Comparison of the reinforcing concrete structures performance of hydraulic structures with carbon fiber composite material

I Maksudov¹, L Maksudova¹, A Abdukhalilov¹, A Bozorov¹ and R Mirzaliev¹

¹Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

white_angel3112@mail.ru

Abstract. Today, in the construction field, high-strength textile materials are increasingly practiced with the external reinforcement of structural elements. For the manufacture of textile externally reinforcing materials, they are mainly used: fiberglass, basalt, carbon fiber, and other high-strength fibers and threads. In combination with an epoxy or polyester matrix, they form an unconventional building material - carbon fiber. Carbon fiber - in comparison with conventional building materials, it has a number of indisputable advantages, such as high tensile strength, low specific gravity, high ability to resist corrosion. Carbon fiber is currently listed as the most promising material used in construction. However, its use is often limited by high prices for reinforcing material, because of this, the use of such material in the designs of large structures is economically irrational. The conclusion is made that it is necessary to determine the best reinforcement method in which the least amount of material is spent without loss of quality.

1. Introduction
In this article[1–3], comprehensive studies of typical sections of reinforced concrete beams made, strengthened, and investigated according to the principle that involves the use of factors that are subject to change — various configuration ratios and the percentage of steel and composite reinforcement — are carried out. Based on the findings, recommendations are made to improve existing calculation methods. The experimental data were studied on crack resistance, deformability and strength of reinforced concrete beams with working reinforcement class: A400, which were reinforced with three different types of multicomponent materials, where the percentages of composite and steel reinforcement were changed during the production and testing by similar technology.

Based on the geometric parameters and initial characteristics of the materials considered in the dissertation[4–8], samples are analyzed and the principles of stress distribution and the anisotropy of physical and mechanical features for general structures are revealed. In heat exchangers and fibrous multicomponent materials, a strong correlation is shown between the structure parameters and the magnitude and nature of the stress distribution. The method developed in the thesis shows significant efficiency both in terms of the accuracy of numerical results and in relation to the cost of computer time. In the process of creating optimal structural solutions for regenerative-type heat exchangers and new multicomponent materials of a fibrous structure, a set of programs for electronic computers has been created that allows calculations to be carried out in a short time.

A significant contribution to the study of methods for constructing models using mathematical methods for calculating and producing constructive multicomponent materials based on an inorganic
matrix was made by A. Kosolapov. He created and calculated mathematical models showing the general basis for obtaining multicomponent materials based on inorganic mass, based on the choice of initial components, methodological aspects of their combination into a single integral system with these characteristics, and ending with the predefinition and study of the properties of the composite.

In the dissertation, Pankova A.V. [9] defends a new reinforced concrete beam reinforcement construction (combined system), confirmed by a patent of the Russian Federation, which as a result is used in the reconstruction of reinforced concrete beams operated in industrial facilities of the city of Penza and the Penza Region. A highly efficient reinforcement structure for reinforced concrete beams has been developed based on existing technical solutions, without the need for auxiliary supporting elements that can significantly increase the strength and stiffness of the beam in the whole range of values of reinforcement ratios.

The author of the article [10–15] established a direct dependence on the development of inclined cracks and the nature of their formation, the type of fracture of the samples and their deformation mechanism on the method and percentage of reinforcement with steel reinforcement and composite. Increasing the strength characteristics of both types of reinforcement and the elastic modulus of composite materials, it should be taken into account that the number of cracks increases, but the average opening width decreases.

The object of study is a concrete prism reinforced with carbon fiber. The prism is made of cement grade M800 conformity to the concrete class B60 W8 F150 based on the laboratory of RENAISSANCE CONSTRUCTION CJSC according to GOST 27006-86. Concrete hardening was carried out under normal conditions (temperature 20 ± 2° C; relative humidity not lower than 95%) for 56 days. The main strength characteristics of concrete are concrete axial compression resistance $R_b$ and concrete axial tensile strength $R_{bt}$. The standard values of concrete resistance to axial compression (prismatic strength) and axial tensile (when assigning the concrete class to compressive strength) are taken depending on the concrete class according to table 6 and 7. SP 63.13330. For concrete grade B60, the standard values of concrete resistance to axial compression $R_b$ (heavy fine-grained and tensile) were determined. As well as the standard values of concrete resistance to axial tension $R_{bt}$ (heavy fine-grained and tensile). The cross-section of the concrete prism and its geometric characteristics are determined by the form of manufacture of the samples in the form of a prism following State standart 22685-89 (Sample FP-100) and are shown in figure 1.

