

Experimental data of RC beams shear strength with different shear span and strengthening by FRCM system

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Abstract. The article presents the results of experimental testing of reinforced concrete beams with different shear spans and strengthened by the FRCM (Fiber Reinforced Cementitious Matrix) system. The shear spans were 2, 1.5, and 1. Strengthening was performed for shear span 2 with three vertical strips of composite fabric 70 mm width each. In total, the results of the eight tests (the four experimental samples) are presented. Each beam was tested twice, separately for each support section of the beam. A change in the failure type of reinforced concrete beams at shear is shown. It was determined how the bearing capacity and deformability of concrete and transverse reinforcement in all samples changed with the change in test parameters. The use of strengthening strips at the level of 20% of their maximum elongation values was achieved.

1 Introduction

With the progress of science and technology, the application of modern composite materials is increasingly being proposed for strengthening structures. Another reason is the presence in Ukraine of a significant number of damaged structures that need to be restored or increase their load-bearing capacity [1, 2]. Composite materials have a lot of advantages over traditional materials used for strengthening: high strength and deformability characteristics, low own weight, low labor intensity during installation [3]. The investigation in the reinforcement methods and the stress-strain state parameters of reinforced concrete structures strengthened with such materials is an urgent issue that is widely studied not only in Ukraine [4], but also in Europe [5, 6].

The reasons for strengthening arise both from environmental or mechanical influences and from the necessity to increase the bearing capacity of reinforced concrete samples. Particular attention should be paid to shear strengthening since the exhaustion of the bearing capacity under this case is sudden and unpredictable. If strengthening is required due to damage, it is very important to pay attention to the actual stress-strain state of the structure: the appearance of cracks [7, 8], history of impacts and loads [9], corrosion of reinforcement

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[10], etc. As a result of all these factors, the most appropriate strengthening method should be selected.

If it is only necessary to increase the load-bearing capacity, using composite materials and systems is an urgent task, since such strengthening is performed quickly and efficiently without significantly increasing the structure's own weight. In this case, it is important to ensure the adhesion between the strengthening system and the existing element [11]. In this research, different types of strengthening were tested, with different diameters and areas of surface treatment type and configuration. The most common types of composite strengthening types are FRCM (Fiber Reinforced Cementitious Matrix), CFRP (Carbon Fiber Reinforced Plastic), FRP (Fiber Reinforced Polymer) and other [12]. The study was conducted for shear reinforcement with a FRCM system installed on 3 sides of the beam. Design considerations based on the algorithms proposed by the ACI guidelines are also presented. Compared to more common classical strengthening methods, such as metal or reinforced concrete jackets [13, 14], it shows comparable parameters for increasing the load-carrying capacity, but composite strengthening systems still retain advantages in terms of weight and labor intensity of its installation.

Paper [15] shows that the effect of strengthening reinforced concrete beams is significantly affected by the level of load at which the strengthening is performed. It is established that with an increase in the level of load at which strengthening is performed, the effect of increasing the bearing capacity from strengthening decreases.

Based on the above scientific sources, it should be noted that before performing strengthening, it is necessary to establish and take into account many factors that have influenced the structure during its operation.

2 The purpose of the research

The purpose of this paper is to determine the effect of shear span on the load-bearing capacity of reinforced concrete beams and to determine the effect of FRCM strengthening on the shear strength and deformability.

3 Materials and construction of the samples

To accomplish the aim 4 samples were designed and manufactured, with a cross-sectional area of 200x100 mm and a length of 2100 mm. The tensile reinforcement is of $\text{Ø}22$ mm class A400C (position 1, fig. 1), the compression reinforcement is of $\text{Ø}12$ mm A400C class (position 2, fig. 1). Transverse reinforcement - A240C $\text{Ø}8$ mm is located in the support zones with a step of 100 mm (Fig. 1).

