

# Investigation of Polymer Composite Cage for Reinforcement of Concrete Columns



Dmitriy Erohin, Tagir Zinnurov , and Ilia Grishin

**Abstract** The authors proposed an innovative solution for strengthening reinforced concrete columns made of polymer composite materials: fiberglass reinforcement and polymer concrete. Investigation of the operation of a cage made of polymer composite materials includes: full-scale compression test of samples of round cross-section racks reinforced with a cage made of polymer composite materials; numerical modeling of a reinforced concrete column strengthened with a spiral of fiberglass reinforcement using three-dimensional models in the ANSYS software package. Within the framework of the studied theory of elasticity and mechanics of a solid body, a method for calculating the reinforcement structure from fiberglass reinforcement together with a concrete cylinder in a linear formulation is proposed. As a result, a comprehensive analysis of the data obtained was carried out and recommendations were developed for the design and calculation of the cage for reinforcing reinforced concrete columns made of polymer composite materials.

**Keywords** Cage · Column · Reinforced concrete · Polymer concrete · Fiberglass reinforcement

## 1 Introduction

The condition of the bridges, overpasses, flyovers and other engineering and technical structures to ensure traffic flow with increased traffic is due to the high quality of the road network indicators and requires special attention. According to the Ministry of Transport of the Russian Federation, there are more than 70,000 bridge observations in the Russian Federation, of which more than 7% are in disrepair. In addition there are side effects in the form of aggressive environments, with a particularly significant increase in the load on vehicles [1, 2]. There is a problem that more than half of all the bridges in Russia were designed according to the old regulatory documents and need to be strengthened [3].

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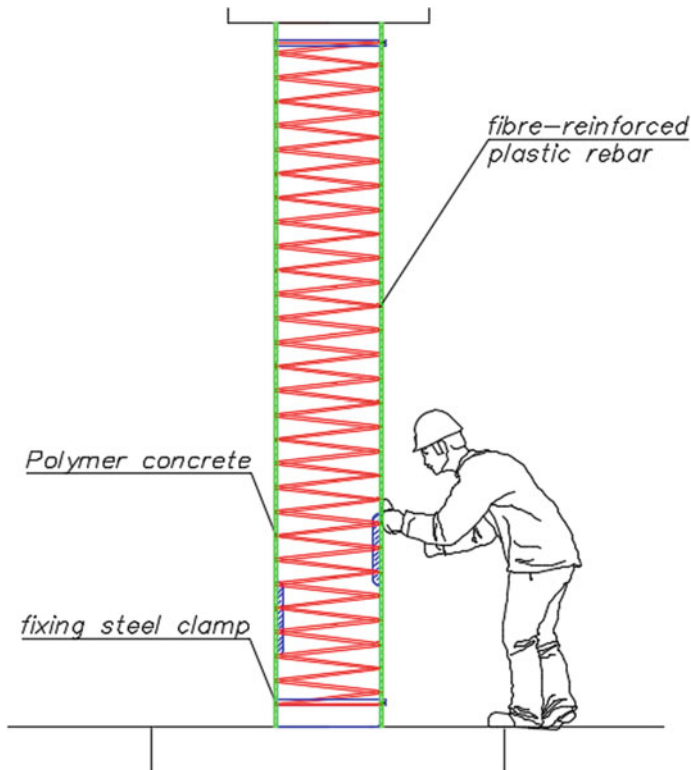
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An urgent task is fast and high-quality strengthening of columns with low economic costs. The problem of is solved when using a cage, usually made of steel or reinforced concrete. However, these materials have significant drawbacks compared to modern polymer composite materials, which are described in [4–8]. Therefore, it is proposed to strengthen the bridge columns with a spiral of fiberglass reinforcement, which is included in the work due to the local tension of the rod, and joint work and mechanical protection is ensured by applying the polymer concrete mixture using the thixotropic method (Fig. 1). Due to the chemical resistance, hydrophobicity and high adhesion of polymer concrete, the support structure is protected from the effects of aggressive media, and the power spiral of fiber-reinforced plastic rebar is securely fixed on the support body [9–11].

The technology of reinforcing columns of bridge structures with polymer composite materials has a number of advantages:

- reduction of economic costs for repair work;
- increase in the durability of the columns of bridge structures;



**Fig. 1** The design of the polymer composite reinforcement cage

- no need for protection from aggressive environments, especially at the level of the watercourse;
- reduction of terms of construction and installation works to strengthen the columns of bridges;
- low weight of the reinforcement cage structure, so there is no need to strengthen the foundation.

