To the Issue of Strengthening the Monolithic Reinforced Concrete Slab with Carbon Canvases

R Aralov¹, V Rimshin¹

¹Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

Abstract. The main issue of the study is the modern ways to improve the bearing capacity of building structures. As one of these methods may be strengthening composite materials. Structural degradation of reinforced concrete structures is largely due to their composite base. The aim of the study is a systematic integrated approach to solving the problem of improving the reliability of structures through the use of composite materials. The main advantages and disadvantages of composites are considered. Their classification by type of reinforcing element is given. The main areas of application of composites in construction – in the composition of plastics, concrete, aluminum panels. Approval of methodical provisions is carried out by calculation of a reinforced concrete plate (δ=0,3 m) in the program complex of the SCAD PC. The gain calculation was performed by the finite element method. The purpose of the calculation was to observe the stress-strain state of the plate before and after its strengthening, to check the correctness of the external composite reinforcement. The calculation results showed that in the case of composite reinforcement in the plate there is a decrease in vertical deformations (about 1.1%) and tensile stresses (1.5%). Conclusions: the results show the feasibility of using composite materials to improve the bearing capacity of building structures.

1. Introduction

Time influence, atmospheric effects and anthropogenic factors lead to a decrease in structures bearing capacity and buildings as a whole. Therefore, the question of choosing design solutions for enhancing damaged structures is always relevant [1].

Nowadays, one of the most popular tools used in the construction industry, is the strengthening with composite materials.

Composite material (showed in Figure 1) is a heterogeneous material, there are reinforcing elements and a matrix (binder) among its components. The task of reinforcing elements is to create the necessary mechanical material characteristics, and the matrix, in turn, ensures their joint operation.

Corresponding author: Aralov.fkr@mail.ru
2. Methods

Composite materials are classified by reinforcing element type into: skeletal, filled plastics, layered, fibrous, and bulk [2].

Since January 1, 2014, GOST 31938-2012 was introduced for composite fiberglass reinforcement, which allows to regulate its use in civil and industrial construction. This regulatory document establishes the General technical conditions and applies to composite reinforcement of periodic profile [3].

Composites reinforced with extra-strong continuous fibers: polymer composites based on thermosetting (epoxy, polyester, phenolic-formaldehyde, polyamide) and thermoplastic binders reinforced with glass fiber, carbon fiber, organic and other fibers are the most interesting for construction [4].

There are the main advantages and disadvantages of this construction material. The main advantages are: high specific strength, high material stiffness, high resistance, high fatigue strength, the ability to manufacture dimensionally stable designs.

There are the disadvantages: high price, this material use requires increased knowledge-intensive production (expensive equipment and raw materials).

Since the beginning of 2015 began to introduce the state Standards (GOST 32656-2017, 57921-2017 GOST R, GOST R 56654-2015, GOST 32492-2015) methods to determine the characteristics of durability, resistance, determination of physical-mechanical and strength characteristics. All this helps to improve the quality of plastic fittings produced by different manufacturers [5-8].

Due to the high coefficient of efficiency, low weight and high final cost, composites are gaining increasing popularity in the construction industry and are replacing traditional concrete, steel and plastics.

Composites and plastics. According to its characteristics, composites are closest to plastics, but in some cases are much superior to them. There is comparison the properties of plastics and composites in Table 1. Such composites are often used to strengthen building structures [9].
Table 1. Comparison of the of purified plastics and composites properties.

| Characteristic          | Purified plastic | Polyurethane | Epoxy resin with unidirectional carbon fibers | Thermosetting plastic with fiberglass |
|-------------------------|------------------|--------------|--------------------------------------------|-------------------------------------|
| Fiberglass content, %   | -                | 15           | 65                                         | 10 – 20                             |
| Material density, g / cm³ | 1,3              | 1,2          | 1,6                                        | 1,7–2                               |
| Tensile strength, MPa   | 70 – 80          | 20 – 27      | 1,500 – 3,000                             | 30 – 40                             |
| Stretching at break, %  | 5                | 0,8 – 2      | 0,6 – 1,8                                 | -                                   |
| Bending modulus, GPa    | 3,3              | 0,8-1,3      | 1-4                                        | 5-11                                |
| Izod impact index, J / m^1/70 | 160 – 430    | -            | 260 – 400                                 |                                     |

It should be noted that as the reinforcement of the polymer increases, its mechanical efficiency increases (Figure 2).

