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USING COMPOSITE PLASTICS FOR RESTORATION OF DAMAGED REINFORCED CONCRETE STRUCTURES

Abstract. *A method is proposed to restore the operational suitability of bent reinforced concrete structures with increased deflections and excessive crack opening. Modern methods of reinforcement by surface gluing composite fibro-reinforced plastics (FRP) on the stretched zone of exploited reinforced concrete structures increase the strength and rigidity of reinforcing elements, but do not reduce deflections and the width of crack opening. To restore the operational suitability of damaged reinforced concrete structures, a preliminary stress is proposed, which is used to strengthen FRP, which is provided by the creation of a temporary construction lift in the damaged elements.*

Keywords: *restoration, reinforced concrete structures, fiber-reinforced plastics, composite, construction.*

Introduction

Modern methods of reinforcing reinforced concrete structures consist in surface gluing of fiber-reinforced plastics to the concrete surface, which act as additional reinforcement [1]. Fiber-reinforced plastics are composite materials consisting of a plastic matrix and high-strength reinforcing fibers. Composite materials are supplied in the form of ribbons (lamellas), fabrics or nets. Epoxy, phenolic, polyester, vinyl ester or other organic resins are used as plastics [2]. Reinforcing fibers are made using nanotechnology from carbon, basalt, aramid or glass. Fiber-reinforced plastics have a high modulus of deformation, an elastic nature of the diagram, increased frost resistance, they tolerate fatigue well, and are resistant to the effects of chemically active substances. increase in strength, economic feasibility, increase the technical level of construction, do not require overburden, welding and embedding works[3]. The process of surface reinforcement of reinforced concrete structures takes several hours, and after a day, the reinforced structure is able to absorb additional loads [4]. These methods of reinforcement are widely used for longitudinal and transverse reinforcement of a stretched zone of reinforced concrete structures, as well as for the creation of reinforcing clips in compressed elements[5].

Materials and methods

This article presents the results of experimental studies of bending elements aimed at studying the operation of normal and inclined sections. The samples were surface-reinforced with S&P Laminate "BASF" carbon laminate tapes (Germany) glued to the compressed and stretched edge of the beams. The prototypes were tested according to the scheme of a single-span hinged supported beam loaded in thirds of the span by equal concentrated forces.

Static tests were carried out while loading the samples with a hydraulic jack. Deformations were measured using an AID-4M automatic strain gauge, and displacements were recorded with PAO-6 deflection meters, the crack opening width was recorded using an MPB-2 microscope. The destruction of reinforced concrete beams without reinforcement was caused by the crushing of the compressed zone of concrete in the zone of pure bending during the flow of tensioned reinforcement. When reinforcing beams in the stretched zone with laminate strips, along with the traditional scheme of destruction of reinforced concrete structures, additional fracture schemes were revealed, caused by the separation of the protective layer of concrete in the tensioned zone or the separation of the stretched laminate ribbons from the concrete. Strengthening the beams by gluing one layer of laminate to the stretched zone led to an increase in strength by 75%, with tensile deformations in laminate strips reaching 0.58-0.61%, and the deformations of tensile steel reinforcement decreased by almost 10% loss of stability or rupture of longitudinal reinforcement. At the same time, an increase in crack resistance and stiffness of normal sections was observed.

Strengthening the beams in the tensile zone with two layers of laminate had little effect on the cracking load and the strength of normal sections, however, the crack opening width decreased by almost two times, the tensile deformations of the laminate decreased by 65%, and the vertical deflections decreased by 31%.

Reinforcement of beams in the tensioned and compressed zones with laminate strips had little effect on the cracking load, stiffness, crack opening width, deformations of the stretched laminate and the strength of normal sections compared to the behavior of the beams, reinforcement with the laminate only in the tensile zone, and the deformations of the compressed laminate corresponded to the ultimate deformations of concrete compressed zone.

Dynamic tests of beams were carried out under cyclic alternating loading using hydraulic jacks and an MWG-1 hydrodynamic unit with a frequency of about one hertz. During the tests, the longitudinal deformations of concrete were measured along the height of the compressed zone using strain gauges glued to the side surfaces of concrete prisms, and vertical deflections were recorded using calibrated cantilever metal plates with strain gauges glued on the lower and upper sides. The electronic system PRIS-1000 was used to record the dynamic characteristics. Dynamic tests were carried out under cyclic loading with a force asymmetry coefficient $\rho = 0.1$ and a loading frequency of 1.0 hertz. The amplitude of the greatest efforts ensured the destruction of the specimens in 10–300 loading cycles. The empirical dependence of the breaking load (M_d) on the number of cyclic loads (n) is as follows:

$$\frac{M_d}{M} = 1.33\text{-}0.116\ \lg n \qquad (1)$$

where M – is the static strength of the normal section.