The aim of the reinforcement structure work is quite simple and consists in constraining the transverse deformations of concrete due to the outer shell. Research in this direction is carried out by both domestic and foreign scientists. There are works of V.A. Rosnovsky and D. Kendal in the area of pipe-concrete structures [12, 13]. Today, with the introduction of polymers in the construction, a large number of works are aimed at studying hybrid shells in the fiberglass (GFRP)-concrete-steel (DSTC) joint, in the cage when the shell becomes a permanent formwork for the construction of columns [14–17]. However, such structures cannot be used when strengthening the operated columns, therefore, it is necessary to provide a technological process for placing such cages [18].

## 2 Materials and Methods

Strengthening of reinforced concrete compressible columns, in order to increase their bearing capacity, is usually carried out in case of increasing the temporary load or extension of service life during repair work.

The polymer composite material creates a constant radial pressure on the element to be reinforced, elastically deforms until its fracture, and therefore exerts an increasing passive radial pressure on the concrete specimen under axial load. This process is well described in [18].

Due to the pretension and adhesion of fiberglass reinforcement with concrete, their joint work is ensured. In theory, it is possible to establish an identity between the relative deformations of concrete  $\varepsilon_c$  and reinforcement  $\varepsilon_k$  [19].

The equilibrium equations in a concrete sample can be written as follows:

$$\varepsilon_z = \frac{-\sigma_z}{E_1} + \frac{\sigma_p \cdot \mu_1}{E_1}, \quad (1)$$

$$\varepsilon_p = \frac{-\sigma_p}{E_1} + \frac{\sigma_z \cdot \mu_1}{E_1}, \quad (2)$$

$E_1, \mu_1$  – the elasticity modulus and Poisson's ratio of concrete, respectively;

$E_2, \mu_2$  – the elasticity modulus and Poisson's ratio of the polymer composite casing, respectively;

$\sigma_z, \varepsilon_z$  – stresses and strains in the material of the compressible sample, in the direction of the  $z$  axis, respectively;

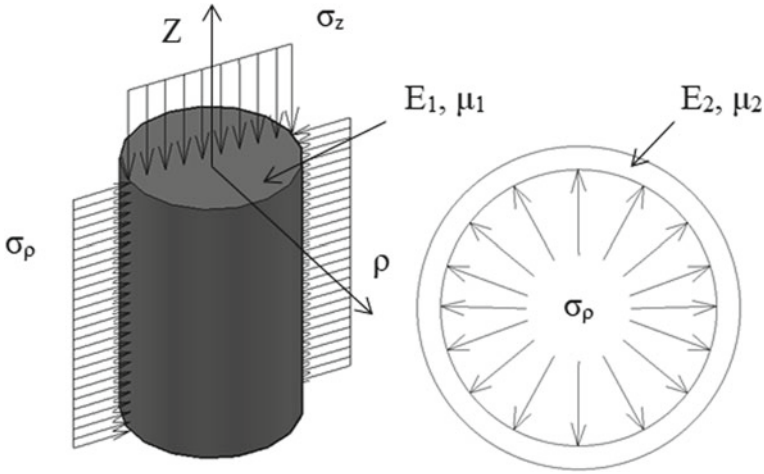


Fig. 2 3D calculation scheme of a column in a holder made of polymer composite materials

$\sigma_\rho, \varepsilon_\rho$  – radial stresses and strains in the material of the compressible concrete sample, numerically equal to the pressure exerted by the concrete sample on the cage, respectively.

Radial deformations can be represented as:

$$\varepsilon_p = \frac{\Delta r}{r_1} = \frac{r_2 - r_1}{r_1}, \tag{3}$$

where  $r_1$  is the radius of the central axis of the holder before deformation,  $r_2$  is the radius of the central axis of the cage after deformation. If  $l_1 = 2\pi r_1$  then the length of the circle running along the central axis of the cage before deformation; if  $l_2 = 2\pi r_2$  then the length of the circle running along the central axis of the cage after deformation. Then the deformations along the fibers of the cage, in accordance with the scheme, can be expressed as:

$$\varepsilon_p = \frac{l_2 - l_1}{l_1} = \frac{2\pi(r_2 - r_1)}{2\pi r_1} = \frac{\Delta r}{r_1} = \varepsilon_p, \tag{4}$$

