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Strength of RC Elements Strengthened with External Fibre Polymer Reinforcement

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ABSTRACT: The paper gives the results of an experimental study of the mechanism of shear transfer across the cracks in reinforced concrete elements strengthened with fibre reinforcing polymers. New findings have been obtained on the ultimate strength, and stiffness evaluation of reinforced concrete cracked sections.

KEYWORDS*:* Concrete, fibre reinforced polymers, shear, surface interlock, displacements, reinforcement.

I. INTRODUCTION

Thousands of reinforced concrete bridges and overpasses of small and medium spans, other artificial constructions in conditions of high seismic activity, severe environmental and climatic conditions and load tension are exploited on the highway network of Uzbekistan. In recent years, there has been an alarming increase in the number of damage to these roads caused by their long service life. During the service period, the modes of their operation have changed: the speed, intensity and load tension have increased, the axial loads from the rolling stock have increased, the aggressiveness of the environment has increased, etc. Under the influence of operational loads and the context in the concrete load-bearing structures there is an intensive, often not very visible, accumulation of damage, which leads to slow degradation of the structure of concrete, "ageing" of the structure, a decrease in its carrying capacity and service life. The development of defects is also affected by the conditions of the sharply continental climate of the region.

In the majority of the operated superstructures of reinforced concrete bridges and overpasses a considerable quantity of defects of different kinds (cracks, destructions of a protective layer, damage of a waterproofing and a drainage system, corrosion defects, etc.), which uncontrolled development can lead to sharp decrease in bearing ability of designs and terms of their service is revealed. The most common mistakes of bridge spans are cracks, the most dangerous of which occur in the shear force zone. The erroneous opinion about bridges and structures on roads and tracks as objects practically not demanding preventive maintenance leads to the fact that often repair and reconstruction are carried out with considerable delay, already when the structure is in critical condition, and it is necessary to take urgent and expensive measures.

The purpose of the work is to study the mechanism of stress transmission through the cracks in reinforced concrete samples reinforced with fabric coal with plastic fibrous material (PFM) by the forces and deformations of the slice. Based on the results of the shear tests of these reinforced concrete samples, appropriate ratios were proposed to evaluate the load-bearing capacity and rigidity of this mechanism.

Problems of strengthening and rehabilitation of reinforced concrete elements have recently acquired great urgency and practical significance in connection with a large number of buildings and structures under operation. The results of the carried out long-term researches testify about presence of various defects in bearing designs which, developing in due course, can lead to severe consequences. The most serious of them is the macro cracks in the cross-sections located in the area of action. Taking into account the dangerous nature of such defects, it is necessary to have a clearer understanding of the mechanisms of their resistance, taking into account shear stresses and displacements in the sections with cracks, when calculating the reinforcement of such elements. The practical importance of taking into account these contact stresses and movements, which are associated with the tangential forces of bank entanglement in the cracks, is evidenced by some essential features in the behaviour of reinforced concrete structures containing macro cracks [1,2,5].

In practice, various methods of repair and reinforcement of reinforced concrete elements with the use of features of steel sheets and profiles have been developed. Taking into account many inconveniences of traditional methods of strengthening, new technologies of strengthening structures with high-strength polymeric fabric materials (made of glass, coal and aramidoplastic fibres) are becoming more and more widespread, differing from the traditional

