

**BEARING CAPACITY, DEFORMITY AND CRACK RESISTANCE OF DAMAGED BEAMS REINFORCED WITH FIBER CONCRETE**

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**Abstract.** The results of experimental studies of the load-bearing capacity, deformability and crack resistance of damaged beams reinforced with fiber concrete in the compressed and stretched zone are presented. Test samples are made of concrete and fiber concrete. The amount of steel fiber in fiber concrete is 2% of the volume of the product. Preliminary tests were carried out on prisms and cubes. During the manufacture of beam samples, before concreting, a foam insert was installed in the area of planned damage, the shape and dimensions of which corresponded to the damage. After the concrete set to 70% grade strength, the liner was pulled out, and the resulting cavity was filled with a 2% mixture of fiber concrete. Tests of material samples showed that the introduction of steel fiber into the composition of concrete in the amount of 2% by volume increases the compressive strength limit by 15.3%. The initial modulus of elasticity of fiber concrete of the specified mixture is 38.0% higher than that of ordinary concrete of this composition.

Conducted experimental studies of damaged beams showed that a beam whose cross-section is 40% damaged in the middle-compressed zone, and the shape of the damage is close to rectangular, has a load-bearing capacity of 92.0 kN, or 93.9% of the load-bearing capacity of an undamaged beam. Cracking started at the 4th loading stage, when the load value was 26.0kN, i.e. 28.3% of the bearing capacity of the damaged beam. The maximum final crack opening width was 0.6 mm. A beam whose section is 40% damaged in the mid-stretch zone has a load-bearing capacity of 92.4 kN, or 93.2% of the load-bearing capacity of an undamaged beam. Cracking started at the 5th loading stage, when the load was 32.5kN, i.e. 35.2% of the bearing capacity of the damaged beam. The maximum final crack opening width was 0.8 mm.

It is claimed that the strengthening of a beam with 40% damage in the compressed or stretched zone in the manner considered in the paper is effective, as it allows achieving its load-bearing capacity, which is more than 93% of the load-bearing capacity of an undamaged beam.

**Keywords:** damaged beam, reinforced concrete, experiment, stand, bearing capacity, crack.

**Introduction.** The field of application of reinforced concrete beams in construction is huge. They are used in various constructions and structures, such as high-rise residential and industrial buildings, airports, bridges, for laying railway and tram lines, etc.

The main advantages of reinforced concrete beams are their increased strength, fire resistance, installation speed, and durability. Due to various reasons, these structures can be damaged, it can be mechanical damage associated with the destruction of concrete and corrosion of reinforcement as a result of long-term operation. This problem is especially relevant in our time, since a large amount of damage occurs as a result of military operations. It is not always advisable to change the structure; in most cases it is more economical to strengthen the damaged part of the structure without its complete replacement.

Analysis of research and publications. Many works are devoted to the strengthening of reinforced concrete beams. All of them can be divided into experimental and theoretical, and the latter include analytical and numerical methods for calculating reinforcements. The complexity of mathematical models describing constructive solutions of reinforcements leads to the fact that most

scientists prefer experimental research methods [1-5].

Current research is mostly related to the use of carbon fiber reinforced polymers (CFRP) for reinforcement. Thus, in the article [6], the results of studies of the load-bearing capacity of ordinary (reference) and reinforced with carbon-plastic webs in the lower stretched zone and at the supporting areas of damaged concrete beams with basalt-plastic reinforcement under the action of a static gradually increasing low-cycle load are presented. In works [7-13], the results of research on strengthening of damaged reinforced concrete beams with various types of fiber-reinforced polymer laminates are presented. Reinforcement of beams with basalt tapes is considered in [14]. In [15] fatigue failure of reinforced concrete beams, damaged by corrosion, strengthened by composites with reinforced fabric is considered. The effectiveness of using carbon fiber as a method of strengthening reinforced concrete beams subjected to shock loads was investigated in [16].

Works related to the use of fiber concrete are much less. Research [17] is devoted to determining the ability of reinforced concrete beams with and without steel fiber to absorb energy during explosive loading. In work [18], reinforced concrete beams reinforced with steel fiber concrete were studied. It was established that the use of a 45 mm thick reinforced concrete shell with a fiber content of 2.5% increases the destructive load by 20%, stiffness by 3.4-11 times, crack resistance by 2.6 times. The effectiveness of ultra-high-strength fiber reinforced concrete (UHPFRC) in the repair of damaged concrete columns is considered in [19]. Article [20] deals with numerical modeling to verify and evaluate the influence of design-oriented parameters affecting the shear behavior of reinforced concrete beams.