The main parameters and dimensions of the $FP-100$ form are determined following table 1.

| Table 1. The main parameters and dimensions of the forms |
|--------------------------------------------------------|
| Sizes, mm | Form weight, kg, no |

Figure 1. Forms for the manufacture of samples in the form of a prism (beam)
Following the above data, the following characteristics of the concrete prism are determined:

- standard values of concrete resistance to axial compression $R_b = 43$ MPa;
- standard values of concrete resistance to axial tension $R_{bt} = 2.75$ MPa;
- length of the considered prism 400 mm;
- width of the considered prism 100 mm;
- height of the considered prism 100 mm;

As a reinforcement of the concrete prism, the FibArm Tape – 230/300 carbon fabric was chosen. For cutting fiber, scissors or a sharp knife were used. It was not allowed to hit the fiber with sand, dust, water, oils, solvents, or other foreign substances as directed by the manufacturer. All carbon fiber specifications are given in table 2.

| Shape mark | more | from | aluminum alloys |
|------------|------|------|-----------------|
|            | $a(d)$ | $l$ | $h$ | steel | - |
| 1FK-150    | 150 | - | - | 8.0 | 3.5 |
| 1FK-200    | 200 | - | - | 15.5 | - |
| 1FK-300    | 300 | - | - | 35.0 | - |
| 2FK-100    | 100 | - | - | 7.5 | 3.0 |
| FP-100     | 100 | 400 | - | 12.5 | - |
| FP-150     | 150 | 600 | - | 28.0 | - |
| FP-200     | 200 | 800 | - | 60.0 | - |
| FC -100    | 100 | - | 200 | 5.0 | - |
| FC -150    | 150 | - | 300 | 8.0 | - |
| FC -200    | 200 | - | 400 | 22.0 | - |
| FC -300    | 300 | - | 600 | 45.0 | - |

Since the test was carried out on a four-point bend and the angle fiber was supposed to be glued in the stretched zone of the concrete prism, the main purpose of the carbon fiber is to increase the bearing capacity by reducing the stretching of concrete. For this, unidirectional carbon fiber was chosen. The form of weaving is shown in figure 3.
The adhesive used was “EDP” epoxy adhesive (TU 2385-012-54804492-2002), made of “ED-20” epoxy resin (epoxy-diane) (State standard 10587-84), PEPA hardener (polyethylene polyamine) (TU 2413-066-1877143-15), plasticizer DEG-I (diethylene glycol) (State standard 10136-77). The ratio between the compositions of the epoxy adhesive is 50: 5: 2. The ratio between carbon fabric and the epoxy adhesive is 60:40.

2. Methods
The test, made of concrete samples reinforced with carbon fiber, for tensile bending due to destructive short-term, four-point static loads, was carried out at "Hydraulic Press PSU-50A" (fig. 4). The press is made following State standard 28840 and is intended for static compression tests of standard samples of building materials.

Three methods of reinforcing concrete samples were chosen for testing. For each method, concrete of the same batch was used, the same hardening conditions, identical carbon fabric, and epoxy resin, the same number of layers. Samples differ from the sticker method and the amount of carbon fiber. Carbon label sticker methods are shown in Figures 5 – 7.
Fig. 4. Method "A" reinforcement only at the bottom of the concrete prism (stretched zone).

Fig. 5. Method "B" 25mm overhang gain

Fig. 6. Method "B" reinforcement with 50 mm side anchors
In all cases, first of all, a layer of epoxy was applied to concrete. Then, with an interval of 30 minutes, two layers of carbon cloth were glued. In method “B”, carbon fiber anchors were also glued in two layers with an interval of 30 minutes. All samples were brought to full hardening of epoxy glue and kept for 5 days at 50°C in a laboratory furnace, which increases the curing speed of epoxy glue.

The sample was installed in a testing machine according to the scheme in fig. 8 – 10 and was loaded to failure at a constant rate of rising of the load of 0.05 ± 0.01 MPa/s.

Figure 7. Scheme of bending tensile test; \( a \) is height and width of samples; \( F \) is load; \( q \) is distributed load; \( l \) is span; 1 is sample; 2 is pivotally motionless support; 3 is pivotally movable support.

Figure 8. Diagram of a device for tensile testing in bending.
3. Result and Discussion

As a result of an experimental study, destructive loads for concrete and all reinforcement methods were identified. The results are shown in Table 3.

Table 3. Test Results

| №  | Sizes, mm | P, kN |
|----|-----------|-------|
|    | b  | h  | l  |     |
| Et-1 | 100 | 100 | 300 | 22.23 |
| Et-2 | 100 | 100 | 300 | 23.57 |
| Et-3 | 100 | 100 | 300 | 25.57 |
| A-1 | 100 | 100 | 300 | 100.5293 |
| A-2 | 100 | 100 | 300 | 74.42884 |
| B-1 | 100 | 100 | 300 | 58.37 |
| B-2 | 100 | 100 | 300 | 89.15 |
| V-1 | 100 | 100 | 300 | 104.54 |
| V-2 | 100 | 100 | 300 | 117.93 |

4. Conclusions

The results of the experimental study were far from theoretical calculations. The reason was the insufficient adhesive property of the epoxy adhesive, which led to the creep of the carbon fabric. With high creep of carbon fabric, it detaches from concrete and leads to the destruction of samples.

According to SP 164.1325800.2014, the destruction of a concrete structure by reinforced carbon cloth occurs when the breaking load reaches the calculated tensile strength (calculation is given in Appendix A) of the composite material. As several experimental studies show, this statement is not valid.

