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RESEARCH OF RC BEAMS WITHOUT STIRRUPS AND SHEAR'S STRENGTHENING BY FRCM SYSTEM

Introduction

Nowadays many industrial and civil buildings have already exceeded their estimated lifetime. Corrosive influence leads to significant corrosion damage of construction's reinforcement, sometimes even to its full destruction. Demolition expenses for these buildings or new construction costs extremely high. It is therefore we consider strengthening of old structures to continue their lifetime and bring them in accordance with the requirements of actual codes and standards.

A lot of studies of concrete structures' shear strength have been conducted, concerning the study of stress-strain state design principles, methods of strengthening using steel or concrete elements. Using a significant amount of consumables, leads to finding of the strengthening material, which would have provided high shear strength increasing of RC beams with lower cost of labor [1, 2]. The composite materials made from carbon composite and others fibers in a cloth or ribbons belong to these materials. The simplicity and quickness of installation of the reinforcement allows us to gain good results without major delays.

Analyzing researches of shear strength with different types of composite materials reinforcing, it can be concluded that the study of stress-strain state of shear reinforced is a key issue, with ongoing development goals and objectives, which are set by the researchers [3-5]. However, few studies are conducted on reinforced beams under simultaneous action loading and reinforcing. Therefore, the establishment of real sheer strength of RC beams with damaged sheer reinforcing and strengthened by composite materials under action of loading is a topical scientific and practical issue.

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1. The testing program

In this article we research the beams without transverse reinforcement, which serve as a beams model with full destructive reinforcement after corrosion influence. The research program involves a one serie of test beams with size 2100×200×100 mm which contains control sample and three reinforced samples by reinforcing FRCM system. FRCM system consisting of two components: mineral mortar based on modified cement Ruredil X Mesh M750 and reinforcing P.B.O. fiber mesh Ruredil X Mesh Gold (Italy) [6].

The strength research of test samples was carried out with the shear distance to effective depth ratio a/d = 2. The strengthening loading levels were selected at 0.0, 0.3, 0.5 from shear strength (V_{ed}) of non-strengthened control sample.

2. Experimental research of shear strength

2.1. Research results of control beams

RC beams designed that the beams destruction after strengthening took place by shear. To accomplish it these beams were designed with a significant margin of tensile rebar. A method of experimental research involves alternate testing of two inclined sections of reinforced concrete beams, which reduces the cost of materials and necessary instrumentation and detailed presented at [7, 8].

At the first stage of research, control sample was tested. Beams mark follows BO - beam ordinary, the first digit - serial number, the second digit - prototypes number and the third digit - section number. For example, BO 1.2-2 means that tested example from the first series of the second beam of the second section.

The limit value of concrete compressed deformation at cross section above the inclined crack was taken as the criterion of shear strength [9]. The shear strength of the RC beams equated with physical destruction of compressed concrete above the inclined cracks. Both limit states (ULS and SLS) of control beam occur in the following sequences:

– crushing compressed concrete and plastic deformation of reinforcement cage (ULS);
– opening limit width of the inclined crack (w_{max} = 0.4 mm) in concrete (SLS).

The first inclined crack disclosed in mid-height cross section, at the load - 50 kN at an angle equal to 45°. At the next stage the inclined crack spread to the bottom surface of the beam. With increasing loading the width of crack increased and the crack propagation occurred to the top surface of the control sample (Fig. 1).

On occurrence of limit width of crack w_{max} = 0.4 mm, another crack was opened in the direction from the loading point to the edge of beam support. This crack was destructive one. Inclined crack spread throughout the height of the beam, then occurred the crushing of compressed concrete. Longitudinal tensile reinforcement received typical plastic bending deformations.

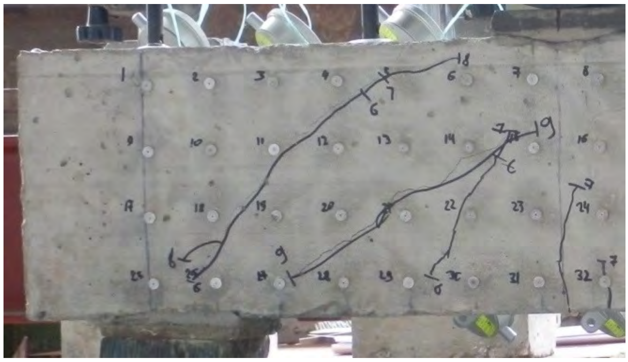


Fig. 1. Distribution of inclined cracks in the control sample

Shear strength of RC beams BO-1.1 was V_{Ed} = 95 kN. General view of the tested control beam is shown in Figure 2.