This short review shows the relevance of research on damaged beams reinforced with steel-reinforced concrete.

**Purpose.** The purpose of the work was experimental studies of the load-bearing capacity, deformability and crack resistance of damaged beams reinforced with fiber concrete in the compressed and stretched zone.

**Research materials and methods.** Samples are made of concrete and fiber concrete. The amount of steel fiber in fiber concrete is 2% of the volume of the product. Preliminary tests were carried out on prisms and cubes, 100×100×400 mm and 100×100×100 mm, respectively, aged for 28 days. 2 groups of prisms and cubes were made. One of ordinary concrete (with the size of large aggregate up to 10 mm) class C20/25 and the second – with anchoring steel fiber. Each group consisted of six samples. During the manufacture of beam samples, before concreting, a foam insert was installed in the area of planned damage, the shape and dimensions of which corresponded to the damage. After the concrete set to 70% grade strength, the liner was pulled out, and the resulting cavity was filled with a 2% mixture of fiber concrete. For research, methods of mathematical statistics, experimental methods of mechanics, and the strain gauge method were used.

**Research results.** In accordance with the research program of bearing capacity, deformability and crack resistance of damaged reinforced concrete beams reinforced with steel fiber concrete, a bench for testing reinforced concrete beams was developed at the departments of construction mechanics and resistance of materials. The flat transverse bending of the load of the tested beam is created with the help of a hydraulic jack and a metal beam with a two-beam traverse, which transmits two equal concentrated forces to the beam. The load created is controlled by a sample dynamometer of the Tokar system and a ring dynamometer that acts as a support (Fig. 1).

During the tests, the load transmitted to the beam, deflections and deformations were recorded. A study of a series of beams with different types of damage was carried out. The damage zone (stretched and compressed), the geometry of the damage zone and the method of strengthening were varied. The research was carried out on beams of rectangular cross-section with dimensions of 200×120 mm, reinforced with two vertical frames.

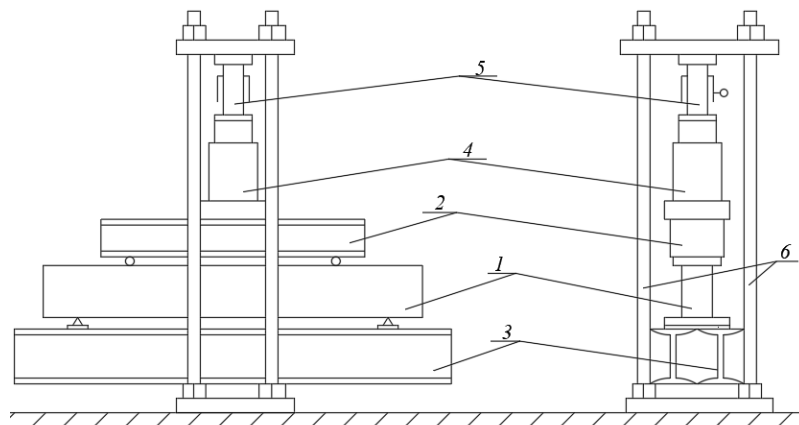


Fig. 1. Test bench: 1 – the beam being tested; 2 – traverse; 3 – the lower load beam (I-beams); 4 – jack; 5 – sample dynamometer; 6 – racks

The studied beam samples (they were named RCD1–RCD6) were divided into three groups. In the first group, the compressed zone was damaged, in the second and third – the stretched zone. Specimens of each group with corresponding damage were produced simultaneously, and an undamaged beam was additionally added to each group. In addition, prisms and cubes were made in order to determine the physical and mechanical properties of the material of these samples. For the production of material samples, when mixing the concrete mass, fiber was added uniformly, the total volume of which was 2% of the volume of the product.

Test samples of the beams were tested for the effect of a one-time short-term gradually increasing load until destruction or reaching the limit state, when the opening width of inclined cracks and the arrow of deflections exceeded the permissible values. The criteria for the failure of the test samples were also the achievement of the limit values of deformations in concrete or reinforcement, excessively large opening of inclined or normal cracks, a significant increase in the deflection of the sample beam, no increase or decrease in the readings of the pressure gauge of the pumping station of the power plant.

The test program provides for the study of a series of beams with different types of damage. The damage zone (stretched and compressed), the geometry of the damage zone and the method of strengthening were varied. This paper describes the results of the study of two reinforced beams (Fig. 2). Both have 40% cross-sectional damage, but one (RCD3) is in the middle-compressed zone, and the other (RCD5) is in the stretched zone.

