Carrying capacity of reinforced concrete columns, reinforced with collars from fiber-reinforced plastics, with little dynamic loads

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Abstract. The article presents the results of experimental studies of the carrier ability, longitudinal and transverse deformations of reinforced concrete columns, reinforced clips made of fiber-reinforced plastics, with a few repeated loads. Dependences of residual strength after cyclic compressive forces are obtained. Are given suggestions for acceptable deformation values of fiber-reinforced plastics, as well as proposals for calculation and design.

1 Introduction

Modern methods of strengthening building structures are based on the use of composite materials. The most common surface reinforcements, in which composite materials are directly glued to concrete surfaces and act as additional reinforcement. Composite materials are fibroplastic products in the form of ribbons, meshes or fabrics, consisting of a plastic matrix containing high-strength fibers from various materials (carbon, aramid, carbon fiber, glass), manufactured by nanotechnological methods. Fiber-reinforced plastics have a high modulus of deformation, increased frost resistance, tolerate fatigue well, and are resistant to the effects of chemically active substances. In contrast to traditional methods of strengthening, surface methods of strengthening are distinguished by high efficiency of strengthening, corrosion resistance, low labor intensity, short terms of work, increased strength and high speed of gaining strength, economic feasibility, increase the technical level of construction, do not require overburden, welding and grouting works. 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. 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 [1-9].

This article presents the results of experimental studies of the stress state, the bearing capacity of reinforced concrete structures reinforced with clips of composite materials, their residual strength, longitudinal and transverse deformations under static and few vertical loads.

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2 Experimental research

Experimental studies of the behavior of compressed reinforced concrete elements under the static and dynamic action of axial compression have been performed. The columns are transversely reinforced with layers of fiber-reinforced plastics that limit the development of transverse deformations of concrete, thereby creating the effect of triaxial compression of concrete. The prototypes of concrete and prisms were reinforced with layers of S&P C carbon meshes manufactured by BASF and differed in cross-sectional dimensions, cross-sectional shape, age of concrete and the number of layers of reinforcement meshes.

Static tests were carried out under the axial action of quasi-static compression on hydraulic presses IPS-200 and ALPHA 3-3000S. In the process of static loading, the longitudinal and transverse deformations of the prototypes were measured using load cells with a base of 50 mm, glued to all the side faces of the samples, and an automatic strain meter AID-4M. The destruction of samples reinforced with carbon fiber fibers occurs gradually. First, there is a crack caused by the rupture of individual fiber fibers, with an increase in the load, the crack increases and there is a brittle crushing of concrete in the area of the mesh break, accompanied by a sharp sound. The more layers of reinforcement, the earlier the process of breaking the mesh fibers begins.

Two series of concrete prisms with dimensions of 100x100x400 mm differed in the age of the concrete. The first series of samples had a concrete age of about 15 years, and the second series of samples was tested at the age of several months of concrete. Strengthening of the samples by wrapping (gluing) with the S&P C Sheet 240 series material led to a significant increase in the strength of concrete, which is about 15 years old. Thus, single-layer meshes caused an increase in strength by an average of 34%, and two-layer meshes led to an increase in strength by 1.81 and 2.35, and three – layer meshes-by 1.95 and 2.3 times. The reinforcement of concrete prisms from concrete at the age of several months led to a greater increase in the strength of concrete than concrete at the age of 15 years. Thus, single-layer meshes caused an increase in strength by an average of 38% and 23%, and two-layer and three-layer the meshes led to an increase in strength by 2.35 and 2.3 times, respectively. This is due to the fact that with the age of concrete, its limiting deformations decrease, therefore, the amount of hardening also decreases. The presence of grids leads to a significant increase in the longitudinal deformations of concrete, however, with an increase in the number of layers of grids, the intensity of the growth of deformations decreases and with three layers of grids, the deformations of concrete differ little from the deformations of samples with two layers of grids. The ultimate compressibility of concrete is about 3 ppm. The presence of grids also causes an increase in transverse deformations of concrete. They increase from 30-40. 10-5 to 300-400.10-5 relative units.