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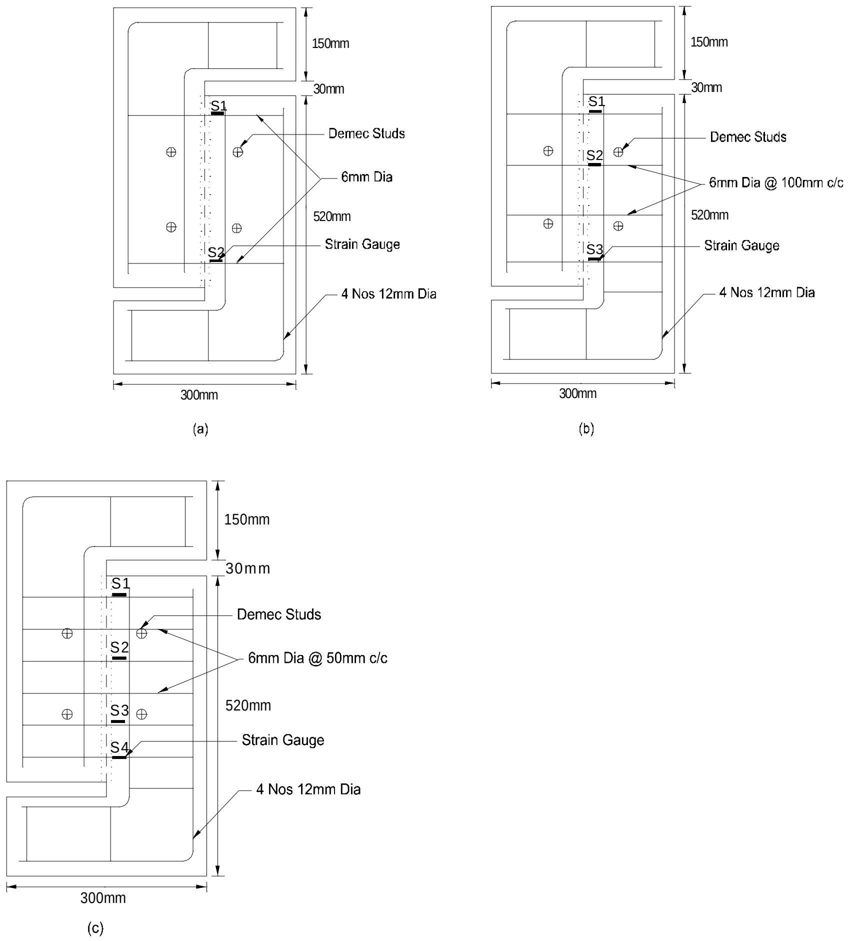
increased lightness and strength, corrosion resistance and low labour intensity of application [3]. The approximately 40-year history of application of such fibres for the strengthening of building constructions already numbers thousands of objects.

II. RESULTS OF THE RESEARCH

In connection with the aforesaid we have conducted investigations of the mechanism of interlocking of crack banks in individual reinforced concrete samples, reinforced by external reinforcement from carbon fibre-plastic fabric materials (PFM) and we have carried out an estimation of bearing ability and rigidity of sections with crack under the action of shearing forces. The test was carried out on individual specimens, in which a crack was created by preliminary splitting. When the shear load is applied along the break, the shear stress along its bank is interlocked with each other due to their roughness, ensuring the transmission of shear stresses arising in the crack through them. According to the method developed in [1,2] the character of dependence between these stresses and corresponding to the shear and normal displacements in cracks of samples from initial stages of loading up to destruction, and also influence on this dependence of internal and external reinforcing of samples by steel collars and polymeric fabric material from PFM.

Individual samples were tested for shear and grouped into three series of PO, P and PF. Each set had three examples. The PO series samples were not reinforced with clamps. P1/PF1, P2/PF2 and P3/PF3 specimens were reinforced respectively with 2, 4 and 6 6 mm diameter mild steel clamps (Rs=660.82 MPa) perpendicular to the cutting plane (Fig. 1).



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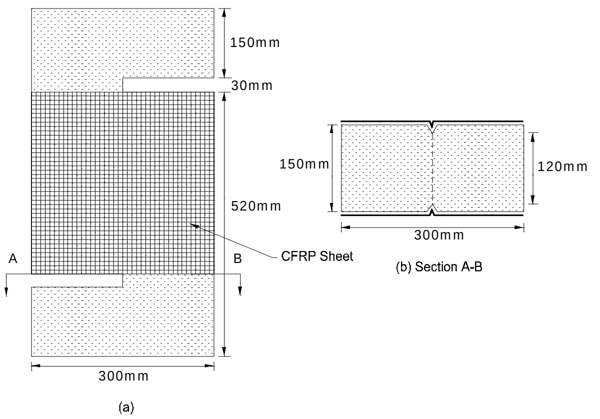

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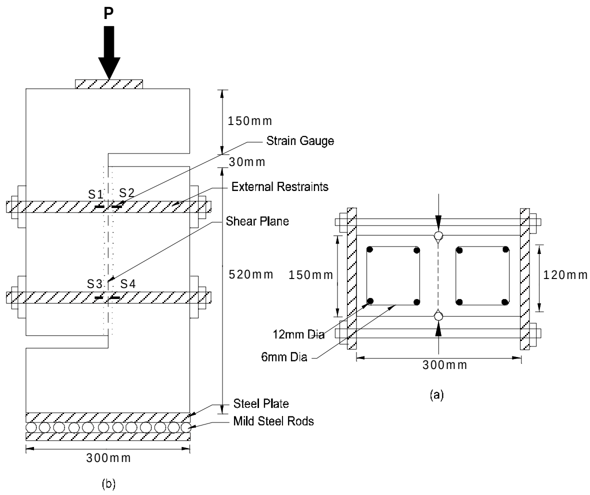

d)

