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Effectiveness of strengthening reinforced concrete structures with fibroarmed plastics

Abstract. *Reinforced concrete has long been a staple in construction due to its exceptional strength and durability. One of the key components in reinforced concrete structures is steel reinforcement, which provides tensile strength to counteract the concrete's weakness in tension. However, recent innovations have led to the exploration of alternative materials that can enhance the performance of reinforced concrete elements. Among these innovations, the use of fiber-reinforced plastics has gained significant attention. The paper presents data on the application of new types of fiber-reinforced plastics for strengthening reinforced concrete structures. Stressing the laminate simultaneously on the tensile and compressed faces resulted increase in the strength of the beam. The compressed laminate strips relieve the compressed zone of concrete and reduce the height of the compressed zone. The results of the study contribute to the reduction of the time of work execution, due also the absence of additional structural elements for the reinforcement of load-bearing structures.*
Keywords: *concrete, reinforcement, strength, fiber plastic, effectiveness.*

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1. Introduction

Due to frequent changes of purpose, reconstruction, and renovation, requirements for increased reliability and comfort, physical wear, and corrosion damage of buildings and structures, the need to reinforce building structures is becoming increasingly important. The especially important role of strengthening and restoring buildings and structures is assigned in seismic areas of construction, in areas of natural disasters, and after accidents [1].

The basic material of bearing structures of buildings and constructions of the present day is monolithic or prefabricated reinforced concrete, therefore the problems of improvement of methods of reinforcement of concrete structures acquire special urgency. Traditional reinforcement methods of concrete structures are very labor-intensive, require stripping, welding, and concrete work, and require considerable time to ensure the required strength [2]. New, modern methods of reinforcement of concrete structures are focused on the use of composite fibroplastic materials for reinforcement, characterized by high strength, corrosion resistance, and durability. Surface reinforcement of concrete structures by direct gluing on concrete surfaces of reinforcing composite materials is characterized by high efficiency of strengthening, simplicity and high speed of performance, low labor intensity of works, and fast terms of strength increase [3-4].

The basic work on studying the stress state of concrete in the shell is the work of American scientists at the University of Illinois [2]. Their research is devoted to the study of concrete performance under triaxial compression. According to the results of the research, the dependence of the strength of reinforced concrete on the strength of the original concrete, radial stress in the casing, and the angle of internal friction is proposed. In the experimental studies, concrete specimens were tested in a stabilometer creating constant hydrostatic pressure.

In works [5-8] the principles of calculation of compressed reinforced reinforced concrete elements reinforced with fiber plastic sheathing have been developed, according to which failure may occur due to rupture of the sheathing material or delamination of the sheathing material in the overlap zone of the material. At the same time, various empirical dependencies are proposed to determine the concrete strength of reinforced concrete columns reinforced with fiber-reinforced plastic shells.

The paper [9] analyzes the stress-strain state of reinforced concrete columns strengthened with composite materials, which shows that the existing dependencies provide high accuracy only for round columns, and for columns of other cross-sectional shapes, significant discrepancies are obtained.

Investigation shows [10] that in addition to the triaxial stress state in concrete associated with the presence of the fiber-reinforced shell, the fiber-reinforced plastic shell itself also acquires a volumetric stress state (tensile stresses from the lateral direction in the longitudinal direction; passive concrete repulsion in the radial direction; compressive stresses acting across the fibers). In addition, the fiber-reinforced plastic cladding elastically deforms until the reinforced element fails, creating increasing passive pressure on the concrete. This differs from the performance of a metal cage, which stops increasing the pressure on the concrete when the metal reaches its yield strength. The performance of a fiber-reinforced plastic cage for rectangular reinforced members is not as effective.

Successful experience in the restoration of emergency columns of the 7-story hotel in Los Angeles, damaged in the June 1992 earthquake [11], was obtained with the construction of a casing made of canvas composite materials. So, the question of designing reinforcement of concrete structures with fiber-reinforced plastics is currently open.

2. Methods and materials

The experimental study studies the peculiarities of the work of normal sections of bent reinforced concrete beams reinforced with fiber-reinforced plastics [12].

