

EXPERIMENTAL STUDIES OF A DAMAGED BEAM REINFORCED WITH FIBER CONCRETE

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Abstract. The paper presents the results of a study of the load-bearing capacity of a beam damaged during hostilities, which was reinforced with steel fiber concrete. A beam with 20% damage in the compressed zone is considered. Before concreting, a foam liner was installed in the area of the planned damage, the shape and dimensions of which corresponded to the planned damage. After the concrete gained 70% of the brand strength, the liner was removed, and the resulting cavity was filled with a 2% mixture of fiber-reinforced concrete. This is one of the options for strengthening a beam in a comprehensive testing program for damaged beams, which involves studying a series of beams with different types of damage, damage zone (tension and compression) and its size, geometry and method of strengthening. The authors have developed a special stand for testing. Plane transverse bending of the loading of the beam under test is created using a hydraulic jack and a metal I-beam with a traverse that transmits two equal concentrated forces to the beam. The created load is controlled by an exemplary dynamometer of the Tokar system and a ring dynamometer, which acts as a support. Experimental studies have shown that a beam, the cross-section of which is 20% damaged in the middle compressed zone, and the shape of the damage is close to rectangular, has a load-bearing capacity of 93.6 kN, which is 95.0% of the load-bearing capacity of an undamaged beam (98.5 kN). Crack formation began on the 5th stage of loading, when the load value was 32.5 kN, that is, 34.7% of the load-bearing capacity of the damaged beam. In this case, 4 cracks formed in the pure bending zone. At the sixth stage, three more cracks appeared. At stages 9, 10 and 14 of loading, 7 more cracks formed. The maximum final crack opening width was 0.8 mm. throughout the testing process, the fiber-reinforced concrete liner worked with the beam as a single unit. It can be argued that strengthening a beam with 20% damage in the compressed zone using the method considered in the work makes it possible to achieve its load-bearing capacity, which is 95% of the load-bearing capacity of an undamaged beam.

Keywords: damaged beam, steel fiber concrete, experiment, test stand, load-bearing capacity, crack.

Introduction. The construction industry is characterized by the widespread use of reinforced concrete structures, which are one of the main load-bearing elements of buildings and structures. Most of these elements operate under bending conditions. For various reasons, these structures can be damaged, this can be either mechanical damage associated with the destruction of concrete and corrosion of reinforcement as a result of long-term operation, or damage as a result of military operations. Unfortunately, the latter problem becomes especially relevant in our time, when hostilities are taking place in many countries of the world. And if we add to this damage from various natural disasters, then naturally the problem arouses great interest. It is not always advisable to change the design; in most cases it is more economical to strengthen the damaged part without completely replacing it. An effective method of strengthening reinforced concrete elements is the use of high-strength materials such as steel fiber concrete.

Analysis of research and publications. In article [1], the use of a fiber-reinforced concrete shell is proposed to strengthen reinforced concrete beams. Full-scale tests were carried out on beams 4.55 m

long. A 40 mm thick fiber-reinforced concrete shell was applied directly to the surface of the beam. Both strengthening and repair of reinforced concrete beams have been studied. In particular, in the latter case, the beam was initially damaged and then repaired. Numerical analysis is also carried out. Experimental and numerical results show the effectiveness of the proposed technology.

Article [2] discusses the use of steel-polymer (SRP) composites for repairing and strengthening damaged concrete structures. The test program involved the examination of six full-scale reinforced concrete beams that were damaged in the middle region and reinforced using SRP sheets. The number of layers and the number and distribution of U-winding strips were varied. Test results showed that repairing beams with SRP layers and U-strips restored their load-bearing capacity to a level similar to a reinforced concrete beam without damage.

Work [3] is devoted to determining the ability of reinforced concrete beams with steel fiber to absorb energy under explosive loads. The compressive strength of concrete with and without steel fibers was measured, and the load-bearing capacity of reinforced concrete beams was determined using a two-point compression test. The damage levels under blast load applied to reinforced concrete beams were observed and the results showed that reinforced concrete beams manufactured with the addition of steel fibers were less damaged than conventional reinforced concrete beams.

Article [4] describes the strengthening of damaged beams using a fiber reinforced polymer (fiberglass) composite. The problems of ensuring the stability of reinforced beams to bending, shear, torsion, fatigue, impact and blast loading are considered.

