Laboratory Tests Analysis of Reinforced Concrete Structures Strengthened with CRFP

Vladimir Rimshin 1, Ekaterina Kuzina 1

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

kkuzzina@mail.ru

Abstract. Modern construction industry is constantly evolving and improving. Therefore, new opportunities are used to solve the constantly emerging new problems. One of the modern innovations in these areas is the use of carbon-fiber nonwoven fabric for strengthening structures and composite materials. Carbon fibers have several advantages in increasing the bearing capacity of the structure: high modulus of elasticity (240-640 GPa) and tensile strength (2500-4000 MPa), minimal coefficient of thermal expansion (approximately 50 times less than steel), high fatigue characteristics, excellent resistance to aggressive environments, withstands many cycles of «freeze-thaw». One of the promising areas for the development for strengthening concrete structures with carbon fiber materials is prestressed carbon fiber reinforced plastic system. This area has a great potential for use in reinforced concrete structures, most often in pavements: to reinforce overloaded elements, external reinforcement of structures with corroded pre-stressed reinforcement, repair of structural nodes. The article reviews and analyzes the laboratory tests result of reinforced concrete structures (slabs and beams), reinforced with prestressed carbon, as well as non-stressed laminates.

1. Introduction

The design and production of reinforced concrete building elements is based on the forces and loads acting on the structure. These loads are fixed in various building codes. However, the load on the structural elements may vary during the operation of a building or structure, often for the following reasons: changes in the design, changes in seismic and fire resistance design data, increased loads on the structure, repetitive effects of loads over time, alternate freezing and thawing as a result of changes in temperature and humidity of the environment at different times of the year, creep and shrinkage of concrete, leading to the formation and development of cracks and redistribution efforts in reinforced concrete structures, prolonged action of loads that can lead to compaction or loosening of concrete, leaching - the first type corrosion (dissolving and removing cement component of limestone from the structure), a surface layer carbonization of reinforced concrete, so concrete loses the ability to protect steel reinforcement from corrosion, reinforcement corrosion, temperature differences characterized by diurnal temperature amplitudes and the total number of days with a transition temperature at 0°C. These processes lead to a change in the stress state of the structure and indicators of its potential carrying capacity in operation [1-4].

Increasing the load on the structure is a prerequisite for developing a comprehensive solution to this problem. Traditional reinforcement methods include the use of gunned concrete with additional
reinforcement, installation of additional external reinforcement, external pre-tension, installation of additional support columns and beams, installation of external steel clamps for gain in shear.

As an alternative to traditional methods, carbon-fiber composites can be used [5]. Reinforcing steel and fiber composites have different physical properties. While steel shows itself as an ideal elastic-plastic material, all composite reinforcement systems are linear-elastic. These differences must be taken into account when designing. The fibers of the composite system are combined into a unidirectional or bidirectional matrix. CFRP composites are used to modify existing reinforced concrete structures. Various types of carbon fiber materials are used to reinforce structures in construction practice. These include unidirectional and bidirectional canvases, unidirectional and bidirectional fabrics (cold and thermal epoxy resin polymerization), lamellas.

2. Materials and methods

**Unidirectional canvases.** The longitudinal fibers are bonded together and are delivered in the form of canvases. Parallel fibers are tensioned before binding, which gives canvases a high modulus of elasticity. They are particularly well increase the element stiffness.

**Bidirectional canvases.** In woven canvas fiber have a wavy shape. Therefore, this product is poorly suited to increase the structure rigidity. Bidirectional canvases are well suited for increasing the plasticity of a reinforced concrete element [6].

**Unidirectional and bidirectional fabrics.** Cold or thermal polymerization of epoxy resin [6] is used to ensure the transfer of load on the canvas.

**Cold polymerization of epoxy.** It is used for dry installation of unidirectional and bidirectional canvases with a basis weight of up to 400 g/m2. Application method: cold polymerizable resin is applied to the structural element. Then clean canvas is glued to the structure. For stretched and woven fabrics with a density of 400-800 g/m2 is applied wet sticker. The canvases are impregnated with glue and glued onto the reinforced concrete element [13,14].

**Thermal polymerization of epoxy resin.** Unidirectional and bidirectional canvases are impregnated with thermally polymerized epoxy adhesive and delivered to the site at low temperatures. Thermal polymerization is completed by heat treatment of epoxy resin on the structure. This type of composite material is called prepreg and is commonly used in the aircraft and sport industries. The prepreg system is not recommended for strengthening concrete structures [7-9].

**Lamels (carbon fiber plates).** The carbon fiber plates are supplied to the construction site in the form of a composite. Fiber impregnation with resin and thermal polymerization is carried out by the manufacturer in the factory [9,10].

Modern construction industry is constantly evolving and improving. Therefore, new opportunities are used to solve the constantly emerging new problems. One of the modern innovations in these areas is the use of carbon-fiber nonwoven fabric for strengthening structures and composite materials.