Application A

The preliminary calculated value of tensile strength should be determined by the formula with a coefficient $\gamma_f = 1.0$:
\[ R' = \frac{\gamma_f_1 \cdot \gamma_f_2 \cdot R_{f,n}}{\gamma_f} = \frac{0.8 \cdot 1 \cdot 400 \cdot 10^6}{1.2} = 266.666 \text{ MPa} \]  

where: \( R_{f,n} \) are standard values of tensile strength determined by a series of tests of samples of composite material carried out earlier and equal 400 MPa. (State standard 25.601-80)

\( \gamma_f \) is the reliability coefficient for the composite material, taken when calculating the limit states of the second group equal to 1.0, and when calculating the limit states of the first group equal to:

- 1.2 - for carbon composite;
- 1.8 - for glass composite.

\( \gamma_f_1 \) - coefficient of the working conditions of the composite material taken according to table 3 (SP 164.1325800.2014) depending on the type of composite material and the operating conditions of the structure. The operating conditions of hydraulic structures are in aggressive environments. Construction operating conditions: in an aggressive environment \( \gamma_f_1 = 0.8 \)

Further determined \( \varepsilon_{f,ult} \) - the value of the ultimate relative deformations of the composite material:

\[ \varepsilon_{f,ult} = \frac{R'_f}{E} = \frac{266,666 \cdot 10^6}{245 \cdot 10^9} = 0.0001 \]  

\( \gamma_f_2 \) is the coefficient of the working conditions of the composite material, taking into account the adhesion of the composite material with concrete, determined by the formula:

\[ \gamma_f_2 = \frac{1}{2.5 \varepsilon_{f,ult}} \left( \frac{R_b}{nE_f t_f} \right) = \frac{1}{2.5 \cdot 0.0001} \left( \frac{45 \cdot 10^6}{2 \cdot 245 \cdot 10^9 \cdot 0.22} \right) = 0.8 \leq 0.9 \]  

here: \( \varepsilon_{f,ult} \) is the value of the ultimate relative deformations of the composite material, determined by the formula (2) with the value \( R'_f \), calculated by the formula (1), for \( \gamma_f_2 = 1.0 \)

\( n \) is the number of layers of the composite material is 2;

\( t_f \) is the dimensionless parameter, numerically equal to the thickness of one layer of the composite material, according to the passport of the carbon fabric equal to 0.22 mm;

\( E_f \) is the elastic modulus of the composite material equal to 245 GPa for unidirectional carbon fabric FibArm 230/300;

\( R_b \) is the calculated value of concrete resistance to axial compression, adopted for concrete B60 equal to 40.85 MPa;

The calculated value of tensile strength is determined by the formula:

\[ R_f = \frac{\gamma_f_1 \cdot \gamma_f_2 \cdot R_{f,n}}{\gamma_f} = \frac{0.8 \cdot 0.8 \cdot 400 \cdot 10^6}{1.2} = 213.3 \text{ MPa} \]
References
[1]. Bokarev S A 2010 Experimental studies of flexible concrete elements reinforced with composite materials Construction 2 pp 112–124
[2]. Chajes M J and Finch W W 1999 Bond and force transfer of composite material plates bonded to concrete ACI Struct 93 pp 295–303
[3]. D N 2010 Assessment of the bearing capacity of reinforced concrete bridge spans reinforced with composite materials (Novosibirsk)
[4]. David E 1997 Repair and strengthening of reinforced concrete beams using composite Faults and Repair pp 169–173
[5]. Dyachkova A A 2009 Calculation of reinforcement of reinforced concrete slabs with carbon composite materials Civ. Eng. 3 pp 25–28
[6]. Ehasani M R 1996 Design recommendation for bond of glass fiber reinforced polymer rebar to concrete Struct. Eng. 102 pp 125–130
[7]. Grace N F and Abdel-Sayed G 2002 Strengthening of concrete beams using innovative ductile fiber- fiber reinforced polymer fabric ACI Struct 99 pp 692–700
[8]. Kishinevskaya E V and Vatin N I 2009 Reinforcement of building structures using post-stressed reinforced concrete Civ. Eng. 3 pp 29–32
[9]. A V P 2010 Strength and deformability of reinforced concrete beams reinforced with a combined system with various design parameters
[10]. Kurlapov D V, Kuvaev A S, Rodionov A V 2009 Reinforcement of reinforced concrete structures using polymer composites. Civ. Eng. 3 pp 22–24
[11]. Mayatskaya I A 2017 Strengthening the structures of architectural monuments using polymer composite materials. Int. Res. 5 pp 58–61
[12]. Morozova T S and K V D External reinforcement of reinforced concrete columns with carbon fiber-based composite material. Civ. Eng. 3 pp 35–38
[13]. Paranicheva N V 2010 Strengthening building structures using carbon composite materials. Civ. Eng. 2 pp 19–22
[14]. Shilin A A and Gaponov V V 2017 Restoring the bearing capacity of the ring lining of tunnels using high-strength carbon fiber nets. Mod. Res. Transp. Sect. 3 pp 466–477
[15]. V I 2001 Damage and methods for calculating the reinforcement of reinforced concrete structures