Generally speaking, strengthening of damaged beams is carried out in both compression and tension zones. In this case, two main methods are used: installing unloading elements and (or) increasing the cross-section of the structure.

Strengthening beams in the tension zone is presented in numerous publications, of which we note the works [5-8]. No less research is devoted to strengthening beams in a compressed zone – works [9-12], etc.

Significant research is related to the use of new highly efficient building materials, such as high-strength concrete, steel fiber concrete, polymer concrete, basalt concrete [13, 14]. Composite reinforcement based on aramid (AFRP), glass (GFRP) and carbon (CFRP) fibers is widely used. Such materials have a number of advantages: high static and fatigue strength, elastic modulus close to metal, low dead weight, high corrosion resistance, etc. [15-19].

The use of fiber-reinforced concrete to strengthen beams is considered in [10, 11, 20-27].

The purpose of this work was to study the load-bearing capacity of a beam damaged during combat operations, which was reinforced with steel fiber concrete.

Materials and methods of research. All studies were carried out in the laboratories of the departments of structural mechanics and strength of materials of the Odessa State Academy of Construction and Architecture. To make samples of the material, when mixing the concrete mass, fiber was evenly added, the total volume of which was 2% of the volume of the product itself. Previous studies had determined the optimal fiber volume to be 1%, but this was doubled to strengthen the damaged structure. The tests were carried out on prisms and cubes with dimensions of 100×100×400 mm and 100×100×100 mm, respectively, aged for 28 days. Prisms and cubes are made in accordance with regulatory documents [28]. 2 groups of prisms and cubes were made. One is made of ordinary concrete (with coarse aggregate sizes up to 10 mm) class C20/25 and the second is with anchored steel fiber. Each group consisted of six samples. To study the beams, experimental methods of mechanics and the strain gauge method were used.

Results and discussion. To conduct experimental studies, a special stand was developed, consisting of a rigid metal frame with a composite cross-section and two metal strands $\varnothing 16$ mm (Fig. 1). The upper part of the rods ends with a thread, with the help of which a traverse is fixed, which serves as a stop for the model dynamometer. The traverse is fixed using nuts. Plane transverse bending of the loading of the beam under test is created using a hydraulic jack and a metal I-beam with a traverse that transmits two equal concentrated forces to the beam. The created load is controlled by an exemplary dynamometer of the Tokar system and a ring dynamometer, which acts as a support. During the tests, the load transmitted to the beam, deflections and deformations of individual concrete fibers were recorded.



Fig. 1. Test bench

The load was applied in steps of 0.05 from the destructive load, the magnitude of which was determined during preliminary loading. The load at which there was a sharp increase in the rate of deformation of individual concrete fibers was taken as the destructive load.

Each loading step was followed by a holding time of 8-10 minutes. Between loading stages, the process of the onset and development of crack formation was monitored. Deflections were measured using a Maximov deflection meter, and deformations were measured using dial indicators with a division value of 0.01 mm. The indicators were located in the characteristic zones of the beam operation. The first four indicators are located in the middle part of the beam where pure bending occurs. Another 6 indicators are in load transfer zones. The base for measuring deformations of all indicators is 24 cm.

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 reinforcement varied. This paper describes the results of strengthening a beam whose cross-section is 20% damaged in the middle compression zone, and the shape of the damage is shown in Fig. 2 (all measurements are in cm).