The dynamic strength of normal sections, reinforced in tension at a single load, exceeded the static strength by 33%. With an increase in the number of cyclic loads required for fracture from 2 to 280, the strains of the stretched laminate ranged from 1,88‰ to 2,05‰, and the vertical deflections increased by 26%. In general, the greatest deformations of a stretched laminate under dynamic loads were 45% less than the deformations of a stretched laminate under static tests. The nature of the destruction of normal sections of beams under dynamic loading differed little from the destruction of similar beams under static loading.

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Investigations of the strength of inclined sections, reinforced with fiber-reinforced plastics, were carried out on similar reinforced concrete beams, reinforced in the support zones with surface gluing of unidirectional meshes FipArm Tape 530/300 mesh with a fiber area of 300 g/m, deformation modulus E =245 kH/m^2, tensile strength 3600 N/m^2. The beams were tested according to the scheme of a single-span hingedly supported beam loaded with two equal shear forces spaced from the supports at distances equal to l_{sr} = 1,75h -2,0 h. In the process of a gradual increase in the vertical load after the formation of normal cracks in the pure bending zone, the appearance of inclined cracks in the support zone was observed, and at the stage of accelerated opening of inclined cracks with a width of about 3 mm, the fracture of the support zone occurred. After removing the reinforcement from the meshes, concrete crushing between the meshes was revealed. Reinforcement of the support zone with vertical or inclined polymer meshes led to a twofold increase in the shear strength of inclined sections, and the deformation of the fiber-reinforced meshes was 3–4 ‰. Along with the traditional scheme of destruction of inclined sections in the transverse force, an additional scheme of destruction was revealed, caused by the breaking off of the protective layer of concrete under the strips of reinforcement meshes. At the same time, the increase in strength did not exceed 50%, and the greatest deformations of the meshes for the stage before fracture were 1,8-2,5‰.

The calculation of the surface reinforcement of reinforced concrete structures using the gluing of fiber-reinforced plastic composites (hereinafter FRP) is performed according to the limit states using partial coefficients.

The strength analysis of normal sections of external FRP-reinforced members should consider the following failure patterns:

- destruction of the compressed zone of concrete until the yield stress in tensile steel reinforcement is reached at stresses in the FRP reinforcement that are much lower than the design ones (re-reinforced tensile zone);

- achievement of yield stresses in tensile steel reinforcement and subsequent rupture of FRP reinforcement without destruction of the compressed zone of concrete;
- the achievement of yield stresses in tensioned steel reinforcement and subsequent failure of the FRP reinforcement and destruction of the compressed zone of concrete;
- destruction of delamination of FRP reinforcement from concrete or detachment of concrete cover with FRP reinforcement.

When calculating the strength of elements normal to the longitudinal axis, reinforced in the tensile zone with FRP laminate strips, the following prerequisites are taken:

- the distribution of deformations of concrete, steel reinforcement and FRP laminate strips is taken according to a linear law (hypothesis of flat sections);
- the relationship between stresses and deformations in the compressed zone of concrete is allowed to be parabolic-linear;
- the relationship between stresses and strains in steel reinforcement is assumed to be bilinear;
- the relationship between stresses and strains of external FRP reinforcement is assumed to be linear;
- the bond between concrete and external FRP is adopted rigid; after reinforcement to destruction, the conditions for compatibility of deformations are preserved;
- the stress-strain state of the element before reinforcement is taken into account.

The selection of the FRP cross-sectional area is carried out by an iterative method by specifying a certain FRP area and then correcting it according to the results of the strength calculation in the desired direction.

The calculation of the internal forces of normal sections of bent reinforced concrete structures is carried out on the hypothesis of flat sections under the assumption that there is no displacement between the glued external FRP reinforcement and the concrete base, as well as the steel reinforcement available in the structure.

The design tensile strength f_{yd} for FRP is given by:

$$F_{yd} = \frac{f_{yd}}{\gamma_F} \tag{2}$$

The calculated tensile deformations ε_f for FRP are determined by the formula:

$$E_f = \frac{\varepsilon_{uf} \cdot \gamma_{Ff}}{\gamma_f} \tag{3}$$

Flaking of FRP can occur if the deformation in it cannot be perceived by the substrate. FRP peeling should be prevented by limiting the level of its deformation using the coefficient K_f, which is determined by the formula:

$$K_f = \frac{1}{60E_f}\left(1 - \frac{\varepsilon_f . A_f}{360000}\right) \leq 180\,000 \qquad (4)$$

The shear strength of an inclined section reinforced with FRP is defined as the sum of the strength of the section without reinforcement and the additional shear force that is absorbed by the FRP reinforcement:

$$V_{cd} = V_{Rd,c} + V_{Rd,xy} + V_{Rd,f} \qquad (5)$$

where $$V_{Rd,f} = A_f . \varepsilon_{fe}\, (\sin\alpha + \cos\alpha)/s_f \qquad (6)$$