Figure 2. Dependence of plastics mechanical efficiency on polymer reinforcement.

Composites and concrete. The composites advantages are particularly noticeable in reinforcing and strengthening concrete structures. It is known that concrete perceives compressive forces well, but poorly - tensile. Stretching leads to cracks so the structure absorbs water, which causes corrosion of the reinforcement and concrete and metal poor adhesion. Since composite reinforcement has good corrosion resistance, the composites use for reinforcement of concrete is more appropriate [10].

Another way to improve the concrete properties is short composite fibers use. Such reinforcement increases the concrete strength and elasticity, as composite fibers are able to hold part of the load when the matrix is damaged, thereby preventing cracks [11].

Aluminum composite panels. These panels are a composite filler located between a pair of aluminum sheets. This building material has some advantages due to its structure: small weight in aggregate with high rigidity. In this regard, this material is perfect for building facades. Panels manufacturing technology involves the top layer by rolling, so a panel is able to withstand twisting forces. Opposition paintwork to environmental influences. Color intensity is maintained for a long time. Aesthetic look. Panels are available with a varnish-and-paint coating in a huge number of shades. In addition, the panel easily takes any form. High wear resistance (due to the complex structure of the panels) for many years. The average lifetime is about 50 years. Resistance to corrosion processes - aluminum sheets are protected by a multi-layer paint and varnish coating. Good sound insulation. The
panels absorb sound waves and vibrations due to their composite filler. Panels almost do not require maintenance during operation (they have the ability to self-clean) [12-16].

These structures are used in the construction of facades of buildings, execution of interior cladding works, fabrication of stands and signage etc In our country manufacturer of such panels is engaged in the manufacturer "Bildex" on the basis of the technical conditions TU 5775-002-79089084-2013 "Aluminum composite panel". [17]

As an example of composites use in construction, we consider the monolithic reinforced concrete slabs strengthening (δ = 0.3 m) with carbon canvases. The slab is based on monolithic reinforced concrete columns with a section of 0.4x0.4 m, located with a step of 8 m in all directions. Strengthening calculation is performed by the finite element method in the SCAD. The calculation model is shown in Figure 3.

**Figure 3.** Calculation slab model in SCAD.

The calculation purpose is monitoring the stress-strain state of the slab before and after its strengthening, checking the correctness of the external composite reinforcement.

It is assumed that the forces in the compressed zone will be perceived by concrete and compressed reinforcement in the limiting state of the bent element, and in the stretched one, by reinforcing rods and composite tapes [18-21].

The slab strengthening is made by sticking composite tapes along the perpendicular to the axis of the structure on the bottom surface. The external reinforcement inclusion of carbon fiber in the operational state occurs due to the prestressing system use. This system allows to bend the slab up (tension), and then glue the external reinforcement, which subsequently take on the tensile force and provide the carrying capacity of the reinforced slab.

SikaWrap530C (VP) carbon fiber fabric and epoxy glue Sikadur-330 were used as materials for reinforcement [14]. Their characteristics are given in Table 2.