Experimental specimens for studying the performance of normal sections of bending reinforced concrete beams are made with a span of 2200 mm, and a cross-section of 120x200 mm from the general mix of naturally hardened concrete. The specimens are reinforced by spatial knitted frames with asymmetrical reinforcement from 2Ø12A—III in the lower zone, 2Ø10A—III in the upper zone, and clamps Ø6 A—I (Figs. 1-2).

To reinforce the tensile zone of the experimental specimens for the study of the performance of normal sections, fiber-reinforced polymer material - -laminate tapes based on carbon fiber fibers of S&H Laminate CFR 150/200 type with a cross-section of 50x1.2 mm were used (Fig.3).

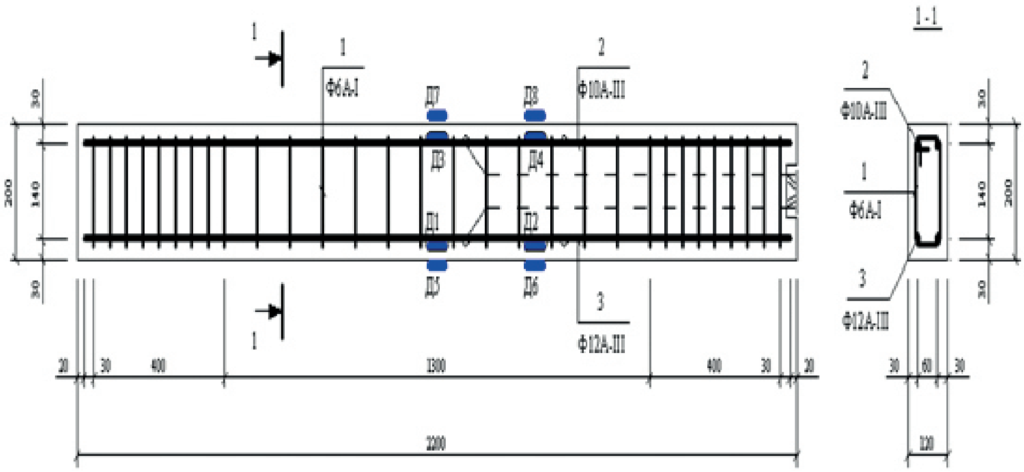

Figure 1. Reinforcement of a bending reinforced concrete beam

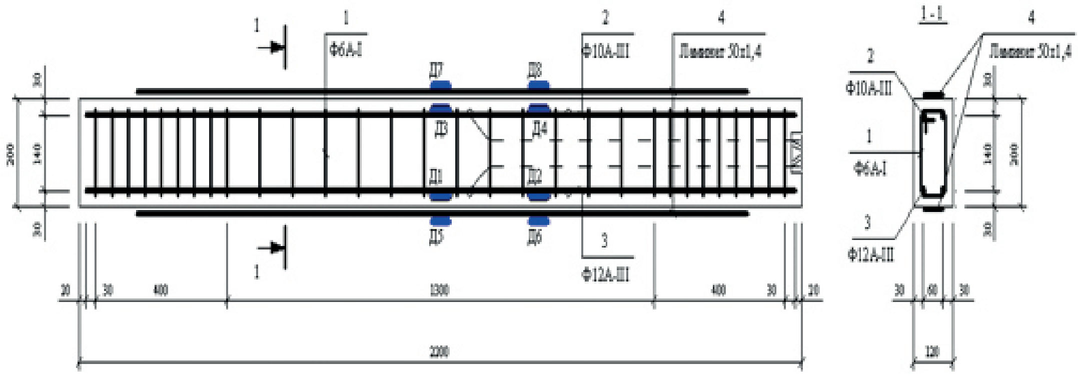

Figure 2. Reinforcement of bending reinforced concrete beam with reinforcement in tensile and compressed zones by laminate

Fig.3 Process of strengthening

To clarify the strength and deformation characteristics of the material used to reinforce the experimental reinforced concrete specimens, laminate specimens were tested. The specimens were tested on a hydraulic tensile machine R-50 by fixing the ends of tapes or meshes (the specimens had reinforced ends) in the grips and creating a step-by-step increasing axial tensile force. In the process of testing, longitudinal elongation deformations were measured using deflection gauges PAO-6 with a division value of 0.01 mm on the base of 180-200 mm and load cells of 50 mm length complete with AID-4M (Fig. 4).