Рис. 1. Reinforcement and testing schemes for special samples: (a) - Clamp reinforcement of P1/PF1, P2/PF2 and P3/PF3 specimens; (d) - external PFM reinforcement of PF1, PF2 and PF3 specimens)

The increase in the percentage of internal reinforcement did not significantly affect the normal and tangential shifts in the P1 and P3 specimens at the limit stage. With the growth of the percentage of internal reinforcement with steel clamps crossing the crack plane, a decrease in the share of external reinforcement in the total shear resistance was observed in the samples. In the initial loading stages, it was observed that the tangential shear displacements and crack opening widths of the reinforced PFM samples were smaller than those without external reinforcement. However, under destructive loading, the same displacements or crack opening widths in the reinforced samples were sharply increased compared to samples without PFM. The increase in load in samples without external reinforcement resulted in shear and normal crack displacement peaks. In PFM reinforced specimens, this increase remained constant up to the breaking load.

The maximum strain of the P-series clamps varied within (2447-3052)x10-5, while the PF-series specimens increased within (2805-7770)x10-5. The increase in load resulted in an increase in the deformation value in the PFM-enhanced examples. The actual deformation in steel clamps was less than the limit deformation. In the reinforced samples, the cracked surfaces showed a sign of separation, followed by a rupture of the PFM sheets along the shear plane or its departure from the concrete surface. External reinforcement held back both shear displacements and crack opening. In the test, the PF1 and PF2 specimens were destroyed by the rupture of the PFM sheets, and the PF3 specimen was destroyed by their separation from the concrete surface along the shear plane.

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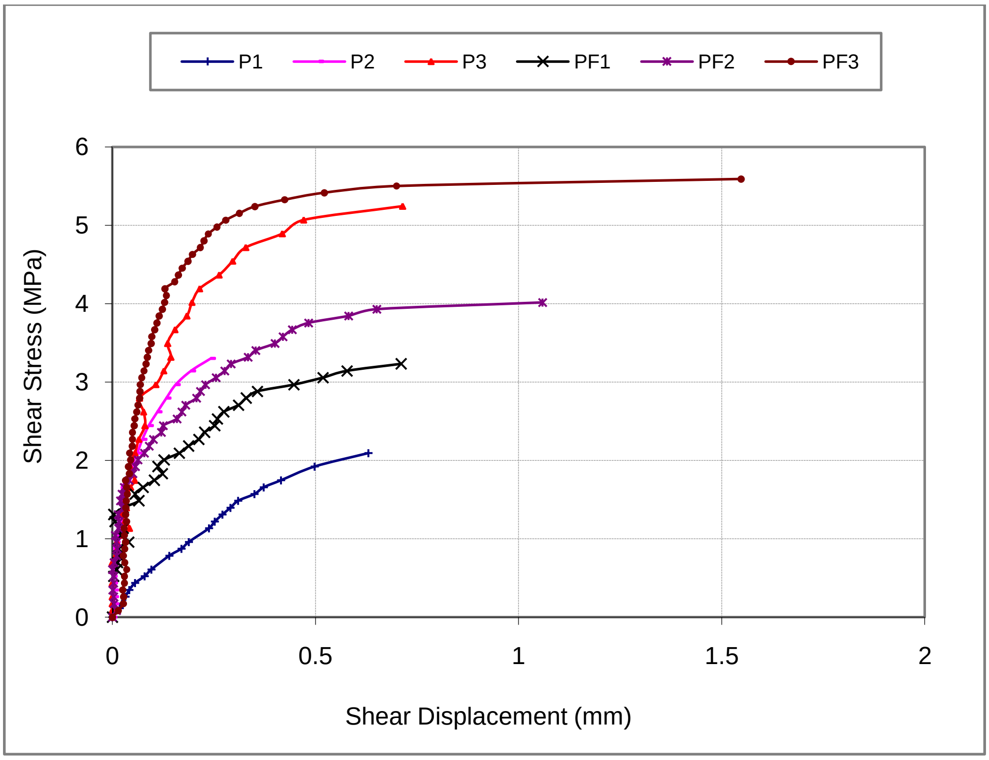