**Table 2.** Materials characteristics.

| Indicator                | Carbon fiber SikaWrap530C (VP) | Epoxy glue Sikadur-330 |
|--------------------------|-------------------------------|------------------------|
| Thickness                | 0.293 mm                      | -                      |
| Width                    | 0.3 m                         | -                      |
| Weight                   | 530 g/m²                       | -                      |
| Elastic modulus index    | 231 kN/mm²                     | -                      |
| Tensile strength index   | 3800 N/mm²                     | 3800 N/mm²             |
| The percentage of deformation at break | 1.64%                      | 1.64%                  |
Material density 1.8 g/cm³
Compressive strength - 65 N/mm²
Shear strength - 6 N/mm²
Adhesion to concrete - 4 N/mm²

The total elasticity modulus adopted for calculation is 63 kN/mm². A step carbon fiber plate is taken as 12 cm in all directions. Since it is assumed that the slab is under long-term load action, the elasticity modulus of the concrete was reduced to 8600 MPa.

Here you can make a conclusion about reliability, quality and safety. Increase safety, reduce the likelihood of hazardous events and reduce unprofitability allows a qualitative assessment of engineering risk and the implementation of measures to prevent and minimize risks in the enterprise. [22-26]

3. Results and discussion
Reinforced concrete slab was calculated before and after strengthening with composite materials. The results are shown in Figure 4.

Figure 4. Vertical deformations from the slab weight: above - before strengthening, below - after strengthening (central part).
It is seen that there is a decrease in vertical deformations (by about 1.1%) and tensile stresses (by 1.5%) in the slab in the second case. [27-30]

4. Conclusions
The conducted researches allow to draw the following conclusions:
- composite materials are gaining more and more popularity in construction due to the high coefficient of performance, light weight and high final cost. Composites can be used in plastics, concrete, aluminum panels.
- since composite reinforcement has good corrosion resistance, the use of composites in the reinforcement of concrete is more appropriate, both in the process of construction and its repair.
- the expediency of using composite materials to increase the bearing capacity of building structures is proved by calculating the reinforced concrete slab ($\delta=0.3$ m) in the SCAD PC software package. At the same time, the calculation results showed that in the case of composite reinforcement in the plate there is a decrease in vertical deformations (by about 1.1%) and tensile stresses (by 1.5%).

References
[1] Kablov E N 2012 Strategic directions of development of materials and technologies for their processing for the period up to 2030 Aviation materials and technologies 8
[2] Malnati P 2011 A hidden revolution: FRP rebar gains strength Composites Technology 12
[3] Interstate standard GOST 31938-2012 (is based on ISO 10406-1:2008, NEQ) Composite polymer reinforcement for reinforcement of concrete structures
[4] Kuzina E, Cherkas A, Rimshin V 2018 Technical aspects of using composite materials for strengthening constructions IOP Conference Series: Materials Science and Engineering 365(3) 032053
[5] N9 1690-st Interstate standard GOST 32656-2017 (ISO 527-4:1997, ISO 527-5: 2009) was introduced as a national standard Polymer composites Test method Tensile test Actualization 01.01.2018 Last modified date 12.09.2018
[6] National standard Russian Federation GOST R 57921-2017 Polymer composites Test methods General requirements Actualization 01.01.2018 Last modified date 12.09.2018
[7] National standard Russian Federation GOST R 56654-2015 Polymer composites A method for determining the density of materials of the inner layer of sandwich structures Actualization 07.08.2016 Last modified date 12.09.2018
[8] Interstate standard GOST 32492-2015 Composite polymer reinforcement for reinforcement of concrete structures Methods for determining physical and mechanical characteristics Actualization 07.08.2016 Last modified date 10.12.2018
[9] Cherkas A, Rimshin V 2017 Application of composite reinforcement for modernization of buildings and structures MATEC Web of Conferences 117 00027
[10] Grashchenkov D V, Chursova L V 2012 Development strategy of composite and functional materials Aviation materials and technologies 8
[11] Erofeev V T, Zavalishin E V, Rimshin V I, Kurbatov V L, Stepanovich M B 2016 Frame composites based on soluble glass Research Journal of Pharmaceutical, Biological and Chemical Sciences 7(3)
[12] Khudyakov V A, Proshin A P, Kislitsyna S N 2007 Modern composite materials M.: DIA
[13] Telichenko V, Rimshin V, Kuzina E 2018 Methods for calculating the reinforcement of concrete slabs with carbon composite materials based on the finite element model IOP Conference Series: Materials Science and Engineering 463(3) 032024
[14] Varlamov A A, Rimshin V I, Tverskoi S Y 2018 The General theory of degradation IOP Conference Series: Materials Science and Engineering 463(2) 022028
[15] Krishan A L, Rimshin V I, Astafeva M A 2018 Deformability of a Volume-Compressed
Concrete *IOP Conference Series: Materials Science and Engineering* **463**(2) 022063