Carbon fibers have several advantages in increasing the bearing capacity of the structure: high modulus of elasticity (240-640 GPa) and tensile strength (2500-4000 MPa), minimal coefficient of thermal expansion (approximately 50 times less than steel), high fatigue characteristics, excellent resistance to aggressive environments, withstands many cycles of «freeze-thaw».

One of the promising areas for the development for strengthening concrete structures with carbon fiber materials is prestressed carbon fiber reinforced plastic system. This area has a great potential for use in reinforced concrete structures, most often in pavements: to reinforce overloaded elements, external reinforcement of structures with corroded pre-stressed reinforcement, repair of structural nodes [11,12].

**Figure 1** shows the stages of installation of a prestressing system.
Figure 1. Installation of prestressing system

Figure 2 shows the complication of carbon prestressed fiber system.

Figure 2. Complement of prestressed CFRP

Reinforced concrete slabs tests: The behavior of slabs reinforced with prestressed carbon plastics was studied during a series of tests conducted at the University of Friborg (Switzerland). All tests were carried out using a material with a section of 80x1.2 mm.

Test conditions: Figure 3 shows the test scheme of reinforced concrete slabs.

Figure 3. Test Scheme

Figure 4. Cross section of reinforced structure
Table 1 presents the characteristics of the reinforcement samples.

| Sample                  | Reinforcement | FRP           | Preload, %o | Prestress, MPa | Tension force, kN |
|-------------------------|---------------|---------------|-------------|-----------------|-------------------|
| LC1 without strengthening | Ø12 Ø8 s=150 | 0             | 0           | 0               | 0                 |
| LC5 FRP                 | Ø12 Ø8 s=150 | 2 lamellas S&P CFK | 0   | 0               | 0                 |
| LP2 FRP 4‰             | Ø12 Ø8 s=150 | 150/2000, Section is 80x1,2 | 4,0 | 640             | 2x61=122          |
| LP4 FRP 6‰             | Ø12 Ø8 s=150 | 6,0           | 960         | 2x92=184        |                   |

### 3. Results and discussions

Figure 5 shows one of the stages of testing a reinforced concrete structure.

During testing, the operational loads of the bending element, reinforced with laminates, significantly decreased the deflection and the amount of crack opening. Due to the predominant force of prestress, cracks in concrete are compressed, and the element can withstand increased operational loads.

The ultimate load on the element in the strengthen state (sample LC5) is significantly increased compared to the non-reinforced state. The carrying capacity of samples with non-stressed carbon plastics increased by 32%, while with stressed carbon plastic by 82% with an extension of 4 and 93% with an extension of 6‰. Table 2 presents the values of destructive loads.

![Tests conducted at the University of Friborg, Switzerland](image_url)
Table 2. Destructive loads

| Laminate | Sample characteristic | Breaking load (kN) | Breaking moment (kNm) | Breaking moment in% of the non-enhanced state |
|----------|-----------------------|-------------------|-----------------------|---------------------------------------------|
| -        | LC5 FRP               | 16,4              | 82,6                  | 100                                         |
| 2 x 80/1,2 | LC5 FRP         | 24,0              | 109,4                 | 132                                         |
| 2 x 80/1,2 | LP2 FRP 4‰  | 35,3              | 150,1                 | 182                                         |
| 2 x 80/1,2 | LP4 FRP 6‰  | 37,9              | 159,4                 | 193                                         |

Figure 6 presents a test results graph.

Reinforced concrete beams tests: The research program was developed and conducted at the University of Gliwice (Poland). This program analyzes the operation of reinforced concrete beams reinforced with laminates. The beams were reinforced with strained and non-stressed laminates. Studies have shown different results. There are the tests results of reinforced concrete beams 8 m long, reinforced with laminate 90 / 1.4.

Test conditions: Figure 7 shows the test conditions for the beam and its cross-section

Table 3 shows the reinforcement samples the characteristics.
Table 3. Sample reinforcement

| Beam          | Reinforcement | FRP material     | Preload, MPa | Prestressing force, kN |
|---------------|---------------|------------------|--------------|------------------------|
| B5 (unreinforced) | -             | -                | 0            | 0                      |
| B4 C-FRP      | 6 Ø 16 mm     | S&P Laminate     | 0            | 0                      |
| B1 C-FRP 3‰  | Ry = 340 MPa  | CFK 150/2000     | 495          | 62                     |
| B6 C-FRP 6‰  | Type 90/1,4   |                  | 990          | 125                    |

Test results: Figure 8 shows one of the stages of testing a reinforced concrete beam.

![Figure 8. Trials at the University of Gliwice, Poland](image)

Beams reinforced with laminates showed a significant increase in bearing capacity along the bending moment, both in the operational stage and in the case of ultimate loads. Beams B1 and B6, due to prestressing, showed a significant reduction in deflection compared to beams B3. All beams reinforced with composite systems increased their crack resistance. In the case of ultimate loads and in case of failure, the beams reinforced in this way are safer, since significant deflections appear before the destruction.