V_{cd} – is the shear strength of the section;

$V_{Rd,c}$ – shear force absorbed by concrete;

$V_{Rd,sy}$ – shear force absorbed by steel clamps;

$V_{Rd,fc}$ – additional shear force perceived by vertical or inclined stripes or polymer-reinforced mesh reinforcement;

A_f, E_f, α and s_f are the cross-sectional area of the reinforcement grids, their modulus of deformation, the angle of inclination and the distance between the strips of the reinforcement grids;

$$E_{fe} = 0{,}004 \leq 0{,}75\, \varepsilon_{fu} \qquad (7)$$

E_{fe} – is the calculated relative deformation of polymer meshes of cross-section reinforcement,

E_{fu} – is the ultimate tensile strength of polymer reinforcement networks.

Conclusions

During the construction and operation of buildings, damage often occurs that is associated with errors in calculation and design, violations of manufacturing technology, low quality materials, excessive loads, insufficient anti-corrosion protection, extreme natural disasters, etc. The most frequently damaged bearing bending reinforced concrete structures (floors, beams, trusses, etc.), which, in addition to aesthetic perception, cause the operational unsuitability of these structures. Surface reinforcement of damaged structures usually does not lead to their significant improvement in the performance characteristics of load-bearing elements, although it increases their rigidity and crack resistance with a further increase in loads.

To restore the serviceability of damaged reinforced concrete structures, it is proposed to create prestressing fiber-reinforced reinforcement materials. The simplest way to prestress surface reinforcement elements is to create a temporary bend (lifting damaged areas) of load-bearing structures, which can be carried out using jacks, telescopic racks, truss systems, etc. In Kazakhstan, telescopic racks are widely used to create a bend in damaged reinforced concrete floors, with the help of which the sagging part of the bending elements is lifted until the cracks are closed and securely clamped.

Telescopic supports were made from two rolling channels with flange cuts in the middle part, in the folds of which tightening straps are installed. Pulling the bent channels leads to their straightening and an increase in the height, which ensures the lifting of structures (Fig. 1).

After creating the rise of the restored bendable reinforced concrete structures, the fiber-reinforced plastics are glued to the stretched edges, and after the strength of the adhesive compositions (after 10-12 hours), the lifted structures are lowered. In this case, not only the serviceability of the normal sections of damaged bending reinforced concrete structures is restored, but the serviceability of the damaged support zones can be restored (the load-bearing capacity in transverse force is restored and the damage is reduced).

Figure 1 – Raising the floor with telescopic racks (author’s material)

In the process of technological support of the process of restoration of damaged reinforced concrete structures, the control of vertical deflections and crack opening width was carried out, which showed that after removing the temporary lifting of structures, the value of structural deflections decreased by 30-50%, the opening width of normal cracks decreased to 0,15-0,25 mm, and inclined cracks closed by 40-60%, and the strength of structures increased by 35-60%.

In general, data have been obtained on the high reliability of systems for surface reinforcement of reinforced concrete structures with composite plastics.

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ЗАҚЫМДАЛҒАН ТЕМІРБЕТОН КОНСТРУКЦИЯЛАРЫН ҚАЛПЫНА КЕЛТІРУ ҮШІН ФИБРОАРМИРЛЕНГЕН ПЛАСТИКТЕРДІ ПАЙДАЛАНУ

Аңдатпа. *Темірбетон конструкцияларыың ақаулығын және пайда болған жарықтарын қалпына келтіру және нығайту мақсатында тәсіл ұсынылады. Заманауи тәсілдер жарықтарды кішірейту емес, тек темірбетон конструкцияларын нығайтуға арналған. Темірбетон конструкцияларын қалпына келтіру үшін фиброармирленген пластиктерді пайдаланылады және ақауланған конструкцияларды иілген бөлігін көтеруіне ықпалын тигізеді.*

Түйін сөздер: *қалпына келтіру, темірбетон конструкциялары, фиброармирленген пластиктер, композит, конструкция.*

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ПРИМЕНЕНИЕ КОМПОЗИТНЫХ МАТЕРИАЛОВ ДЛЯ ВОССТАНОВЛЕНИЯ ПОВРЕЖДЕННЫХ ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ

Аннотация. *В статье приводятся результаты исследования усиления и восстановления эксплуатационной пригодности поврежденных железобетонных конструкций. Приводятся сведения о применении поверхностного усиления железобетонных конструкций фиброармированными пластиками, излагаются их преимущества над традиционными усилениями с использованием стальной арматуры. Рекомендуются практические способы создания предварительного напряжения путем создания временного подъема поврежденных элементов.*

Ключевые слова: *восстановление, железобетонная конструкция, фиброармированныq пластик, композит, конструкция.*