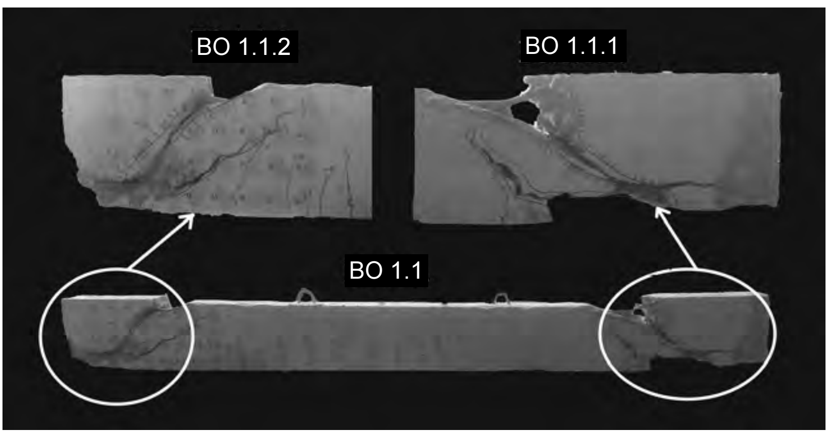


Fig. 2. The tested control beam BO-1.1

For each cross section of test specimen at shear area there was obtained area of distribution concrete deformation by using comparator measurement (Fig. 3).

Measurement of concrete deformation was performed using a grid frame of comparator with grid spacing 50×50 mm. Grid frame of comparator located on the front edge of specimen (Fig. 3c). The distance between the rappers were measured with an accuracy of 0.1 mm.

Tensile deformations fixed with cracks width in concrete. This method of measurements provides a distribution of strains from the support point to the loading point. As we can see (Fig. 3b) the tensile deformations are in the direction of distribution inclined cracks, and compression deformations are around them.

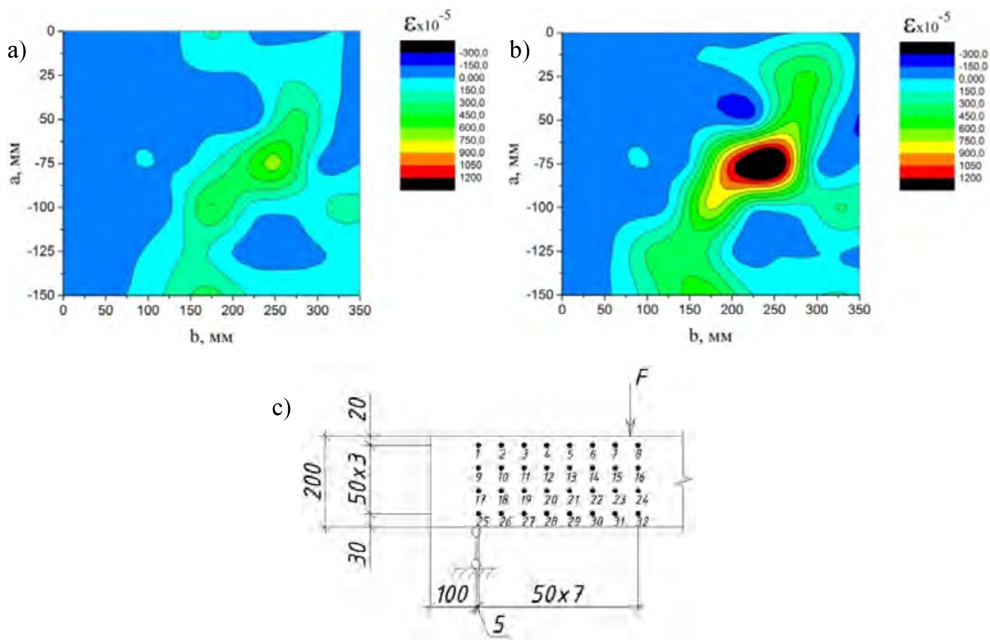


Fig. 3. The distribution of concrete deformation in the shear area for beam BO-1.1: a) the area before the opening inclined crack; b) the area before the exhaustion of ULS; c) the scheme of rappers of the comparator measurement