To assess the scale factor, samples of concrete prisms with dimensions of 200×200×800 mm were tested. Concrete samples without reinforcement are characterized by an almost linear decrease in the volume of concrete to a value of-73.10-5 relative units when compressive stresses reach about 75% of the prismatic strength. Then comes the period of stopping the reduction in the volume of concrete, and with a further increase in stresses, the process of a slight increase in the volume of concrete begins (up to a value of-60.10-5 relative units). For samples with reinforcement by one layer of the grid to stresses amounting to about 90% of the destructive ones, the process of constant reduction of concrete to values -93.10-5 relative units occurs. Then there is a process of a sharp increase in volume, which before destruction reaches a value of -25.10-5 relative units. For samples with reinforcement by two layers of mesh to stresses amounting to about 70% of the destructive ones, the process of constant reduction of concrete to values-98.10-5 relative units occurs. Then there is a process of a sharp increase in volume, which before destruction reaches a value of +250.10-5 relative units, i.e. an increase in the volume of concrete is observed. A similar pattern of changes in the volume of concrete is observed in samples with three-layer wrapping with S&P C Sheet 240 grids. In general, an increase in the size of concrete prisms led to a decrease in the strength growth of reinforced samples due to a decrease in the coefficient of transverse reinforcement with polymer meshes.

To assess the influence of the cross-sectional shape of the compressed elements, concrete cylinders with a diameter of 150 mm and a height of 300 mm were tested. Strengthening of 240 concrete cylinders by wrapping (gluing) with S&P C Sheet series material led to a significant increase in the strength of concrete (Figure 1). Thus, single – layer meshes caused an increase in strength on average by 2.62 times, double – layer meshes-by 3.75 times, and three-layer meshes-by 5.22 times, respectively. The analysis of the development of longitudinal and transverse deformations of samples shows that the longitudinal deformations of samples with one mesh layer increased by 2.26 times, transverse deformations-by 6.9 times; for samples reinforced with two mesh layers, longitudinal deformations increased by 3.53 times, transverse deformations-by 9.56 times; for samples reinforced with three mesh layers, longitudinal deformations increased by 2.74 times, transverse deformations-by 10.3 times (Figure 2).

The analysis of concrete damage shows (Figure3) that the beginning of the formation of microcracks in concrete in samples reinforced with FAP grids begins after exceeding the strength of non-reinforced concrete, then an accelerated increase in the volume of concrete begins, with the magnitude of stresses in samples reinforced with one layer of mesh about 85% of the destructive stresses, the volume of concrete increased compared to a decrease in the volume of concrete at the initial stages of loading by 6 times, and with two and three layers of grids after exceeding the stresses of 40% and 48% of the destructive ones, the volume of concrete increased, respectively, by 20 times and 9 once.

Fig. 1. Compression failure of concrete cylinders without reinforcement and with reinforcement fibro-reinforced nets.

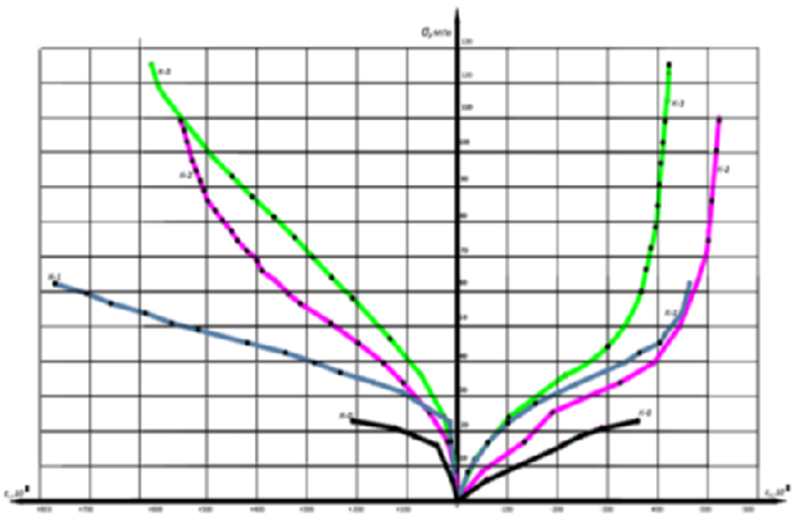

Fig. 2. Diagram of longitudinal and transverse deformations of concrete cylinders (0, 1, 2, 3 layers of gain grids).