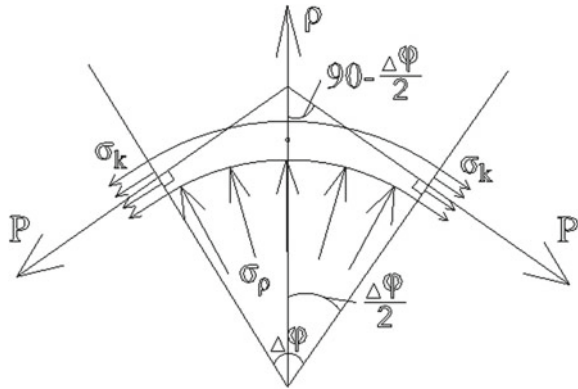
According to Hooke's law  $\sigma_k = E_2 \cdot \varepsilon_k$ .

Let us determine the radial stresses of the sample. We replace the stresses  $\sigma_k$  with the resulting force  $P$  (Fig. 3).

$$P = \sigma_k \cdot b \cdot h, \tag{5}$$

$b$  and  $h$  are the width and height of the cage, respectively. Let us assume that at small angles  $\varphi \rightarrow 0$ , then  $\sin \varphi \approx \varphi$  can be counted.

**Fig. 3** Calculation model of a sample with a cage in a horizontal plane



The equilibrium equation, in accordance with the model in Fig. 3, will look like:

$$\sigma_p \cdot \Delta\varphi \cdot b \cdot R = P \cdot \cos(90^\circ - \varphi/2) \cdot 2, \tag{6}$$

Following that it converts to:

$$\sigma_p = \sigma_k \cdot \frac{h}{R}. \tag{7}$$

As it has already been noted, we accept the equality of the deformation in the contact zone of the cage and the reinforced concrete sample  $\varepsilon_p = \varepsilon_k$  we have:

$$\sigma_k = E_2 \cdot \varepsilon_p, \tag{8}$$

We get

$$\sigma_k = h \cdot E_2 \cdot \frac{\varepsilon_p}{R}, \tag{9}$$

Using Eq. (9) we express  $\varepsilon_p$  in terms of  $\sigma_p$ , and we get:

$$\varepsilon_p = \frac{\sigma_p \cdot R}{E_2 \cdot h}. \tag{10}$$

We substitute Eq. (10) into Eq. (1) and express in terms of:

$$\sigma_p = \frac{\sigma_z \cdot \mu_1}{\left(\frac{E_1 \cdot R}{E_2 \cdot h} + 1\right)}. \tag{11}$$

Tensions  $\sigma_z$  are given as an external load distributed over the cross-sectional area of the sample,  $\sigma_p$  are calculated by formula (10). To determine the dependence  $\sigma_k$ , we use the following dependence:

$$\sigma_p = \frac{\sigma_z \cdot \mu_1 \cdot R}{\left(\frac{E_1 \cdot R}{E_2} + h\right)}. \quad (12)$$

Formula (12) allows analyzing the dependence of the tensions in the cage  $\sigma_k$  on the parameters  $\sigma_z$ ,  $E_1$ ,  $E_2$ ,  $R$ ,  $h$ .

It is reasonable to assume that the greater the pitch of the power spiral turns and the larger the diameter of the reinforcement, the greater the increase in the bearing capacity of the sample. The diameter of the reinforcement and the pitch of the turns should be set based on the design requirements for the twisting of the reinforcement around the column according to the formula:

$$d_a = \frac{d_k \cdot R_f}{E_f}, \quad (13)$$

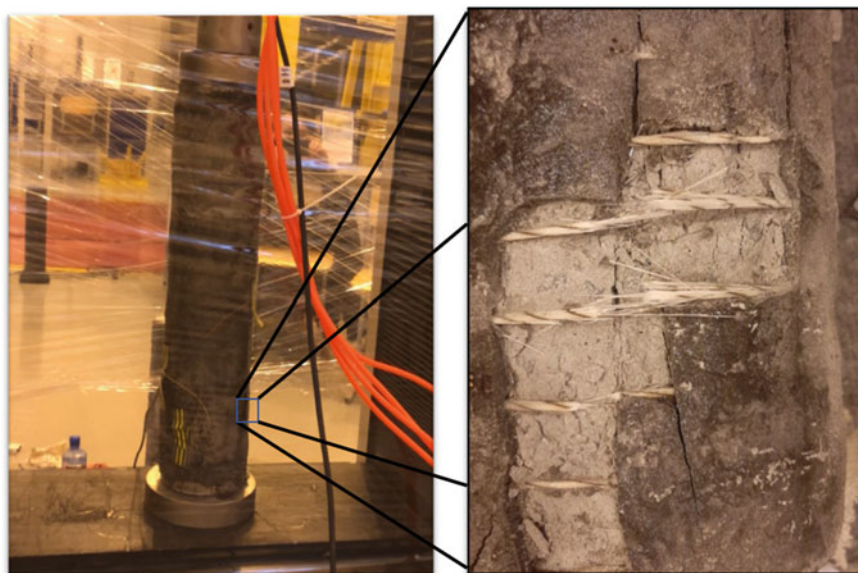
where  $d_a$  is the diameter of fiberglass reinforcement, mm;  $d_k$  is the diameter of the column, mm;  $R_f$  is the tensile strength fiberglass reinforcement, MPa;  $E_f$  is the tensile modulus fiberglass reinforcement, MPa.

### 3 Results and Discussion

In order to confirm the operation of a polymer composite cage and further study of its the stress–strain state, 10 samples with a diameter of 105 mm and height of 470 mm were made from fine-grained heavy concrete class B30, with working reinforcement of a periodic profile class A400, with a diameter of 6 mm. Five samples of the total number had reinforcement in the form of a spiral of glass fiber reinforced polymer (GFRP) with a diameter of 2.5 mm, located at a pitch of 20–25 mm and covered with polymer concrete 4 mm thick. (Fig. 4). Upon reaching the age of 28 days, the strength of the concrete was tested by a non-destructive ultrasonic method and using a hydraulic press. Load cells were installed on the samples with polymer composite cage to record the stresses in the concrete and fiberglass reinforcement.

The test results have shown that the reinforcement cage made of polymer composite materials operates together with the compressible sample and engages immediately after the load is applied to the sample. Polymer concrete reliably fixes the power spiral on the sample and redistributes stresses among all the turns of fiberglass reinforcement. The fracture of polymer concrete has a cohesive nature, and occurs along the material of the compressed sample (Fig. 4).

Comparing the two variants of samples, we noted a significant increase in the breaking load for samples with a polymer composite cage, which amounted to 60%

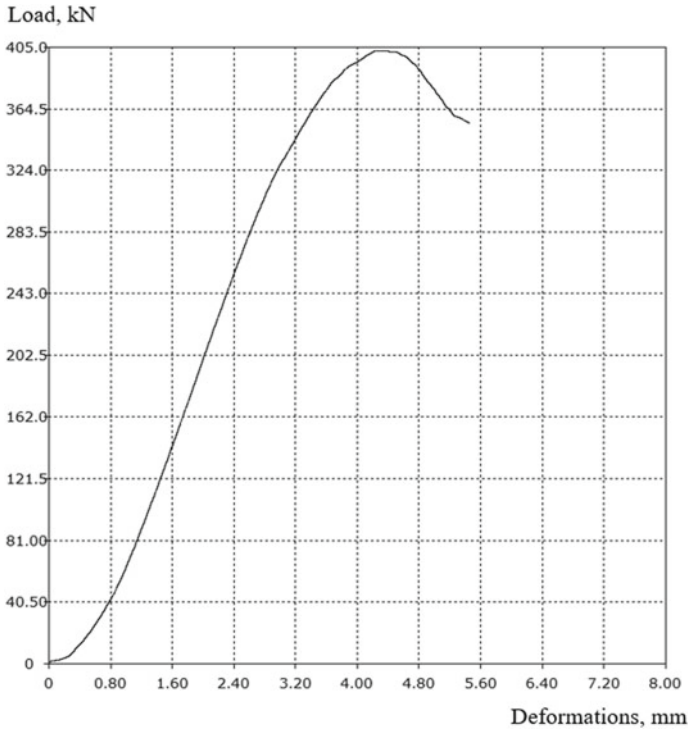


**Fig. 4** Testing a sample reinforced with a polymer composite cage

relative to unreinforced samples. The results of testing the samples are presented in Table 1. The authors have found that changing the pitch and diameter will affect the bearing capacity of the sample, which is proved using numerical simulation. It is also planned to use glass fiber reinforced polymer with sand dressing for better mechanical engagement with polymer concrete, as well as a decrease in the amount of hardener in the composition of polymer concrete for greater stress relaxation and less brittle destruction of the reinforcement cage. Analyzing the graph of the dependence of vertical deformations on the load during full-scale tests of compressible samples (Fig. 5), we note the appearance of a zone of plastic deformation, which demonstrates the ductile fracture of the sample reinforced by the cage.