Brand sample	Damage scheme
RCD3	
RCD5	

Fig. 2. Nature of damage

The research was carried out on beams of rectangular cross-section with dimensions of 200×120 mm, reinforced with two vertical frames. Lower longitudinal armature – Ø12 mm, upper – Ø8 mm. For transverse reinforcement, Ø6 mm rods with a step of 87.5 mm were used. In the zone of the span of the section, the transverse reinforcement is made with rods of Ø4 mm.

The bearing capacity of three undamaged reinforced concrete beams (one from each group) is given in the Table 1.

Table 1 – Bearing capacity of undamaged reinforced concrete beams

Brand sample	Total load, kN	Final moment, kNm
RCI	98.0	26.95
RCII	99.1	27.25
RCIII	98.4	27.06

In the Table 2 shows the bearing capacity of reinforced beams recorded in experimental studies.

Table 2 – Bearing capacity of reinforced beams

Brand sample	Zone damage	Volume damage, %	Bearing capacity, kN
RCD1	Squeezed	20	80.6
RCD2	Squeezed	20	93.6
RCD3	Squeezed	40	92.0
RCD4	Stretched	40	91.0
RCD5	Stretched	40	92.4
RCD6	Stretched	40	93.6

According to the results of the tests, graphs of the dependence of the relative longitudinal deformation on the load for the left and right supporting parts of the beam, for the zone of pure bending for all tested samples, as well as graphs of the dependence of the deflections on the load, which we do not present here due to the limited scope of the article, were constructed.

A little more detail about the bearing capacity and crack resistance of samples RCD3, RCD5.

*Sample RCD3.* The load-bearing capacity of the RCD3 sample was 92.0 kN, or 93.9% of the load-bearing capacity of the undamaged beam.

Cracking started at the 4th loading stage, when the load value was 26.0kN, i.e. 28.3% of the bearing capacity of the damaged beam. At the same time, 5 cracks formed in the area of pure bending. At the fifth stage, two more cracks appeared. At the 8th and 9th loading stages, 4 more cracks formed. A total of 12 cracks were formed. The maximum final crack opening width was 0.6 mm. General indicators of crack formation are given in Table 3.

Table 3 – Indicators of cracking in sample RCD3

Degree load	Size load, kN	Number cracks	Final width disclosure, mm
1	6.5		
2	13.0		
3	19.5		
4	26.0	1-6	1– 0.25; 2, 4 – 0.2; 3, 5 – 0.1; 6 – 0.05
5	32.5	7-8	7 – 0.1; 8 – 0.05
6	39.0		
7	45.5		
8	52.0	9-10	9 – 0.2; 10 – 0.15
9	58.5	11-12	11 – 0.6; 12 – 0.25
10	65.0		
11	71.5		
12	78.0		
13	84.5		
14	91.0		
15	92.0		

The destruction of the sample started with crack 11. The general appearance of the cracks formed at the end of the RCD3 sample tests is shown in Fig. 3.

*Sample RCD5.* The load-bearing capacity of the RCD5 sample was 92.4 kN, or 93.2% of the load-bearing capacity of the undamaged beam.



Fig. 3. Cracks in the sample RCD3

Cracking started at the 5th stage of loading, when the load value was 32.5kN, i.e. 35.2% of the bearing capacity of the damaged beam; the first crack appeared. Another one is at the second stage. At stages 7-9 of loading, 8 more cracks formed, and at stages 11-14, the last six. 4 cracks formed in the zone of clean bending. The total number is 19 cracks. The maximum final crack opening width was 0.8 mm. General indicators of crack formation are given in Table 4.

Table 4 – Indicators of cracking in sample RCD5

Degree load	Size load, kN	Number cracks	Final width disclosure, mm
1	6.5		
2	13.0		
3	19.5		
4	26.0		
5	32.5	1	1 – 0.3
6	39.0	2	2 – 0.1
7	45.5	3, 4	3 – 0.2; 4 – 0.15
8	52.0	5-8	5, 6 – 0.15; 7, 8 – 0.2
9	58.5	9-10	9 – 0.1; 10 – 0.05
10	65.0		
11	71.5	11-12	11 – 0.1; 12 – 0.25
12	78.0	13	13 – 0.8
13	84.5	14-15	14, 15 – 0.1
14	91.0	16	16 – 0.1
15	92.4		

The destruction of the sample began with crack 13.

The general appearance of the cracks formed at the end of the RCD5 sample tests is shown in Fig. 4.