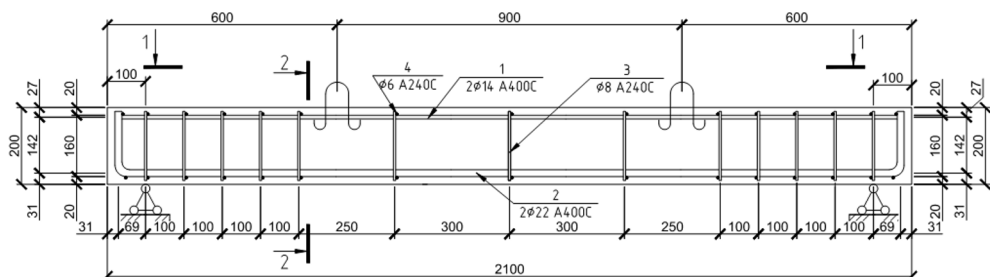


Fig. 1. Geometric dimensions and reinforcement of samples.

All samples were designed to ensure the carrying capacity on the bending moment [16, 17, 18]. At the same time, the shear strength of the samples is insufficient to cause the destruction on the shear in all samples. The experiment was conducted according to the recommendations described in [19].

4 Experimental data

The testing was carried out using the research methodology described earlier [4]. Clock-type gauges were placed on the support section at an angle of 45° to the axis of the beam (Fig. 2). The strengthening element, FRCM fabric, was arranged in the form of a jacket by gluing it to all four surfaces of the beam, which ensured its reliable adhesion to the surface. The shear strengthening was performed using 70 mm wide fabric strips glued with a 100 mm spacing (Fig. 3). The strains in the strengthening element were measured in the longitudinal direction using clock-type gauges (Fig. 3).

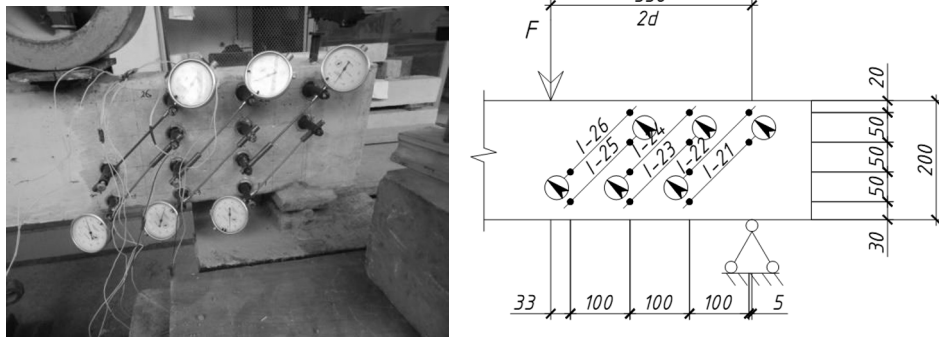


Fig. 2. Scheme of devices placement in the support zone.

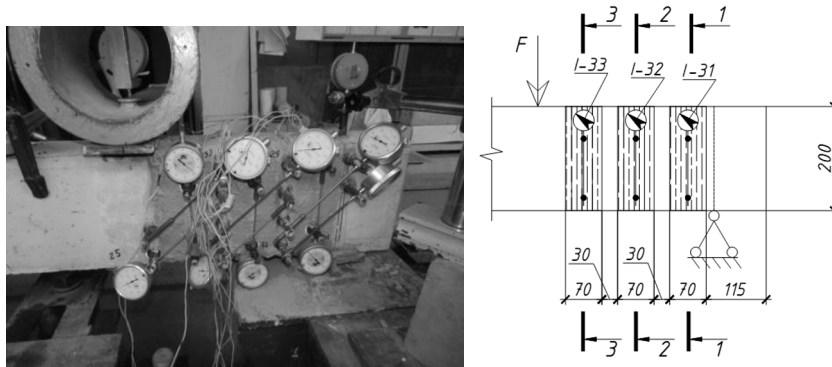


Fig. 3. Support section strengthened by the FRCM system with the measuring devices positioned.

