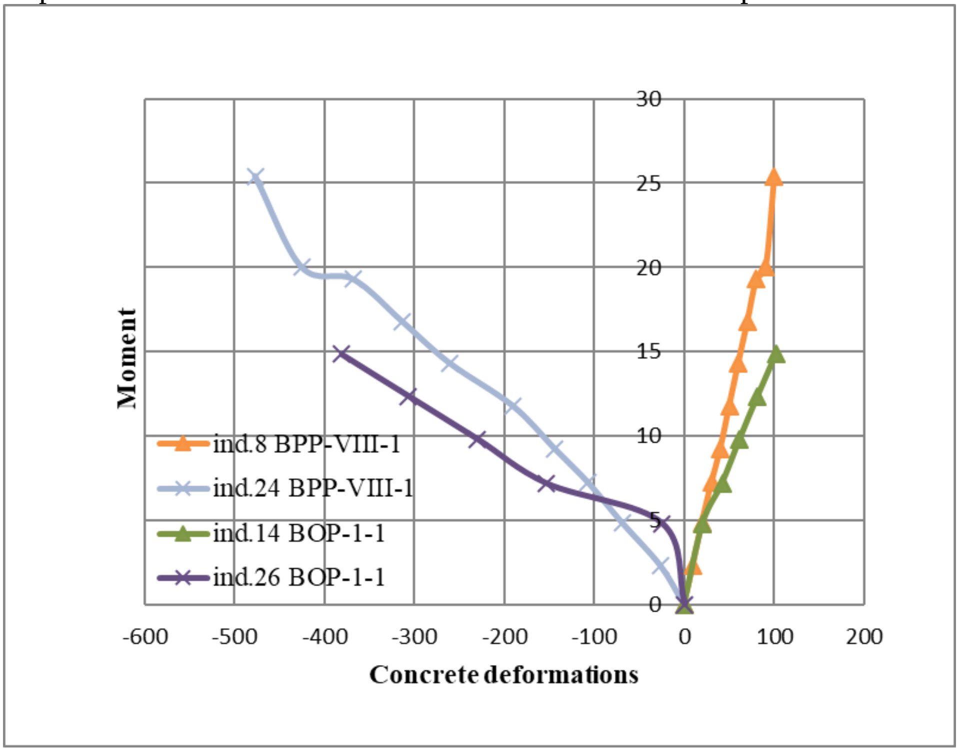


Fig. 6 Comparison diagram of concrete deformations in the middle of the span of beams

When testing beams, the deflections of experimental samples are measured using hour-type indicators mounted on a special metal frame. Five indicators are installed on each sample: in the middle of the span and in the thirds of the span. Fig. 7 shows a compatible deflection – bending moment dependency diagram for investigated beams.

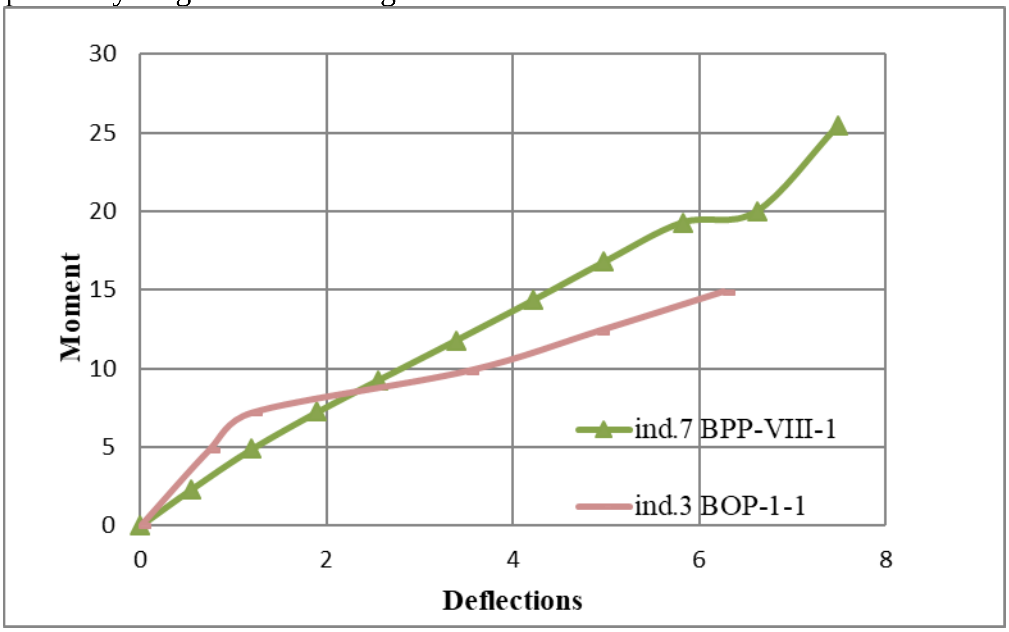


Fig. 7 Comparative diagrams of the "deflection – bending moment" dependence for beams in the middle of the span

During testing of the reinforced beam, an external system of the BPP-VIII-1 series on the longitudinal reinforcement is installed 2 hour-type indicators. After processing the results obtained during the experiment, a graph is constructed of the dependence of the reinforcement deformation on the applied moment (Fig. 8).