**Table 1** Sample test results

Sample №	With cage					Without cage				
	1	2	3	4	5	1	2	3	4	5
$P_{max}$ – breaking load, κN	232.9	208.4	245.2	269.6	236.8	403.1	378.5	359.8	378.1	381.2
Average breaking load, κN	238.6					380.1				



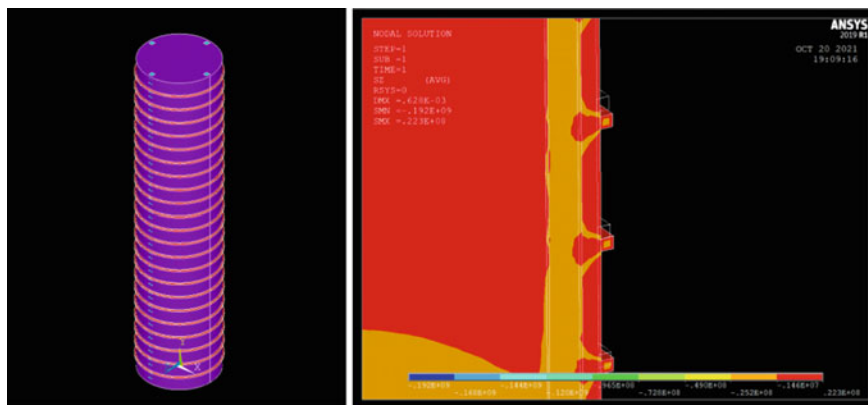
**Fig. 5** «Deformations – load» during full-scale tests of compressible samples

The problem of numerical study of the stress–strain state of a reinforced concrete cylinder in a polymer composite casing was solved by making and analyzing three-dimensional models of bridge columns created using the ANSYS software package. The numerical model of the sample is shown in Fig. 6.

In the sample model, the lower nodes have movement restrictions in all directions, to simulate the embedding of the rack in the grillage, and the upper nodes do not move along the Z axis. The applied longitudinal compressive force is implemented over the entire cross-sectional area of the sample.

The general results of numerical simulation and full-scale testing of samples demonstrate the adequacy of the model, since the vertical displacements have discrepancies of no more than 6%. In Fig. 6, one can see a clear distribution of stresses in the contact zone of concrete with fiberglass reinforcement, namely, the inclusion of only the outer fibers of the helix in the tensile work. Therefore, it is not recommended to take the diameter of the glass composite reinforcement more than 8 mm, due to the incomplete use of the reinforcement section. Another reason for limiting the diameter of the rod is the difficulty in winding the helix onto the column. The surface of interaction of fiberglass reinforcement and old reinforced concrete is a stress concentrator, therefore, there is a destruction of the protective layer of concrete at the points





**Fig. 6** Tension distribution in a 3D model of a compressible sample

of contact and a redistribution of stresses in the power spiral. The numerical model made it possible to reveal an increase in radial displacements in the sample, which were observed along the outer face in the interval of 0.1–0.3 of the sample height, which was well substantiated by the momentless theory of thin shells. When testing samples reinforced with a cage in this zone, crack development was observed and a break in the power spiral occurred.

## 4 Conclusions

The design solutions developed for the abutment reinforcement caging demonstrated good resistance to compressive forces. The breaking load of samples with a polymer-composite holder increased on average by 60%. The conducted studies prove that the developed reinforcement method can significantly increase the bearing capacity of a compressible structure, protect it from atmospheric and other types of influences. The developed calculation method takes into account the influence of the pitch of the turns of the power spiral and the diameter of the fiber-reinforced plastic rebar on the bearing capacity of the structure. The diameter of the reinforcement and the pitch of the turns are set based on the design requirements and the complexity of the work.

An analysis of numerical simulation results and full-scale testing of samples shows the true operation of the cage. Only the outer fibers of the fiberglass reinforcement of the spiral work in tension, therefore the diameter of the rebar for the power spiral must be limited to 8 mm. The helix pitch should be increased at an interval of 0.1–0.3 of the sample height from the embedment, in order to absorb the maximum tensile stresses in the rebar.

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