The following markings are used for beams: BO - beam tested without strengthening ("ordinary"), BSC - beam strengthened with composite materials, the first digit is the series number, the second digit is the section number.

All samples were tested in "pure bending" under a static constant load. The load was applied by 2 forces at $1/3$ of the sample span. The experimental beams collapsed in the bearing zone due to exhausted shear strength. The criterion for the exhaustion of the bearing capacity is the achievement of the limit strains in the concrete compressed zone above the inclined crack in the direction of the main compressive stresses [1, 18].

The limit strains of concrete and reinforcement were not reached in the central section.

A general view of the tested beams is shown in Fig. 4.

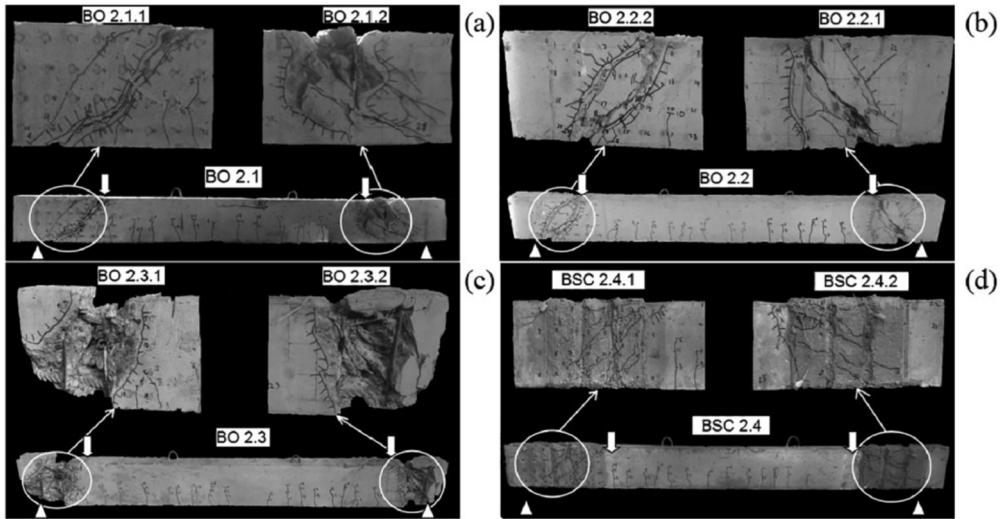


Fig. 4. General view of the RC beam after exhaustion of the bearing capacity: (a) BO 2.1; (b) BO 2.2; (c) BO 2.3; (d) BSC 2.4

The unstrengthen samples collapsed brittle, with the onset of ultimate strains in the concrete compressed zone. Failure occurred as a result of shearing of one part of the concrete relative to another.

In the beams, it was noted that crack propagation occurred in the following order:

- opening of an inclined crack at an angle of 45° to the longitudinal axis of the beam under a load equal to $V_{Ed} = 50 \dots 60$ kN;
- propagation of the inclined crack along the height of the inclined section, to the concrete compressed zone with an opening width $0.05 \dots 0.15$ mm;
- opening of a destructive inclined crack from the support in the direction of load application;
- propagation of the destructive crack along the entire height of the section, reaching the limit values of opening.

This type of crack propagation is typical for samples BO 2.1. In tested beams BO 2.2 and BO 2.3, only one crack opened, which was destructive.

For sample strengthened with strips, the concrete surface is characterized by preservation of integrity, but there are significant tensile strains of the strengthening element and the appearance of the bearing fiber. The crumbling of the fiber of the concrete compressed zone was largely restrained by the applied mineral cement mortar. There are also no visible indications of plastic deformation of the frame of the test element.

For all the test samples, we created graphs of concrete strains in the support area (fig. 5).