Figure 4. Test equipment

Destruction of experimental samples was accompanied by the formation of longitudinal cracks in the laminate starting in the grip of the tensile machine, after which the load-bearing capacity of the samples sharply decreased. The tensile diagram of the laminate and meshes has a linear form, the fibers were elastically stretched. Measurements of the length of the specimens, made along the reapplied notches along the length with a step of 20 mm, confirmed that there were no residual deformations in the fibers after the tests. The study of the performance of normal sections of bending reinforced concrete elements reinforced in the tensile and compression zones with fiber-reinforced laminate tapes was performed on experimental reinforced concrete beams tested according to the scheme of a hinged-open beam with a span of 2.0 m, loaded in the span by two equal concentrated forces located at a distance of 0.7 m. The static tests of the beams were carried out in a force bench under stepwise loading by transverse loading created by a hydraulic jack and a manual pumping station. Static tests of the beams were carried out in a power bench under stepwise loading with transverse load created by a hydraulic jack and a manual pumping station. Two beams of series B-I-0 of the batch had no reinforcement.

3. Results and Discussion

Their failure occurred in the zone of pure bending and was accompanied by splitting of the compressed concrete zone at stresses in the tensile reinforcement corresponding to the yield strength of steel, the beam deflections were 1/27.5 of the span, and the crack opening width reached 2 mm and more (Fig. 5).

Figure 5. Failure of a reinforced concrete beam without reinforcement

Beams of B-I-1 series, reinforced by gluing S&H Laminate CFR 150/200 with 50x1,2 mm cross-section on stretched tapes, had the failure shown in Fig.6.

Figure 6. Beam failure with laminate reinforcement of the tensile zone

Table 1 summarizes the static test results for the beams of the Б-I series.

Table 1 Test Results of B-I Series Bending Beams

Mark samples	Strengthening of samples	Breaking load kNm	Deflections cm	Opening width cracks mm	Limit deformations		Deformations laminate	
					ε_b 10^{-5}	ε_s 10^{-5}	$\varepsilon_{лр}$ 10^{-5}	$E_{лс}$ 10^{-5}
B1-0-1c		+20.4	5.6	1.6	-	+591	-	-
B1-0-2c	Without strengthening	+18.68	5.1	1.3		+430	-	-
B1-0-3c		-	5.8	2,2		+464	-	-
B1-0-4c			5.9	2,3		+439	-	-
B1-1-1c	laminate flooring	+35.07	2.4	0.6	-	+472	+610	-
B1-1-2c		+33.79	2.2	0.7		+480	+580	-

Analysis of the data in Table 1 shows that sticking S&P CFK 150/2000 laminate on the tensile face of beams resulted in an increase in the strength of beams by 76% on average (Fig.7). At the same time, the deformations of the compressed zone of concrete and tensile reinforcement remained unchanged, while the deformations of the tensile laminate amounted to about 6%, and the beam deflections and crack opening widths decreased more than twofold.