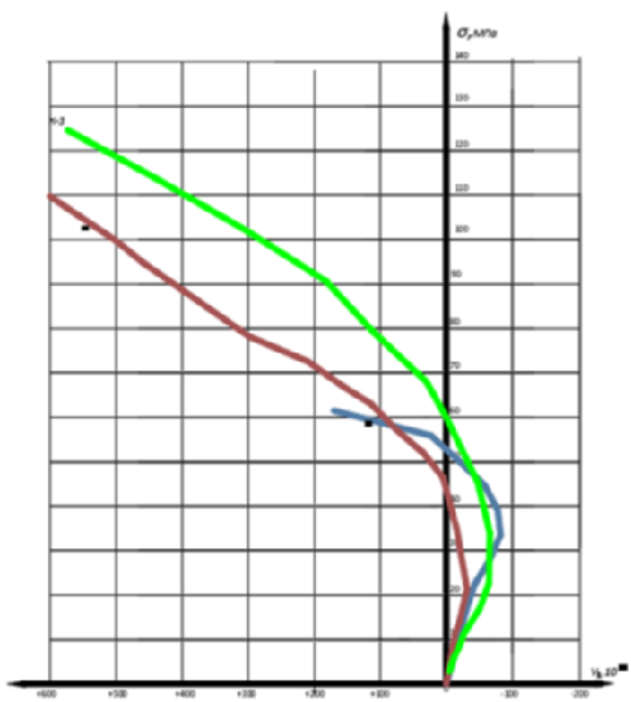

Fig. 3. Diagram of the volume change of concrete cylinders (1, 2, 3 layers of reinforcement grids).

The influence of dynamic repeated loads on the physical and mechanical properties of samples reinforced with fiber-reinforced meshes was studied under axial compression created using the MVG-1 hydrodynamic machine after centering the samples along the physical axis. Dynamic tests were carried out with a positive coefficient of asymmetry of

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the force change (p = 0.0 ÷ 0.10), a loading frequency of 1.0 hertz and a compressive stress value that ensures the destruction of prototypes in 1 ÷ 300 loading cycles (Figure 4).

According to the results of cyclic tests of concrete prisms with dimensions of 100x100x400 mm, not reinforced with grids, an empirical semi-logarithmic dependence of the maximum stresses in concrete on the amount of loading was obtained, which shows that the coefficient of dynamic hardening of concrete under the accepted loading mode was 1.256, i.e. the compressive strength of concrete under dynamic loading exceeds the strength of this concrete under static loading by 25.6 %:

$$\Sigma cn = 1.256\ fc\ (1\text{-}0.11\ \lg n) \quad (1)$$

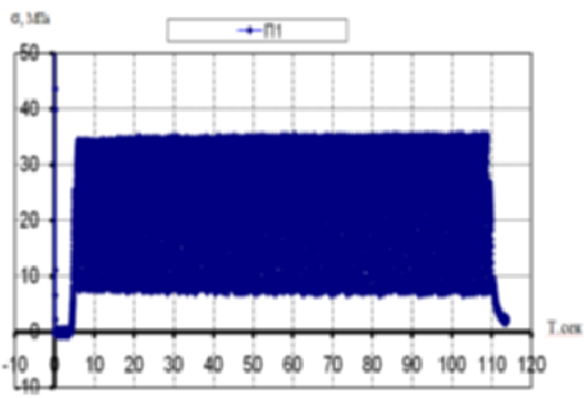

Fig. 4. Diagrams of cyclic loads.

Concrete prisms with dimensions of 100x100x400 mm were subjected to repeated loading until the destruction of the samples. Specimens with one layer of polymer meshes withstood 25-65 loading cycles with maximum stresses exceeding the static strength by 9-56%. Longitudinal deformations practically did not change with residual deformations of 5-12.10^{-5} relative units, and transverse deformations decreased almost two times with residual deformations of 10-20.10^{-5} relative units.