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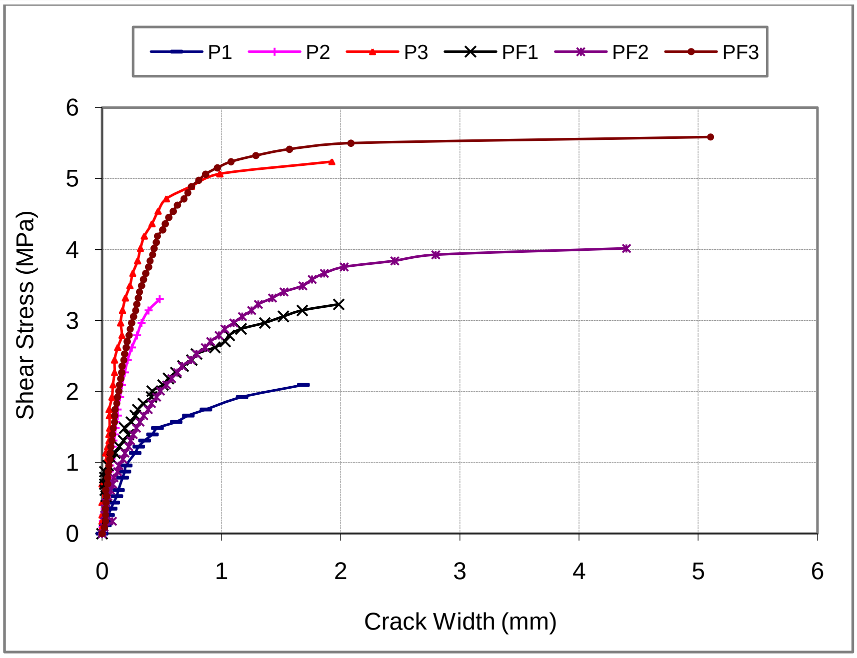

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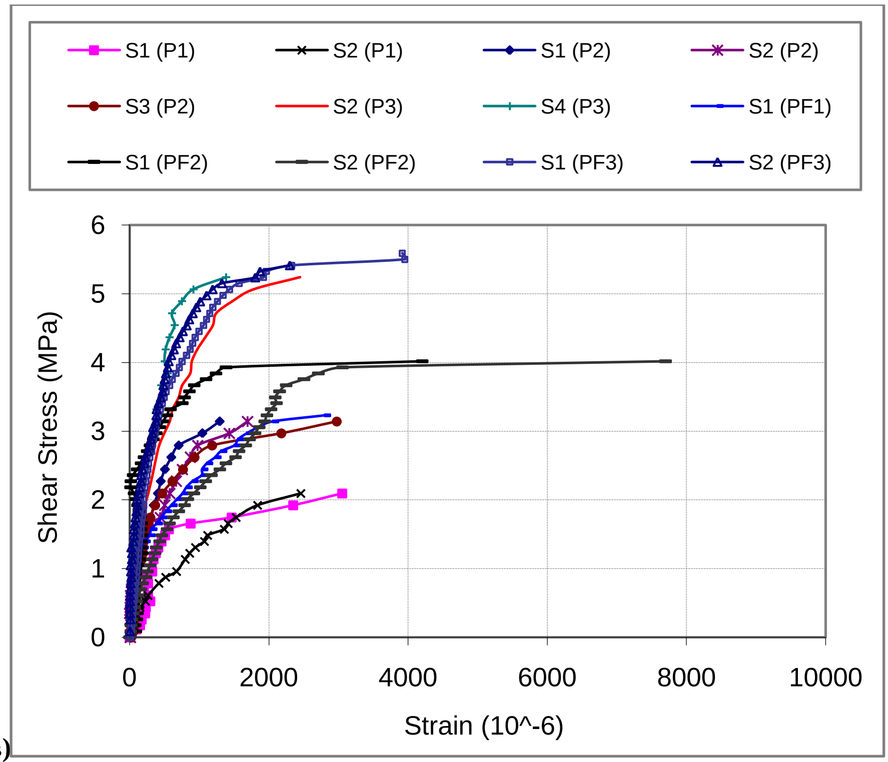