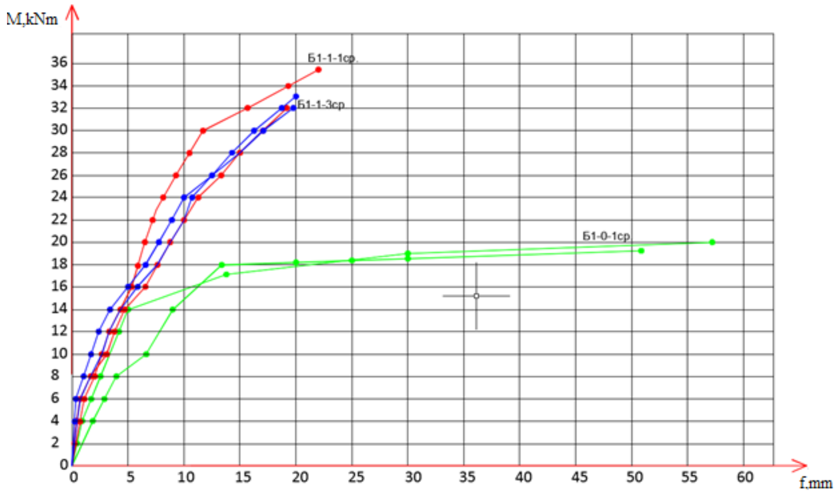

Figure 7. Graphs of vertical deflections of beams without reinforcement and reinforced with laminate.

4. Conclusion

The traditional method of reinforcing reinforced concrete structures is to increase the cross-sectional dimensions using monolithic reinforced concrete cages or metal structures. These methods are labor-intensive, accompanied by stripping, welding, and concrete works, and require considerable time for concrete strength gain. The reinforcement of concrete elements with fibroarmed plastics, or FRP composites, presents a promising avenue for improving the performance and durability of structures. The unique properties of FRP, including corrosion resistance, high tensile strength, and compatibility with concrete, make it a compelling alternative to traditional steel reinforcement. The results of tests of bending reinforced concrete structures reinforced in the tensile zone by surface gluing of different types with the help of fiber plastics showed that reinforcement of beams increases the strength by 1.5-2 times in normal sections.

However, engineers and researchers must collaborate on refining design practices and establishing standardized guidelines to ensure the safe and effective utilization of this innovative material in construction projects.

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Темірбетон конструкцияларын фибробласттармен арматуралаудың тиімділігі

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Андатпа. Ерекше беріктігі мен беріктігіне байланысты темірбетон бұрыннан құрылыстың негізгі материалы болды. Темірбетон конструкцияларының негізгі құрамдас бөліктерінің бірі бетонның созылу әлсіздігіне қарсы тұру арқылы созылу беріктігін қамтамасыз ететін болат арматура болып табылады. Дегенмен, соңғы инновациялар темірбетон элементтерінің жұмысын жақсартатын балама материалдарды іздеуге әкелді. Олардың ішінде талшықты арматураланған пластмассаларды пайдалану айтарлықтай назар аударады. Мақалада темірбетон конструкцияларын нығайту үшін талшықты арматураланған пластмассалардың жаңа түрлерін қолдану туралы мәліметтер келтірілген. Ламинатты бір уақытта созу және қысу беттеріне жабыстыру сәуленің беріктігінің өсуіне әкелді. Зерттеу нәтижелері жұмысты аяқтауға қажетті уақытты қысқартуға, сондай-ақ жүк көтергіш құрылымдарды нығайтудан қосымша құрылымдық элементтердің болмауына ықпал етеді.

Түйінді сөздер: бетон, арматура, беріктік, шыны талшық, тиімділік

Эффективность усиления железобетонных конструкций фиброармированными пластиками

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Аннотация. Благодаря своей исключительной прочности и долговечности железобетон давно стал основным материалом для строительства. Одним из ключевых компонентов железобетонных конструкций является стальная арматура, которая обеспечивает прочность на растяжение, противодействуя слабости бетона при растяжении. Однако последние инновации привели к поиску альтернативных материалов, способных повысить эксплуатационные характеристики железобетонных элементов. Среди них значительное внимание привлекает использование фиброармированных пластиков. В статье представлены данные по применению новых типов фиброармированных пластиков для усиления железобетонных конструкций. Наклеивание ламината одновременно на растянутую и сжатую грани привела к повышению прочности балки. Сжатые ленты ламината разгружают сжатую зону бетона, уменьшают высоту сжатой зоны. Результаты исследования способствуют сокращению сроков выполнения работ, также отсутствию дополнительных конструктивных элементов для усиления несущих конструкций.

Ключевые слова: бетон, арматура, прочность, фибропластик,эффективность

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