Concrete prisms with two layers of polymer meshes withstood 10-61 loading cycles with maximum stresses of 84-125% of static strength. Longitudinal deformations were less than deformations during static tests by an average of 35% with residual deformations of 25-30.10^{-5} relative units, and transverse deformations decreased by almost 2-2.5 times with residual deformations of 25-60.10^{-5} relative units.

Concrete prisms with three layers of polymer meshes withstood 43-440 loading cycles with maximum stresses exceeding the static strength by 22-53%. Longitudinal deformations decreased by almost 4.5 times with residual deformations of 50.10^{-5} relative units, and transverse deformations decreased by almost 3 times with residual deformations of 10-35.10^{-5} relative units.

Based on the results of dynamic tests of concrete cylinders with dimensions of 150x300 mm (bzh) without reinforcement, an empirical semilogarithmic dependence of the maximum stresses in concrete on the amount of loading was obtained, which shows that the coefficient of dynamic hardening of concrete under the accepted loading mode was 1.23, i.e. the compressive strength of concrete under dynamic loading exceeds the strength of this concrete under static loading by 23%:

$$\Sigma cn = 1.23\ fc\ (1\text{-}0.07\ \lg n) \quad (2)$$

During dynamic tests of cylinders reinforced with one layer of polymer meshes, the prototypes were subjected to a different number of cyclic loads (from 90 to 414 cycles) with maximum stresses of 50-60% of the static strength, and then the prototypes were subjected to static tests until fracture. During the action of cyclic loads, the magnitude of the longitudinal and transverse deformations remained practically unchanged, however, an increase in the longitudinal residual deformations by 15% and transverse deformations by 24% occurred. The action of cyclic loads did not affect the strength of the samples (the average strength increased by 6.7%) and the longitudinal and transverse deformations.

According to the results of dynamic tests of concrete cylinders with dimensions of 150x300 mm (bzh), which do not have reinforcement, an empirical semi-logarithmic dependence of the maximum stresses in concrete on the amount of loading was obtained, which shows that the coefficient of dynamic hardening of concrete under the accepted loading mode was 1.23, i.e. the compressive strength of concrete under dynamic loading exceeds the strength of this concrete under static loading by 23 %:

$$\Sigma cn = 1{,}23\ fc\ (1-0{,}07 \lg n) \quad (3)$$

During dynamic tests of cylinders reinforced with a single layer of polymer meshes, the prototypes were subjected to a different number of cyclic loads (from 90 to 414 cycles) with maximum stresses amounting to 50-60% of static strength, and then the prototypes were subjected to static tests until destruction. During the action of cyclic loads, the value of longitudinal and transverse deformations practically did not change, but at the same time there was an increase in longitudinal residual deformations by 15% and transverse deformations by 24%. The effect of cyclic loads did not affect the strength of the samples (the average strength increased by 6.7%) and longitudinal deformations, but transverse deformations increased almost twice.

3 Analysis of the results of experimental studies

Experimental studies of the strength of compressed reinforced concrete structures reinforced by surface gluing of clips made of new types of carbon fiber mesh used in Kazakhstan have been carried out. Reinforcement of compressed reinforced concrete elements with clips of fiber-reinforced plastics causes triaxial compression in concrete, in which the strength of the elements can increase several times.

In the studies, two schemes of destruction of compressed concrete samples, reinforced with clips of their carbon fiber fibers, have been implemented:
- rupture of fiber-reinforced mesh reinforcement and brittle crushing of concrete;
- the gap of the grid interface joints associated with the insufficiency of the overlap of the grids.

The formation of microcracks in compressed concrete elements reinforced with FAP clips is observed after reaching compressive stresses in concrete corresponding to the initial concrete strength before loading. With a further increase in the longitudinal compressive force, an accelerating increase in the volume of concrete occurs, and before destruction the increase in the volume of concrete reaches 0.8-1.1%.