в)

Fig. 2. Dependencies: a) «$\tau - \delta_{crc}$»; b) «$\tau - a_{crc}$»; c) «$\tau - \varepsilon$» in steel clamps across the shear plane of the series P and PF

The papers [1,4] propose expressions for the ultimate shear resistance of cracked specimens by analogy with the theory of shear friction. This theory is precious for estimating shear stress limits transmitted through the cracks of a reinforced concrete element. The concrete surfaces of the crack are rough and irregular, and when they are displaced along the shear plane, its banks will move apart, which will lead to additional tensile stresses in the internal steel reinforcement crossing the crack and compressive stresses in the concrete. Compressive stress across the crack provides resistance to shear displacement due to friction between the rough surfaces of the crack. It can be assumed that crack opening can lead to the flow of rods crossing the crack. According to [4], for a section with a "reinforced" crack, the shear limit resistance can be written as:

$$Q_u = A_{sw} R_{sw} tg\alpha \,, \qquad (1)$$

Where the value $tg\alpha$ is understood as the coefficient of friction between the crack surfaces. By dividing this equation by the area of the shear plane, it can be represented in stresses:

$$\tau_u = \rho R_{sw} tg\alpha \,. \qquad (2)$$

In reinforced samples, PFM sheets resist horizontal specimen separation (normal displacement or crack opening) and shear displacement in the shear plane. Fibres oriented perpendicular to the crack work similarly to steel clamps. Vertical fibres (i.e. parallel to the crack) act as deformation limiters for other fibre directions and prevent the sheets from peeling off the concrete surface. Based on the results of the regression analysis of the experimental data, the following empirical expression, which takes into account the contribution of external reinforcement from PFM to the overall shear resistance of the reinforced samples, is proposed:

$$\tau_R = 0{,}88544\left[\rho R_s \tan\alpha + \left(\frac{2t_f}{b}\right) + R_{fu}\right] - 2{,}9802 \,, \qquad (3)$$

где: $\rho = A_{sw} / A_{crc}$; $tg\alpha$ = 1,4; A_{sw} – cross section area of steel clamps; A_{crc} – shear surface area; R_s – tensile

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strength of steel; t_f - sheet thickness; b – shear width; R_{fu} - sheet tensile strength.

Samples	Number and diameter of clamps, mm	ρ (%)	Destroying load, kN	The effort at the PWM, the IPs	Shear stress τ, MPa		$\frac{\tau(теор)}{\tau(эксп)}$
					Theoretic.	Expert.	
P1	2Ø6	0,14	85,50	---	1,28	2,09	1,63
PF1			131,82	46,32	3,20	3,23	1,04
P2	4Ø6	0,28	135,38	---	2,56	3,30	1,28
PF2			167,45	32,07	4,34	4,10	0,95
P3	6Ø6	0,42	213,87	---	3,84	5,24	1,36
PF3			228,02	14,15	5,48	5,58	1,02

III.CONCLUSION

1. The applicability of expression (3) is limited by the cubic strength of concrete within 30 - 40 MPa. In the table comparison of theoretical and experimental data of the tested samples is resulted. It can be seen that the proposed equation well approximates the experimental values and allows to determine with sufficient accuracy the bearing capacity when cutting examples of reinforced PFM.

2. The results of the tests show that the share of external reinforcement in the bearing capacity of the sample decreases with the increase in the percentage of internal support by steel rods (clamps). In the initial stages of loading, the external reinforcement restrained the tangential displacement in the cracked section and its opening; these were smaller compared to samples without external support for the same level of loading. However, in the limiting stage, there was a sudden increase in average and tangential displacements compared to samples without external amplification. The increase in shear stress of the reinforced samples varies between 7% and 56% compared to the samples without external amplification (Table 1). In general, the stiffness of the reinforced samples was higher than that of the unenforced examples, which can be explained by lower deformations in steel clamps at the same load level.

3. Distortion in steel clamps of reinforced specimens was less than in non-strengthened ones at the same load. However, in the fracture stage, the reinforced specimens showed more significant deformation than the non-strengthened examples. The dependence of "τ - δ" of reinforced and non-strengthened individual samples is approximately the same. The proposed theoretical expression for the calculation of shear stress on externally amplified samples can be used provided that there is sufficient correlation with the experimental results. Further research is needed to apply the proposed equation more widely.

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