The ultimate loads perceived by the beam increased significantly after strengthening. Breaking force increased by 33% for reinforced with non-stressed laminates. In the case of prestressed laminates, the breaking load increased by 42% with a 3‰ tension and 58% with a 6‰ tension. Table 4 presents the destructive loads obtained during the tests.

Table 4. Destructive loads

| S&P Laminate | Sample characteristic | Destructive load (kN) | Destructive moment (kNm) | Breaking moment in% of the non-enhanced state |
|--------------|-----------------------|-----------------------|--------------------------|-----------------------------------------------|
| -            | B5 (unstrengthen)     | 122,0                 | 204,1                    | 100                                           |
| 90/1,4       | B4 C-FRP              | 166,2                 | 270,4                    | 133                                           |
| 90/1,4       | B1 C-FRP 3‰           | 176,6                 | 289,0                    | 142                                           |
| 90/1,4       | B6 C-FRP 6‰           | 201,6                 | 322,7                    | 158                                           |

Figure 9 shows the test results graphs for reinforced concrete beams.
4. Conclusions

Prestressed laminates have a positive effect on reinforced construction. The deflections and crack opening width are significantly reduced under operating loads of relatively non-reinforced condition. It is possible to pull plastics up to 6‰ with lightweight prestressing equipment. The prestressing system is specifically designed to reinforce large-span reinforced concrete slabs.

Similarly, as for reinforced concrete slabs, a significant positive effect was found for beams reinforced with laminates during testing reinforced concrete beams. Tested beams showed a decrease in the deflections and the crack opening width. Ultimate load was significantly increased. The critical elongation for pre-stressed laminates is 1.0-1.2% in the limiting state.

References

[1] V D Antoshkin, V I Travush, V T Erofeev, V I Rimshin, V L Kurbatov, The problem optimization triangular geometric line field. Modern Applied Science 9(3), pp. 46-50, 2015
[2] A. Krishan, V. Rimshin, V. Erofeev, V. Kurbatov, S. Markov, The energy integrity resistance to the destruction of the long-term strength concrete. Procedia Engineering 117(1), pp. 211-217, 2015.
[3] V.T. Erofeev, A.D.Bogatov, V.F. Smirnov, V.I. Rimshin, V.L. Kurbatov, Bioreistant building composites on the basis of glass wastes. Biosciences Biotechnology Research Asia 12(1), pp. 661-669, 2015.
[4] Y M Bazhenov, V T Erofeev, V I Rimshin, S V Markov, V L Kurbatov, Changes in the topology of a concrete porous space in interactions with the external medium. Engineering Solid Mechanics 4(4), pp. 219-225, 2016.
[5] A Cherkas, V Rimshin, Application of composite reinforcement for modernization of buildings and structures. MATEC Web of Conferences 117,00027.
[6] V T Erofeev, E V Zavalishin, V I Rimshin, V L Kurbatov, M B Stepanovich, Frame composites based on soluble glass. Research Journal of Pharmaceutical, Biological and Chemical Sciences 7(3), pp. 2506-2517, 2017.
[7] V Erofeev, V Kalashnikov, S Karpushin, I Tretiakov, A Matvievskiy, Physical and mechanical properties of the cement stone based on biocidal Portland cement with active mineral additive. Solid State Phenomena 871, pp. 28-32, 2016.
[8] S A Korotaev, V I Kalashnikov, V I Rimshin, I V Erofeeva, V L Kurbatov, The impact of mineral Aggregates on the thermal conductivity of cement composites. Ecology, Environment and Conservation 22(3), pp. 1159-1164, 2016.
[9] A L Krishan, V I Rimshin, V I Telichenko, V A Rakhmanov, M Yu Narkevich, Practical implementation of the calculation of the bearing capacity trumpet-concrete column. Izvestiya Vysshikh Uchebnykh Zavedenii, Seriya Teknologiya Tekstil'noi Promyshlennosti, pp. 227-232, 2017.
[10] A L Krishan, E A Troshkina, V I Rimshin, V A Rahmanov, V L Kurbatov, Load-bearing capacity of short concrete-filled steel tube columns of circular cross section. Research Journal of Pharmaceutical, Biological and Chemical Sciences 7(3), pp. 2518-2529, 2016.

[11] I L Shubin, Y V Zaitsev, V I Rimshin, V L Kurbatov, P S Sul'tygova, Fracture of high performance materials under multiaxial compression and thermal effect. Engineering Solid Mechanics. 5(2), pp. 139-144, 2017.

[12] V I Telichenko, V I Rimshin, A V Karelskii, B V Labudin, V L Kurbatov, Strengthening technology of timber trusses by patch plates with toothed-plate connectors. Journal of Industrial Pollution Control, 2017.

[13] V.I.Rimshin, E.A. Larionov, V.T. Erofeyev, V.L. Kurbatov, Vibrocreep of concrete with a nonuniform stress state. Life Science Journal. 11(11). Pp. 278–280, 2014.

[14] E. Kuzina, A. Cherkas, V. Rimshin, Technical aspects of using composite materials for strengthening constructions. IOP Conference Series: Materials Science and Engineering 21, Construction - The Formation of Living Environment, 2018.