The destruction of concrete specimens reinforced with carbon fiber fibers under axial compression occurs gradually. First, a crackling appears, caused by the rupture of individual fiber fibers, with an increase in the load, the crackling increases and then brittle crushing of concrete occurs in the zone of mesh rupture, accompanied by a sharp sound. The more layers of reinforcement meshes, the more the relative level of stresses in concrete, at which the process of rupture of mesh fibers begins, decreases.

The gluing of clips made of unidirectional vertical meshes led to an increase in the strength of compressed elements of a circular cross-section by 2.0-5.5 times, and of a square cross-section by 1.8-2.3 times.

With an increase in the age of concrete, the efficiency of reinforcing compressed elements with FAP clips decreases. The increase in the compressive strength of test specimens made of concrete at the age of concrete 2-3 months exceeded the increase in the strength of similar specimens made of concrete at the age of 15 years by 20-30%. Ultimate deformations of concrete reinforced with FAP clips increased to 0.4-0.5%, while transverse deformations of concrete and deformations of FAP fiber elongation reach values of 0.45-0.55%. The strength of eccentrically compressed reinforced concrete specimens, reinforced with FAP clips, with the application of a longitudinal compressive force at the boundary of the section core, was about 70% of the strength of similar specimens tested under central compression. In this case, the diagram of compressive stresses is parabolic, and the longitudinal and transverse deformations of concrete on the compressed face before fracture are close to the ultimate deformations of the specimens tested under axial compression.

The nature of damage accumulation in concrete reinforced with FAP clips under the dynamic action of repeated loads depends on the amplitude of compressive stresses. When the value of the dynamic load causing fracture for the number of repeated loads exceeding 100 cycles, after the first loading cycles, the concrete deformation diagram changes little over a significant number of subsequent loads. Several dozen before the destruction of concrete, an accelerating increase in inelastic deformations is observed, up to the exhaustion of the concrete strength. When the value of the maximum compressive stresses in concrete exceeds 90% of the strength of concrete, concrete failure occurs after several loading cycles, while with each subsequent loading cycle, an accelerating increase in inelastic deformations of concrete occurs, ending in concrete destruction.

Dynamic tests of experimental prisms reinforced with FAP clips, destroyed by a few repeated loads in the range of 25-440 cycles, showed that the dynamic strength exceeds the static strength, and the longitudinal and transverse deformations were several times less than the static ones. The action of dynamic repetitive cycles in the amount of 90-414 cycles with maximum stresses equal to 50-60% of the static strength had an insignificant effect on the strength and deformations of the prototypes.

4 Recommendations for the design of reinforcement

Compressed reinforced concrete columns, reinforced by wrapping with fiber-reinforced plastics, must meet the requirements of the calculation of the load-bearing capacity (ULS) and the suitability for normal operation (SLS). In the extreme state of the load-bearing capacity of compressed columns reinforced by wrapping the composite FAP, the transverse expansion of the concrete is perceived by a shell (bandage) of fibroamated plastics.

The selection of the cross-sectional area of the elements of fiber-reinforced plastics is carried out by an iterative method, setting its initial value, and then adjusting the latter according to the results of strength calculations.

The design characteristics of fiber-reinforced plastics are determined by the standard characteristics of fiber-reinforced plastics, taking into account the safety factor for reinforcement γ_f and the factor of operating conditions of the reinforcement γ_{fl}, taking into account the influence of the environment [13-15].

The strength of concrete in a cage of a round concrete element is determined by the formula:

$$N_{cd} = \gamma_f . f_{cd} . A_c [2.25 \sqrt{1 + 7.9 \frac{\sigma_f}{f_{cd}}} - 2 \frac{\sigma_f}{f_{cd}} - 1.25] \quad (4)$$

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The maximum calculated stress in the cage is determined by the formula:

$$\sigma_f = \frac{k_f \rho_f \varepsilon_{fe} E_f}{2} \tag{5}$$

Calculated deformations in the cage are determined from the expression:

$$\varepsilon f = 0.004 \leq 0.75\ \varepsilon_{fu} \tag{6}$$

For columns of square and rectangular cross-section, in contrast to columns of round cross-section, the coefficient kf is introduced, taking into account the size of the columns and the coefficient of longitudinal reinforcement.

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