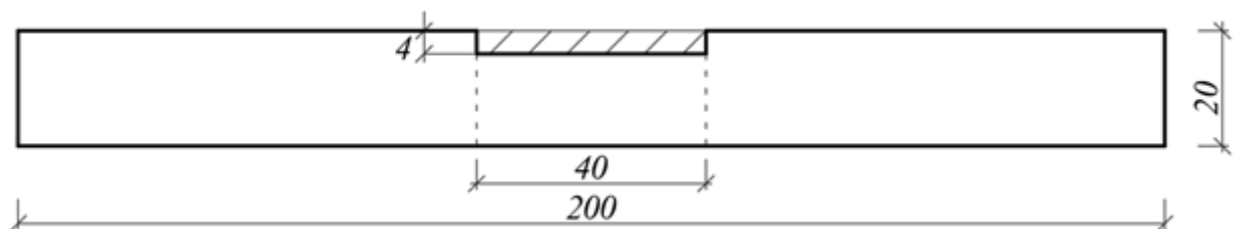


Fig. 2. Nature of beam damage

The studies were carried out on rectangular beams with dimensions of 200×120 mm, reinforced with two vertical frames (Fig. 3). Lower longitudinal reinforcement – $\varnothing 12$ mm, upper – $\varnothing 8$ mm. For transverse reinforcement, $\varnothing 6$ mm rods with a pitch of 87.5 mm were used. In the shear span area, transverse reinforcement is made with $\varnothing 4$ mm bars (A400 class fittings). Shear span length $2h_0$. Working section height 170mm.

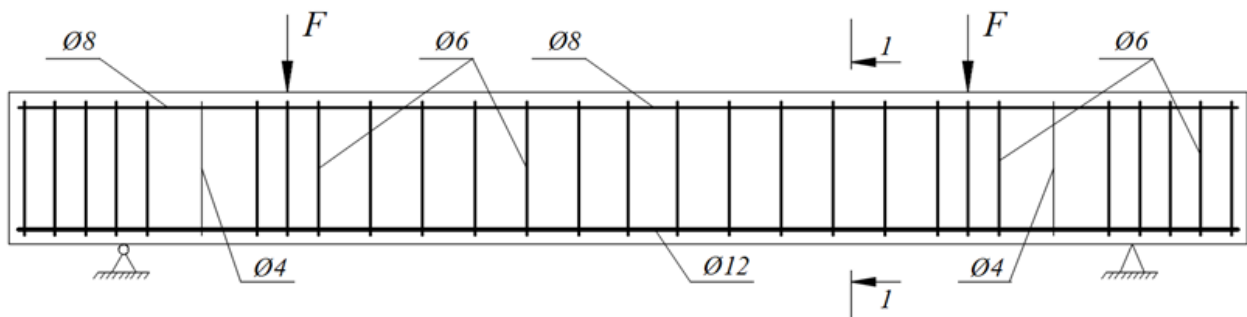


Fig. 3. Beam reinforcement

Before concreting, a foam liner was installed in the area of planned damage, the shape and dimensions of which corresponded to the damage. After the concrete gained 70% of the strength, the liner was removed, and the resulting cavity was filled with a 2% mixture of fiber-reinforced concrete.

The load-bearing capacity of the damaged beam was 93.6 kN, which is 95.0% of the load-bearing capacity of the undamaged beam (98.5 kN). Crack formation began at the 5th stage of loading, when the load value was 32.5 kN, that is, 34.7% of the load-bearing capacity of the damaged beam. In this case, 4 cracks formed in the pure bending zone. The formation of cracks (Fig. 4) and the width of their opening at all stages of loading are given in Table 1.