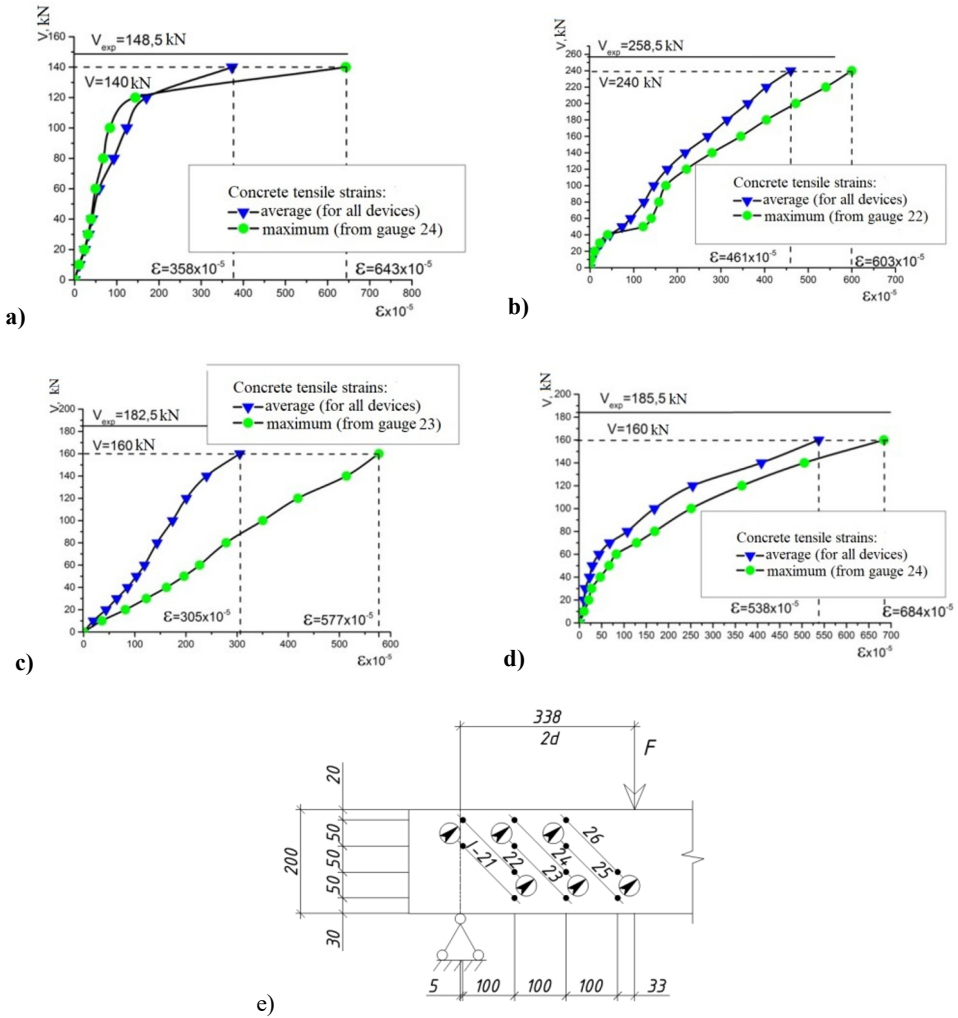


Fig.5. Concrete strains in the support zone of the beam: a) BO 2.1; b) BO 2.2; c) BO 2.3; d) BSC 2.4; e) cross-sections of strains measurement

It should be noted here that the graphs were constructed in such a way as to record the maximum tensile strains in the concrete. After reaching the limit values, the increase in strains showed the formation and subsequent opening of the inclined crack in the support zone.

The concrete strain in the support area is characterized by the linear increase of the load-strain relationship with a decrease in the shear span of the section. The transverse reinforcement restrains the increase in deformation by absorbing part of it.

