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Research into the bearing capacity of reinforced concrete bent elements strengthened by the FRCM system

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Abstract: This article presents the experimental results of reinforced concrete beams strengthened by the FRCM system. To realize the set goal of the work, 4 reinforced concrete beams of real dimensions 2100 mm × 180 mm × 140 mm were manufactured. Exhaustion of the load-bearing capacity of all samples occurred due to the fluidity of the reinforcement. After the moment of reaching the flow of the reinforcement, physical destruction occurred in all samples due to the fragmentation of the compressed zone of concrete. Studies of reinforced samples showed that the non-shearing capacity was 16 % higher compared to non-reinforced control samples.

Keywords: reinforce concrete, beam, FRCM, strengthening, stress-strain state

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Introduction

Due to the fact that reinforced concrete structures have been used in building construction for a long time (Azizov & Pereiras, 2023; Iakovenko et al., 2017; Palyvoda et al., 2021), it is important to generalize and analyze the existing proposals for the design and use of effective methods of strengthening such structures (Brachaczek & Gałuszka, 2023; Brozda et al., 2017; Kopiika et al., 2022; Kotes, 2014; Lipiński, 2017; Pietrzak, 2024; Świt et al., 2023; Vavrus & Kotes, 2019). In recent years, along with traditional methods of strengthening (steel, concrete, reinforced concrete brackets, reinforcing reinforcement) (Li et al., 2022; Sakr et al., 2020; Zhang et al., 2022), modern methods of strengthening with composite

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materials has also been used (reinforced fibrous polymers (FRP), reinforcement with carbon fiber meshes) (Frhaan et al., 2021; Liu et al., 2023; Rogowski & Kotynia, 2022). Despite the relatively high cost, reinforcement using composite materials is becoming more widespread.

One of these methods is reinforcement with a mesh made of P.B.O. fibers in a stabilized inorganic matrix (Ruredil X Mesh Gold system) (Bressan et al., 2022; Dang et al., 2024; Trapko & Musial, 2020). When using this method of reinforcement, the bending and shear strength of concrete increases. Strength is one of the main factors in assessing the technical condition and operational suitability of reinforced concrete beam structures. In this regard, the study of the strength, deformability and crack resistance of reinforced concrete elements reinforced with the Ruredil X Mesh Gold system is of particular importance for construction sciences and practice. Based on these results, methods for calculating the crack resistance of reinforced concrete elements can be developed (De Domenico et al., 2020; Marcinczak & Trapko, 2022).

Equally important in such studies is that they give an idea of the joint operation of the structure with reinforcement and make it possible to understand the essence of the phenomena that occur in grid-reinforced reinforced concrete structures. The way to studying the work of reinforced concrete structures and developing justified methods of their calculation lies in an in-depth study of crack resistance and establishing the laws of the occurrence and propagation of cracks in reinforced concrete beam elements in comparison with unreinforced ones.

Thus, the study of reinforced concrete structures reinforced with the Ruredil X Mesh Gold system is relevant and important when assessing the technical condition, load-bearing capacity and operational suitability of beam structures.

1. Material and methods

To realize the set goal of the work, 4 experimental reinforced concrete beams with the real dimensions of 2100 mm × 180 mm × 140 mm were manufactured. The reinforcement of the test beams is shown in Figure 1.

As part of the research, 4 beams were tested, of which 2 were beams under short-term load without reinforcement, and 2 were reinforced with the Fiber Reinforce Cement Polymer (FRCM) system, namely, Ruredil X Mesh Gold (Fig. 2).

Testing continued no earlier than five days after reinforcement. During the hardening of the reinforcement solution, the load level was monitored every other day according to the readings of ring dynamometers. When the load level fell below the design level, the beam was loaded with nuts. Beams were loaded by two concentrated forces applied along the upper face at every one third of the span (Fig. 2). The load was applied in steps of 5 % until the formation of cracks and then 10 % with a waiting time of 15 minutes after each step (10 min waiting time before the removal of the instrument displays and 5 min for the filming of the cracks). Concentrated forces were applied using a hydraulic jack with a capacity of 500 kN (50 ts) and a distribution beam.