[16] Telichenko V, Rimshin V, Eremeev V, Kurbatov V 2018 Mathematical modeling of groundwaters pressure distribution in the underground structures by cylindrical form zone *MATEC Web of Conferences* **196** 02025

[17] The technical conditions  **TU 5275-002-79089084-2013** "Aluminum composite panel" of the manufacture Bildex Actualization 12.04.2017

[18] Varlamov A A, Rimshin V I, Tverskoi S Y Planning and management of urban environment using the models of degradation theory *IOP Conference Series: Earth and Environmental Science* **177**(1) 012040

[19] Rimshin V I, Labudin B V, Melekhov V I, Orlov A, Kurbatov V L Improvement of strength and stiffness of components of main struts with foundation in wooden frame buildings *ARPN Journal of Engineering and Applied Sciences* **13**(11)

[20] Varlamov A A, Rimshin V I, Tverskoi S Y 2018 Security and destruction of technical systems *IFAC-PapersOnLine* **51**(30)

[21] Rimshin V I, Varlamov A A 2018 Three-dimensional model of elastic behavior of the composite *Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Tekhnologiya Tekstil'noi Promyshlennosti* **3**

[22] Borkovskaya V G 2014 Complex models of active control systems at the modern developing enterprises *Advanced Materials Research* **22** Manufacturing Management and Engineering Management pp 3012-3015 DOI: 10.4028/www.scientific.net/AMR.945-949,3012

[23] Borkovskaya V G 2013 The concept of innovation for sustainable development in the construction business and education *Applied Mechanics and Materials* **15** Engineering Management pp 1703-1706 DOI: 10.4028/www.scientific.net/AMM.475-476.1703

[24] Borkovskaya V G, Passmore D Behavioral engineering model to identify risks of losses in the construction industry Advances in Economics, Business and Management Research (France-Netherlands) *Atlantis Press In press*

[25] Borkovskaya V, Passmore D 2018 Application of Failure Mode and Effects Analysis in Ecology in Russia *MATEC Web of Conferences* **193** 05027 DOI: https://doi.org/10.1051/matecconf/201819305026

[26] Borkovskaya V G 2018 Project Management Risks in the Sphere of Housing and Communal Services *Journal MATEC Web of Conferences* **251** 06025 DOI: https://doi.org/10.1051/matecconf/201825106025

[27] Krishan A L, Rimshin V I, Telichenko V I, Rakhmanov V A, Narkevich M Yu 2017 Practical implementation of the calculation of the bearing capacity trumpet-concrete column *Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Tekhnologiya Tekstil'noi Promyshlennosti* **2**

[28] Bazhenov Y M, Erofeev V T, Rimshin V I, Markov S V, Kurbatov V L 2016 Changes in the topology of a concrete porous space in interactions with the external medium *Engineering Solid Mechanics* **4**(4)

[29] Karpenko N I, Eryshev V A, Rimshin V I 2018 The Limiting Values of Moments and Deformations Ratio in Strength Calculations Using Specified Material Diagrams *IOP Conference Series: Materials Science and Engineering* **463**(3) 032024

[30] Bazhenov Y M, Erofeev V T, Rimshin V I Markov S V, Kurbatov V L 2016 Changes in the topology of a concrete porous space in interactions with the external medium *Engineering Solid Mechanics* **4**(4)