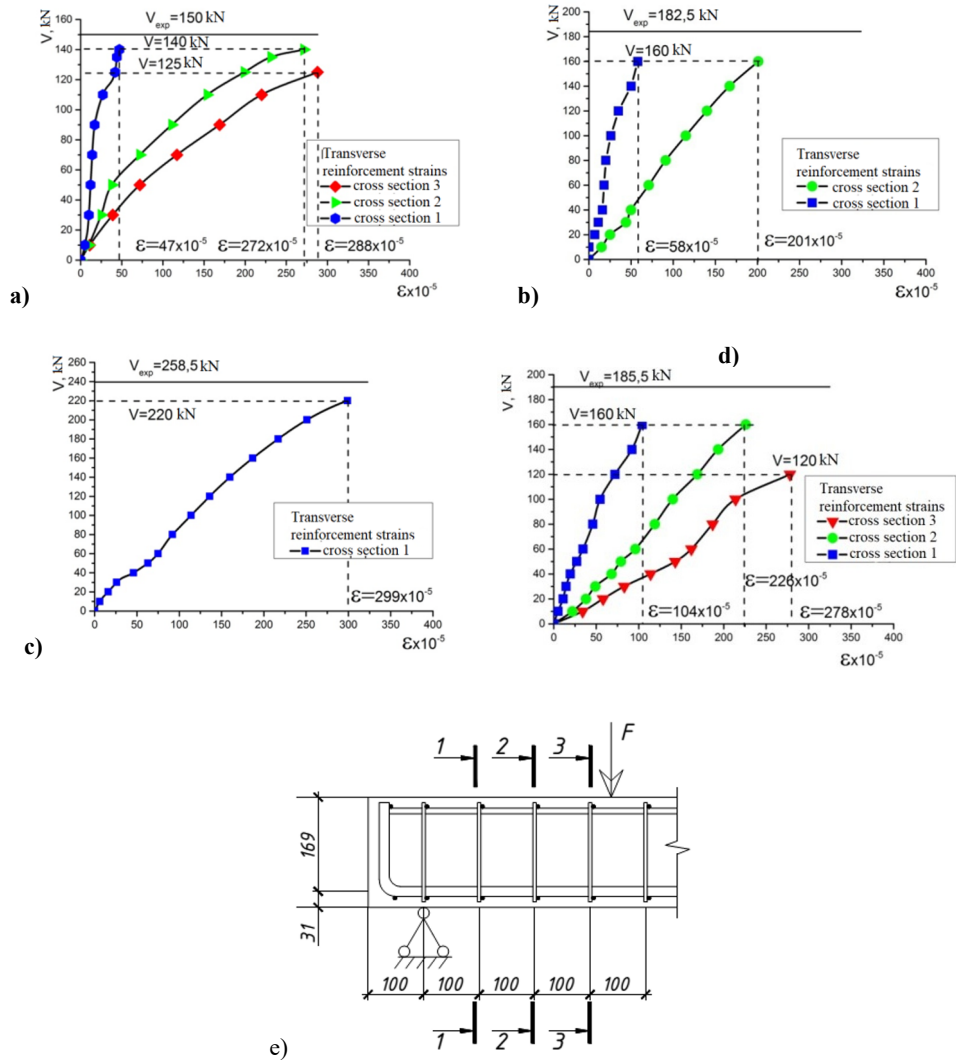


Fig.6. Transverse reinforcement strains in the beam: a) BO 2.1; b) BO 2.2; c) BO 2.3; d) BSC 2.4; e) cross-sections of strains measurement

None of the test beams achieved yielding of the transverse reinforcement. With a decrease in the shear span of the section in the support areas, the influence of concrete and longitudinal reinforcement on the bearing capacity increased, while the strains of the transverse reinforcement remained within the same limits $\varepsilon=201\dots299\times10^{-5}$.