2.2. Research results of strengthened beams

According to the testing program the tree specimens were strengthened by reinforcing FRCM system with 70 mm width strips (Figs. 4-6). These beams mark follows BSC - beam strengthened by composite material; the first digit - serial number, the second digit - prototypes number and the third digit - section number. Index 0...0.5 means the loading level under which the strengthening was performed and defined from shear strength (V_{Ed}) of non-strengthened control sample.

The criterion of achievement shear strength was the same as for control sample. The shear destruction of RC beams, strengthened by composite materials took place in the following order:

– opening limit width of inclined crack (w_{max} = 0.4 mm) on the concrete surface;
– distribution inclined crack to the compressed concrete and appearance mesh of cracks with width w_{max} = 0.2 mm on the surface of strengthening system;
– concrete damage in the area of the main tensile stress and exfoliation strengthening system in this area;
– plastic deformation of rebar and crushing of compressed concrete, large deformation reinforcing materials, which can be seen due to the damage of the cover layer.

With further increasing loading the materials detachment from beam continues and there occurs a violation of anchoring.

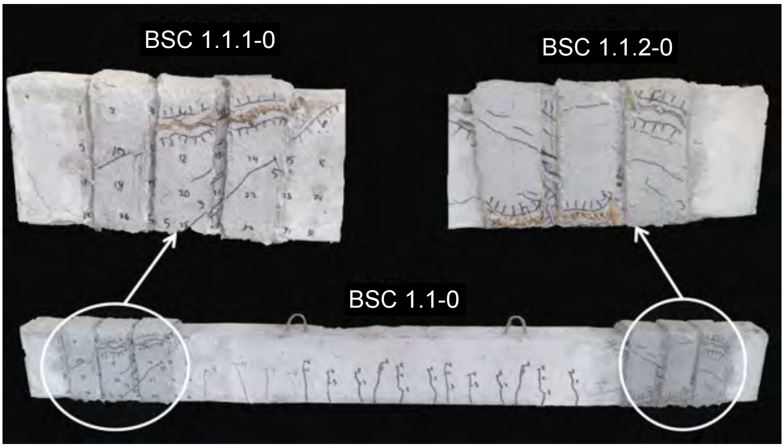


Fig. 4. The tested strengthened beam BSC 1.1-0

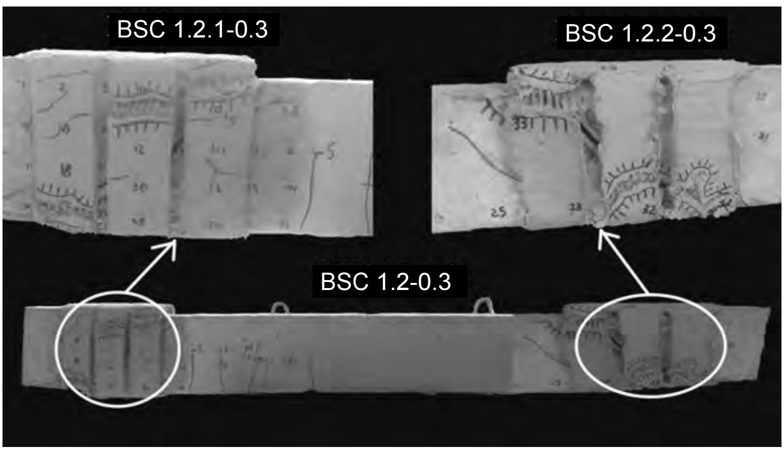
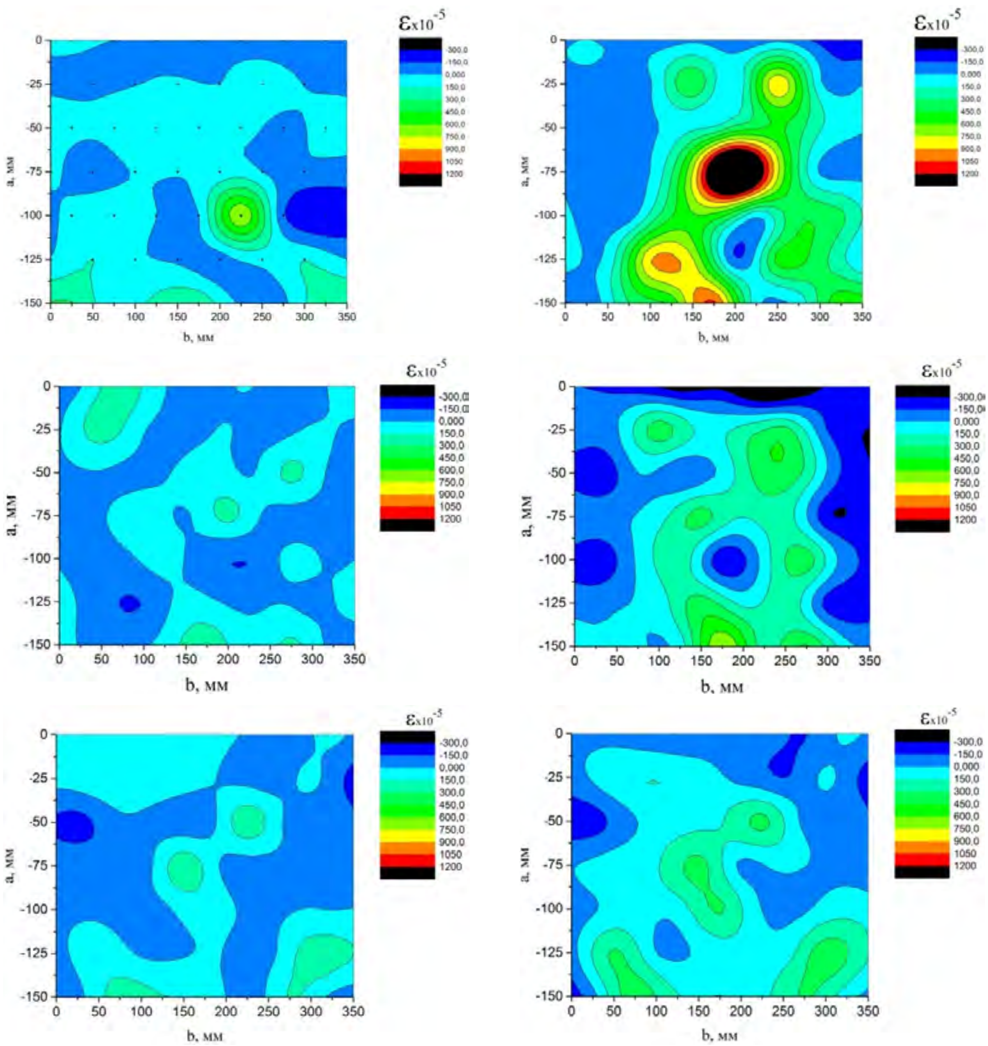


Fig. 5. The tested strengthened beam BSC 1.2-0.3

Fig. 6. The tested strengthened beam BSC 1.3-0.5

The shear strength of samples strengthened without any loading was amounted to $V_{Ed} = 137.5$ kN. Average shear strength for samples strengthened with some loading level were: for beam BSC 1.2-0.3 $V_{Ed} = 120$ kN and for BSC 1.3-0.5 $V_{Ed} = 110$ kN.



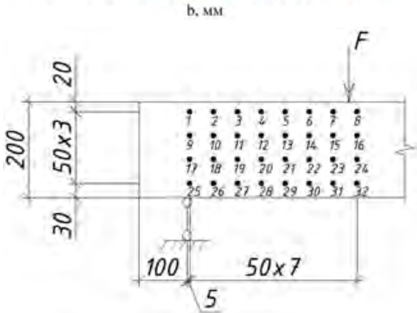


Fig. 7. The distribution of strain in the beam: area of deformation before opening inclined cracks in the beam: a) BSC 1.1-0; c) BSC 1.2-0.3; e) BSC 1.3-0.5; area of deformation before exhaustion bearing capacity for beams: b) BSC 1.1-0; d) BSC 1.2-0.3; f) BSC 1.3-0.5; g) layout rappers of the comparator

At strengthened beams there was changed a type of fracture, it was more plastic, without any concrete particles and plastic deformation of steel reinforcement cage. The distribution of concrete deformations is shown in Figure 7. As we can see, the tensile deformations occupy a larger area.