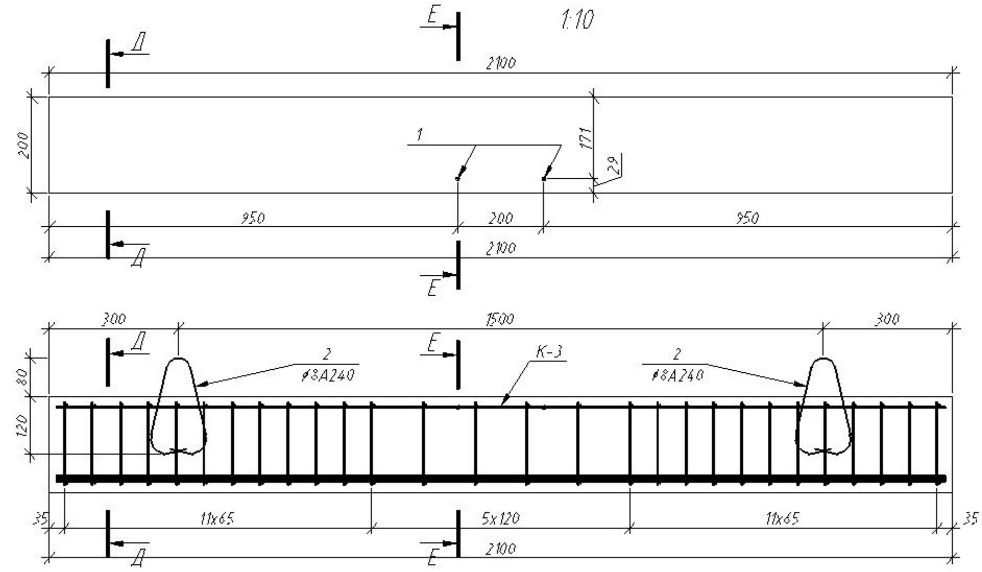

Fig. 1. Dimensions and reinforcement of experimental samples (*own research*)

Fig. 2. General view of test samples reinforced by the FRCM system (*own research*)

The load was controlled by a model manometer paired together with a pumping station and a jack, as well as two ring dynamometers, which were located on the supports of the beams. At the same time, one dynamometer was mobile, and the second – stationary.

The strain of the beams was measured using four watch-type gauges with a division value of 0.01 mm. Two of them are installed on supports, on the upper face of the beam. Two other indicators were connected to the lower face of the beam: in the place of the concreted rod and in the middle of the beam. Indicators were mounted on tripods, which were located on separate supports independently of the beam (Fig. 3).

Concrete deformations were measured using 11 watch-type micro-indicators with a scale of 0.001 mm. One indicator was fixed in concreted metal rods at a height of h = 50 mm from the face of the beam to measure deformations of the compressed zone of concrete and another one in additionally glued holders for duplicating readings. Two more indicators were mounted on reinforcement rods. The other 8 indicators were pasted on the side faces of the beam with a measurement base of 200 mm.

Fig. 3. General view of test samples installed on the test stand for short-term bending load (*own research*)

This made it possible to determine concrete deformations along the cross-section height of the beam. The indicator fixed at the top point of the rods gave concrete deformations at a height of h = 50-55 mm (the duplicating indicator was fixed at a height of h = 30 mm). With the help of a specially developed technique, these deformations were reduced to the level of the upper face of the compressed zone of concrete.

2. Results and discussion

The destruction of the control samples occurred due to the fluidity of the working fittings. Graphs showing the deformations of the reinforcements and control unreinforced concrete beams B-1 and B-2 are presented in Figure 4.

According to the test results of the control samples, the actual bearing capacity of the control beams was determined, which was equal to the average value of the yield moments of the working armature $M_{u,exp}$ = 1447 kNcm.

Beams B-3-0.7 and B-4-0.7 were loaded to 70 % of the bearing capacity of the control samples before reinforcement, and then reinforcement was performed. This simulates the operation of real structures when unloading is difficult or impossible.