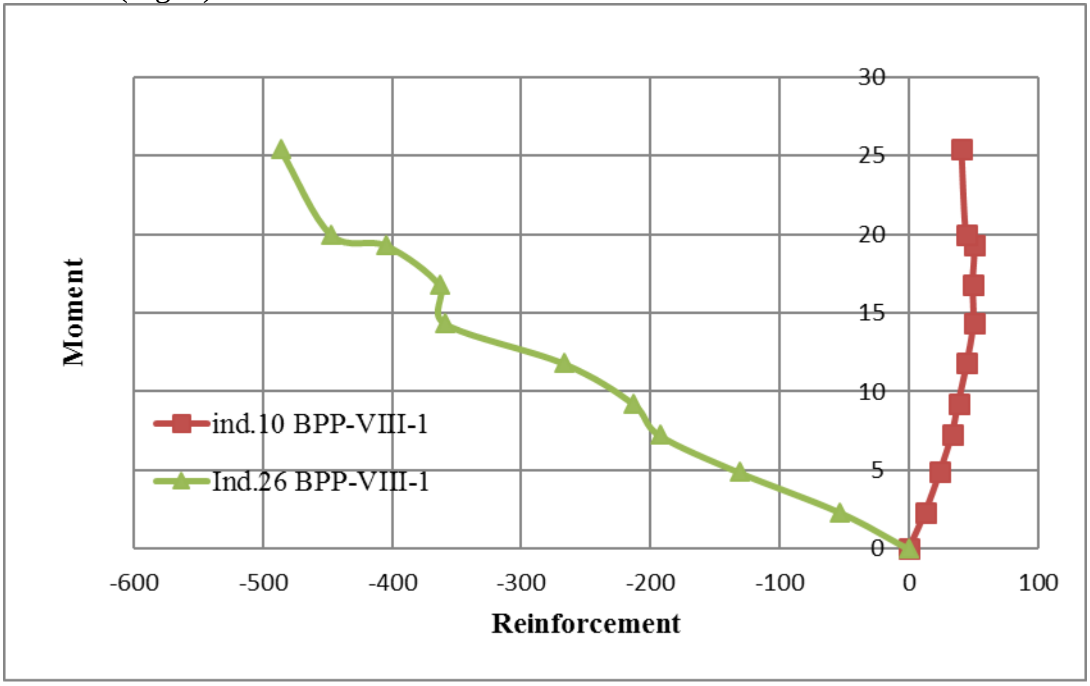


Fig. 8 Graph of reinforcement deformations according to the results of measurements of two indicators.

Table 1 shows the experimental values of moments at the time of crack formation and load, as well as the value of the deflection in the middle of the span.

Table 1

Beam test results

BPP-VIII-1 beam			BOP-I-1beam		
Load, *P* kN	Moment, *M* kN m	ind. 7	ind. 3	Moment, *M* kN m	Load, *P* kN
0	0	0	0	0	0
7,307	4,871	1,195	0,74	4,82906	7,24359
10,851	7,234	1,9	1,2	7,186761	10,78014
13,865	9,243	2,55	3,52	9,834515	14,75177
17,682	11,788	3,39	4,92	12,36203	18,54305
21,510	14,34	4,215			
25,171	16,78	4,98			
28,938	19,29	5,82			
30,001	20,0	6,62			
38,125	25,42	7,49			

Conclusions. The bending moment at the crack formation moment in the BPP-VIII-1 beam is M = 25.4 kN·m under load P = 38.125 kN, and in the BOP-I-1 beam, the maximum bending moment at the crack formation moment reaches M = 12.3 kN·m under load P = 18.54 kN. The crack formation moment in reinforced beams by an external system (self-adjusting tightening) doubles.

The deflection of reinforced concrete beams reinforced in the compressed zone by the extruded element and the external system is 65% less than in reinforced beams only by the extruded element.

On the basis of experimental studies, the system for strengthening beams BPP- VIII-1 is the most effective way to strengthen bending reinforced concrete elements.

The development of this reinforcement method is very relevant, since a comparison of theoretical studies with the results of the experiment will provide an opportunity to confirm the accuracy of the theoretical conclusions and assumptions underlying them, as well as talk about their application in practice.

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