For the sample strengthened without initial loading, stress concentration was held at half of the beam height, similar to the control sample. Samples, strengthened with some initial loading, have another type of stress distribution, that is caused by the inclusion strengthening materials at working similar to the transverse steel reinforcement.

Concrete deformation with a width of opening inclined cracks, the nature of the growth are the same as for the control samples but reach much higher values.

Concrete tensile deformation is in its maximum values $\varepsilon = 1150 \cdot 10^{-5}$ for beam BSC 1.1-0 and reduced according to a decrease the shear strength. The maximum strain of composite strips achieved $\varepsilon = 1233 \cdot 10^{-5}$ for beam BSC 1.1-0, which is 57% of the limit value. This is a high level using composite strengthening. With the increasing of the initial loading the shear deformation of composite material is reduced to 26%.

With the exhaustion of shear strength, strengthening materials received significant deformation which led to the loss of its original appearance but the gap was not observed.

According to recommendation [10] the deformation of composite materials should be 40% of its limit tensile deformation. What we can see according to experimental data, this type of FRCM system strengthening is effective one for shear strengthening.

3. Analysis of research results

The maximum effect of increasing the shear strength was 45% for samples strengthened without initial loading. It should be noted that with increasing loading level up to 0.5 of shear strength of control beam (0.5 V_{Ed}) the effect of strengthening decreased to 16%. For beams reinforced at the level of 0.3 V_{Ed} effect decreases to 21%.

Namely for samples, according to the level loading, the effect of strengthening decreases by 2.8 times, from 45 to 16%, so to perform strengthening at the level of more than 0.5 is impractical.

The results of the comparative analysis of the shear strength of strengthening RC beam on the shear are shown in Table 1.

The inclined crack width $w_{max} = 0.4$ mm was the criterion for serviceability limit state. The results of the experimental data of the shear strength for serviceability are in Table 2.

TABLE 1

The ultimate limit state (ULS) inclined cross sections of testing beams

Types of beams	Types of the beams' cross section	Cross section bxh [mm]	Span of the beam l_0 [mm]	Shear span to depth ratio a/d	Experimental shear strength V_{Ed}^{exp} [kN]	Average experimental shear load V_{Ed}^{exp} [kN]	Increasing shear strength $\frac{V_{ed}}{V_{ed}^{BO1.1}}$
BO 1.1	BO 1.1.1	201x106	1900	2	97	95	–
	BO 1.1.2		1550		93		
	BO 1.3.2		1650		204		
BSC 1.1-0	BSC 1.1.1-0	199x100	1900	2	130	137.5	1.45
	BSC 1.1.2-0		1650		145		
BSC 1.2-0.3	BSC 1.2.1-0.3	200x100	1900	2	126	120	1.26
	BSC 1.2.2-0.3		1650		117		
BSC 1.3-0.5	BSC 1.3.1-0.5	201x98	1900	2	116	110	1.16
	BSC 1.3.2-0.5		1650		114		

TABLE 2

The serviceability limit state (SLS) inclined cross sections of testing beams

Types of beams	Types of the beams' cross section	Maximum inclined crack width [mm]	Experimental shear strength V_{Ed}^{exp} [kN]	Average experimental shear load V_{Ed}^{exp} [kN]	Increasing shear strength $\frac{V_{ed}}{V_{ed}^{BO1.1}}$
BO 1.1	BO 1.1.1	0.4	80	80	–
	BO 1.1.2		80		
BSC 1.1-0	BSC 1.1.1-0	0.4	120	110	1.38
	BSC 1.1.2-0		100		
BSC 1.2-0.3	BSC 1.2.1-0.3		100	100	1.25
	BSC 1.2.2-0.3		100		
BSC 1.3-0.5	BSC 1.3.1-0.5		90	90	1.13
	BSC 1.3.2-0.5		90		