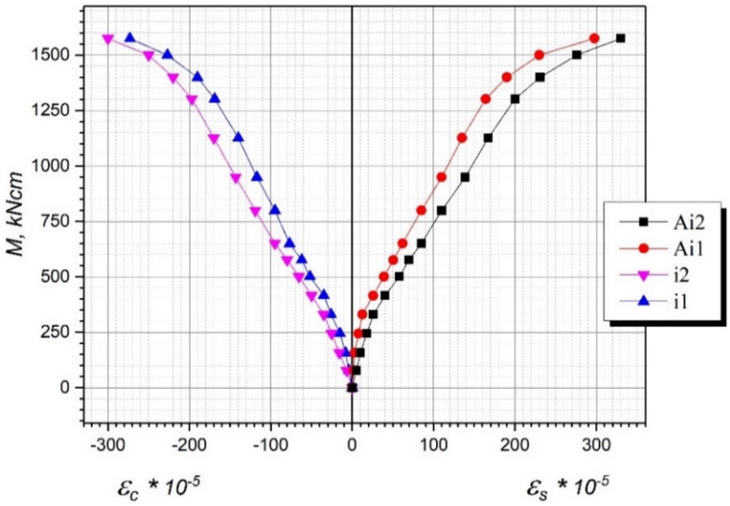

Fig. 4. Strain of reinforcement and compressed concrete fibers of control samples (*own research*)

The test results of beams B-3-0.7 and B-4-0.7 are shown in Figure 5.

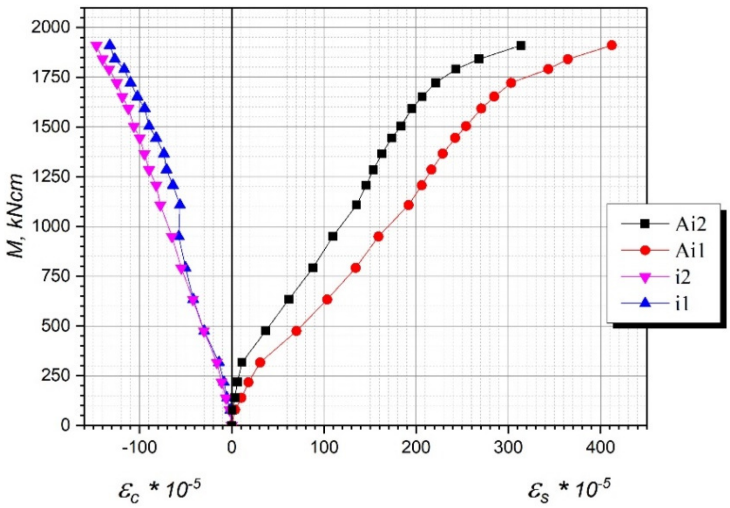

Fig. 5. Strain of reinforcement and compressed concrete fibers of reinforced samples (*own research*)

As a result of the tests, it was established that the bearing capacity of reinforced beams B-3-0.7 and B-4-0.7, which were equal to the average value of the yield moments of the working reinforcement, was $M_{u,exp}$ = 1685 kNcm.

The general test results are shown in Table 1.

Table 1. Results of experimental tests of samples (own research)

Samples	Bearing capacity	Strain	Effect of strengthening
	M_u^{exp} [kNcm]	$\varepsilon_{s0,ri}$	[%]
B-1 and B-2	1447	0.00215	–
B-3-0.7 and B-4-0.7	1685	0.00220	16.4

That is, the level of load affects the stress-strain state of reinforced concrete structures, and the effect of 70 % of the previous load gives the effect of strengthening by 16.4 %.

The destruction of the samples occurred as a result of the fluidity of the working fittings. The average relative deformations of reinforcement elongation were within 0.00215-0.00220.

Conclusions

Studies of reinforced concrete beams reinforced at an initial load level of 70 % of the bearing capacity of the control samples showed that the effect of reinforcement was only 16 %. On the graphs showing the relative deformations of reinforcement and extreme compressed concrete fibers, after the moment of reinforcement, a change in the angle of inclination of the graph is observed. This is due to an increase in the stiffness of the section due to the inclusion of reinforcing elements. Due to the large increase in strain after the flow of the working reinforcement, it was impossible to control the load level up to the physical destruction of the beam. The destruction occurred due to the fragmentation of the compressed zone of concrete.

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