A graph of strains of the strengthening system ε was prepared (Fig. 7). A separate curve is shown for each tape in order to establish the efficiency of its use

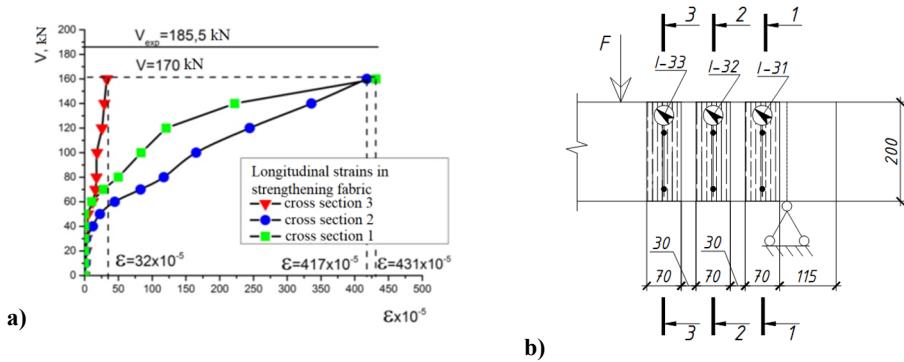


Fig.7. Strains of the beam strengthening system: a) BSC 2.1-0; b) position of the strengthening element strains measurement

The strains of the strengthening fabric reached $\epsilon = 431 \times 10^{-5}$, which is 20% of the maximum elongation of the tape.

All graphs show the value of the transverse force V - the level up to which the measurements were made, and V_{exp} - the value at which the bearing capacity of the test sample was exhausted.

The results of determining the shear strength of tested beams are summarized in Table 1.

Table 1. Shear strength of reinforced concrete beams

Beam number	Number of support zone	Cross section of the beam $b \times h$ mm.	Beam span l_0 mm	Shear span, a/d	Shear strength V_{Ed}^{exp} , kN	Average shear strength, V_{Ed}^{exp} , kN	Increasing shear strength. $\frac{V_{ed}}{V_{ed}^{BO 2.1}}$
BO 2.1	BO 2.1.1	201x102	1900	2	150	148.5	-
	BO 2.1.2		1550		147		
BO 2.2	BO 2.2.1	200x103	1900	1.5	186	182.5	1.23
	BO 2.2.2		1650		179		
BO 2.3	BO 2.3.1	198x98	1900	1	250	258.5	1.74
	BO 2.3.2		1750		267		
BSC 2.4	BSC 2.1.1	199x100	1900	2	187	185.5	1.25
	BSC 2.1.2		1500		184		

The load-bearing capacity of reinforced concrete beams on the shear was: for BO 2.1 – $V_{ed} = 148.5$ kN, BO 2.2 – $V_{ed} = 182.5$ kN and BO 2.3 at the value of $V_{ed} = 258.5$ kN. Shear capacity for strengthened beam BSC 2.4 was $V_{ed} = 185.5$ kN. The effect of strengthening reinforced concrete beams with the FRCM composite system is comparable to reducing the shear span from 2 to 1.5.

5 Conclusion

Based on the experimental data obtained from the testing of reinforced concrete beams on shear, with different shear spans and with FRCM, the following conclusions were made:

- at shear spans of 2, 1.5 and 1, concrete in the bearing zone significantly affects the bearing capacity. The load-bearing capacity of the beams increased by 23 and 74 %, respectively, with a reduction in the number of transverse reinforcements;
- the FRCM system changes the type of the failure of the support zone from sharp and brittle to more plastic and without crumbling of concrete in this area;
- the strengthening system allowed to increase the shear strength of the beams by 25 % (an increase of 37 kN);
- regardless of the shear span and the presence of a reinforcement system, the strains of the transverse reinforcement remain within the same limits $201 \dots 299 \times 10^{-5}$;
- when strengthening the support zone with three vertical strips, the efficiency of use is 20% based on the comparison of measured and ultimate strains in the strengthening fabric.

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