Character and value of increasing shear strength by SLS for all samples reinforced composite system is close in meaning to ULS. But the fixed disclosure of limit crack width w_{max} = 0.4 mm inclined at 20 kN was lower than the loss of the shear strength of inclined section. Also, the maximum values of crack opening constitute the 0.5 ... 0.6 mm at sample BSC 1.2-0.3 and BSC 1.1-0, and 0.7 mm at BSC 1.3-0.5. On the surface of the material limit the width crack disclosure constitutes the w = 0.2 mm, which is considerably less than the limit one. The sharp increase in the width of the crack opening exposing the composite materials, is observed with physical destruction in specimens.

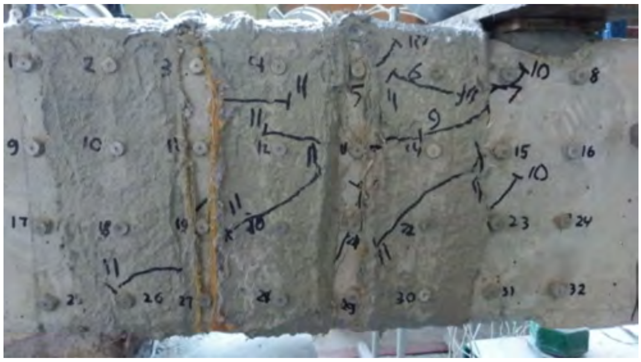


Fig. 8. Distribution of cracks on the surface of the strengthening

It should be noted that the inclined crack width was measured on the concrete surface between strengthening elements. In the cover layer of strengthening material opening width of cracks was less than 0.25 mm, but on the surface of a there were a mesh of cracks (Fig. 8).

Conclusions

1. The maximum effect of increasing the shear strength (ULS) is 45% for samples strengthened without initial loading. In accordance with the increase of the initial loading the strengthening effect decreases. For beams reinforced at the level of $0.3V_{ed}$ the effect decreases to 21% and for BSC 1.3-0.5 to 16%.
2. Character and value of increasing shear strength by SLS for all samples reinforced composite system is close in meaning to ULS. But the fixed disclosure of limit crack width w_{max} = 0.4 mm inclined at 20 kN was lower than the loss of its shear strength. The maximum effect of ULS is 38% for samples strengthened without initial loading. For beams reinforced at the level of $0.3V_{ed}$ the effect decreases to 25% and for BSC 1.3-0.5 to 13%.
3. For samples, according to the level loading, the effect of strengthening falls to 2.8-2.9 times, from 45 to 16% or from 38 to 13%, so to perform strengthening at the level of more than 0.5 is impractical.
4. This peculiarity that strengthening effect depends on loadings level should be considered when we design the strengthening systems.

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Abstract

In this article shear strength of strengthened and non-strengthened reinforced concrete (RC) beams are described. The research program involves a one serie of test beams which contains control sample and three reinforced samples by reinforcing FRCM system. RC beams designed that the beams destruction after strengthening took place by shear. To accomplish it these beams were designed with a significant margin of tensile rebar. The maximum effect of increasing the shear strength (ULS) is 45% for samples strengthened without initial loading.

Keywords: design; shear strength; RC beam, FRCM system

Badania belek żelbetowych bez strzemion zbrojonych na ścinanie systemem FRCM

Streszczenie

W artykule opisano wytrzymałość na ścinanie wzmocnionych i niezbrojonych belek żelbetowych. Program badawczy obejmował jedną serię badawczą, w skład której wchodziła grupa belek kontrolnych i trzy grupy belek wzmocnionych z wykorzystaniem systemu FRCM. Belki żelbetowe zaprojektowano tak, że zniszczenie belek po wzmocnieniu nastąpiło przez ścinanie. Aby to osiągnąć, belki zostały zaprojektowane ze znacząco małą ilością zbrojenia podłużnego. Maksymalny efekt zwiększenia wytrzymałości na ścinanie (ULS) wynosi 45% dla próbek wzmocnionych bez początkowego obciążenia.

Słowa kluczowe: projektowanie, wytrzymałość na ścinanie, belki żelbetowe, system FRCM