Fig. 4. Cracks in the sample RCD5

**Conclusions.** According to the results of experimental studies of prisms, a diagram of concrete deformation, graphs of changes in relative linear deformations of fiber concrete, as well as graphs showing a comparison of the nature of deformation of concrete and fiber concrete were constructed. Tests of material samples showed that the introduction of steel fiber into the composition of concrete in the amount of 2% by volume increases the compressive strength limit by 15.3%. The initial modulus of elasticity of fiber concrete of the specified mixture is 38.0% higher than that of ordinary concrete of this composition.

Conducted experimental studies of damaged beams showed that a beam whose cross-section is 40% damaged in the middle-compressed zone, and the shape of the damage is close to rectangular, has a load-bearing capacity of 92.0 kN, or 93.9% of the load-bearing capacity of an undamaged beam. Cracking started at the 4th loading stage, when the load value was 26.0kN, i.e. 28.3% of the bearing capacity of the damaged beam. At the same time, 5 cracks formed in the area of pure bending. At the fifth stage, two more cracks appeared. At the 8th and 9th loading stages, 4 more cracks formed. A total of 12 cracks were formed. The maximum final crack opening width was 0.6 mm.

A beam whose section is 40% damaged in the mid-stretch zone has a load-bearing capacity of 92.4 kN, or 93.2% of the load-bearing capacity of an undamaged beam. Cracking started at the 5th stage of loading, when the load value was 32.5kN, i.e. 35.2% of the bearing capacity of the damaged beam; the first crack appeared. Another one is at the second stage. At stages 7-9 of loading, 8 more cracks formed, and at stages 11-14, the last six. 4 cracks formed in the zone of clean bending. The total number is 19 cracks. The maximum final crack opening width was 0.8 mm.

It can be argued that strengthening a beam with 40% damage in the compressed or stretched zone by the method considered in the paper is effective, because it allows achieving its bearing capacity, which is more than 93% of the bearing capacity of an undamaged beam.

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**НЕСУЧА ЗДАТНІСТЬ, ДЕФОРМАТИВНІСТЬ ТА ТРІЩИНОСТІЙКІСТЬ ПОШКОДЖЕНИХ БАЛОК З ПІДСИЛЕННЯМ ФІБРОБЕТОНОМ**

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**Анотація.** Представлені результати експериментальних досліджень несучої здатності, деформативності та тріщиностійкості пошкоджених балок з підсиленням фібробетоном у стиснутій та розтягнутій зоні. Зразки для випробувань виготовлені з бетону та фібробетону. Кількість сталевих фібри у фібробетоні становить 2% обсягу виробу. Попередні випробування проводилися на призмах та кубах. При виготовленні зразків балок перед бетонуванням у зоні запланованого пошкодження встановлювався пінопластовий вкладиш, форма та розміри якого відповідали пошкодженню. Після набору бетоном 70% марочної міцності вкладиш витягувався, а порожнина, що утворилася, заповнювалася 2% сумішшю з фібробетону. Випробування зразків матеріалів показали, що введення до складу бетону сталевих фібрових волокон у кількості 2 % за обсягом збільшує межу міцності на стиск на 15,3%. Початковий модуль пружності фібробетону означеної суміші на 38,0% вище, ніж у звичайного бетону такого складу.

Проведені експериментальні дослідження пошкоджених балок показали, що балка, переріз якої на 40% пошкоджено в середній стиснутій зоні, а форма пошкодження має вигляд, близький до прямокутного, має несучу здатність 92,0 кН, або 93,9 % несучої здатності непошкодженої балки. Тріщиноутворення почалося на 4-му етапі навантаження, коли величина навантаження становила 26,0кН, тобто 28,3 % несучої здатності пошкодженої балки. Максимальна кінцева ширина розкриття тріщин становила 0,6 мм. Балка, переріз якої на 40% пошкоджено в середній розтягнутій зоні, має несучу здатність 92,4 кН, або 93,2 % несучої здатності непошкодженої балки. Тріщиноутворення почалося на 5-му етапі навантаження, коли величина навантаження становила 32,5кН, тобто 35,2% несучої здатності пошкодженої балки. Максимальна кінцева ширина розкриття тріщин становила 0,8 мм.

Стверджується, що посилення балки з 40% пошкодженням у стиснутій або розтягнутій зоні розглянутим у роботі способом є ефективним, оскільки дозволяє досягти її несучої здатності, яка становить понад 93 % несучої здатності неушкодженої балки.

**Ключові слова:** пошкоджена балка, сталеві фібробетон, експеримент, стенд, несуча здатність, тріщина.

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