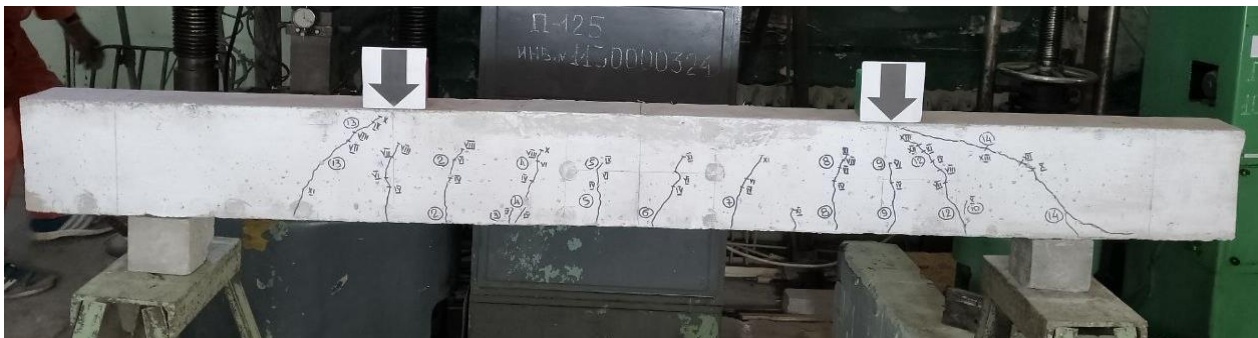


Fig. 4. Formation of cracks in a damaged beam

Table 1 – Cracks in a damaged beam

Stage loads	Magnitude load, kN	Number cracks	Final width opening, mm
1	6.5		
2	13.0		
3	19.5		
4	26.0		
5	32.5		1, 3 – 0.3; 2 – 0.1; 4 – 0.2
6	39.0	5-7	5 – 0.2; 6, 7 – 0.1
7	45.5		
8	52.0		
9	58.5	8-11	8, 9, 11 – 0.1; 10 – 0.05
10	65.0	12-13	12 – 0.7; 13 – 0.8
11	71.5		
12	78.0	14	0.7
13	84.5		
14	91.0		
15	93.6		

It should be noted that until its destruction, the steel-fiber-concrete liner worked with the beam as a single whole.

Conclusions. Thus, experimental studies have shown that a beam, the cross-section of which is 20% damaged in the middle compressed zone, and the shape of the damage is close to rectangular, has a load-bearing capacity of 93.6 kN, which is 95.0% of the load-bearing capacity of an undamaged beam (98.5kN). Crack formation began on the 5th stage of loading, when the load value was 32.5 kN, that is, 34.7% of the load-bearing capacity of the damaged beam. In this case, 4 cracks formed in the pure bending zone. At the sixth stage, three more cracks appeared. At stages 9, 10 and 14 of loading, 7 more cracks formed. The maximum final crack opening width was 0.8 mm. throughout the testing process, the fiber-reinforced concrete liner worked with the beam as a single unit. It can be argued that strengthening a beam with 20% damage in the compressed zone using the method considered in the work makes it possible to achieve its load-bearing capacity, which is 95% of the load-bearing capacity of an undamaged beam.

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ЕКСПЕРИМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ ПОШКОДЖЕНОЇ БАЛКИ, ПОСИЛЕННОЇ ФІБРОБЕТОНОМ

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Анотація. У роботі наведено результати дослідження несучої здатності пошкодженої під час бойових дій балки, яка була армована сталевібробетоном. Розглядається балка з 20% пошкодженням у стиснутій зоні. Перед бетонуванням в зоні планового пошкодження встановлювався пінопластовий вкладиш, форма і розміри якого відповідали плановому пошкодженню. Після набору бетоном 70% марочної міцності вкладиш видаляли, а утворену порожнину заповнювали 2% сумішшю фібробетону. Це один із варіантів зміцнення балки в комплексній програмі випробувань пошкоджених балок, яка передбачає дослідження серії балок з різними видами пошкоджень, зони пошкодження (розтягнення і стиснення) та її розмірів, геометрії та способу зміцнення. Для тестування автори розробили спеціальний стенд. Плоско-поперечний вигин навантаження досліджуваної балки створюється за допомогою гідравлічного домкрата і металевої двотаврової балки з траверсою, яка передає на балку дві рівновеликі зосереджені сили. Створене навантаження контролюється зразковим динамометром системи Токаря і кільцевим динамометром, який виконує роль опори. Експериментальними дослідженнями встановлено, що балка, поперечний переріз якої у середній стиснутій зоні пошкоджений на 20 %, а форма пошкодження наближена до прямокутної, має несучу здатність 93,6 кН, що становить 95,0 % від несучої здатності непошкодженої балки (98,5 кН). Тріщиноутворення почалося на 5 ступені навантаження, коли значення навантаження становило 32,5 кН, тобто 34,7 % несучої здатності пошкодженої балки. При цьому в зоні чистого вигину утворилося 4 тріщини. На шостому етапі з'явилися ще три тріщини. На 9, 10 і 14 етапах навантаження утворилося ще 7 тріщин. Максимальна кінцева ширина розкриття тріщини становила 0,8 мм. Протягом усього процесу випробувань фібробетонний вкладиш працював з балкою, як єдине ціле. Можна стверджувати, що підсилення балки з 20% пошкодженням у стиснутій зоні розглянутим у роботі методом дозволяє досягти її несучої здатності, яка становить 95% від несучої здатності непошкодженої балки.

Ключові слова: пошкоджена балка, сталевібробетон, експеримент, стенд, несуча здатність, тріщина.

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