USE OF FIBER-REINFORCED PLASTICS IN BRIDGE CONSTRUCTION IN RUSSIA

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Abstract: *Research on composite materials for use in bridge structures began at the Siberian Bridge Research Institute (SBRI) of STU in 2007. Over time, numerous laboratory, field, and theoretical studies have been conducted on various types of composite materials, fiberglass structures, and carbon fiber-reinforced concrete elements. In 2014, with the participation of SBRI specialists, the first road bridge in Russia with supporting structures made of fiberglass was designed and built. The research results presented in the article formed the basis for many regulatory documents on the design of composite superstructures and external reinforcement systems for strengthening spans and supports with insufficient load-bearing capacity.*

Keywords: *polymer composite material, reinforcement, bridge, span, test, composite structures, fiberglass, carbon fiber plastic.*

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Introduction

Over the last 20 years, sales of polymer composite materials (FRP) and products made from them have more than tripled, from $41.5 million to $130 million. In particular, in the construction industry, the use of FRP is steadily increasing, owing to the high strength of composite materials, their low specific self-weight, resistance to aggressive influences, and other advantages over steel and concrete. These advantages allow not only to increase the service life and maintenance periods of bridge structures, but also to reduce the cost of transportation and installation of materials and products, and maintenance of structures in general.

The main directions of using FRP in bridge construction are the manufacture of bearing and auxiliary structures from them, as well as the reinforcement of spans and supports with external reinforcement systems.

The experience of designing and examining bridges with FRP-made or FRP-reinforced elements consistently shows that the potential of composite materials in such structures is not yet fully realized. Existing calculation methods, constructions, and approaches to the technical condition of composite auxiliary structures require improvement to enhance the efficiency of using composite materials, while the scope of application for these structures remains inadequately addressed.

Materials and Methods

The use of FRP as bearing elements in bridge spans. The first road bridge in Russia featuring a composite span (Fig. 1) was commissioned in 2014 in the Novosibirsk region. The span structure, with a total length of 18 meters, consists of six multi-braced fiberglass trusses and a reinforced concrete deck. This design was first implemented in global bridge engineering practice [1]. The adopted layout of the span structure facilitates the passage of vehicles on a 4.5-meter roadway and pedestrians on sidewalks, each 0.75 meters wide.

All node connections of the fiberglass elements, including the tie attachments, are made with 12-mm-diameter rigid bolts. To eliminate the influence of bending moments on the operation of the braces, their connections to each other are designed as hinged. The roadway slab is made of monolithic reinforced concrete after the trusses have been installed in their design position. Consequently, the calculations have taken into account stages of the operation of the span structure in accordance with the technology of sequential slab concreting. The connection of the roadway slab to the trusses was made using stops that prevent the displacement of the slab relative to the trusses and its detachment from the upper chords of the trusses.

Fig. 1. *General view of a bridge with a composite span*

The analysis of the span structure was conducted utilizing the Midas Civil software package, taking into account the staged construction process. Fiberglass was considered as an anisotropic material, with its properties specified along three orthogonal axes.

Before the bridge was put into operation, static and dynamic tests on the span structure were conducted [2]. Two four-axle trucks with a gross weight of 51 and 55 tons were used as a test load (Fig. 2). To determine the response parameters of the span structure to the dynamic impact of a moving load, loaded trucks were driven across the bridge at speeds of 20...30 km/h.

Fig. 2. *Static test of the composite span*

During the tests, local deformations were measured using mechanical strain gauges and TDM electronic strain gauges from the Tensor-MS system. The deflections of the span structure were recorded using an optical level with the rails.

During subsequent bridge operations, SBRI specialists conduct annual inspections and instrumental measurements in accordance with a specially developed monitoring program [3]. The main parameters recorded during these works are the stress-strain state of the span and its dynamic characteristics.

The use of FRP for strengthening of bearing structures. Research on composites as elements of external reinforcement systems for reinforced concrete bridge structures was initiated at the SBRI in 2009 and was among the first in Russia [4-6]. The main part of the laboratory tests was performed on reinforced concrete beam specimens measuring 1650x160x220 mm and column specimens measuring 800x200x200 mm [7]. Scaled models of beam spans, each 4 meters long, were also tested. In addition to laboratory tests, strengthening and subsequent static tests were carried out on spans of two road and one railway bridges located in the Novosibirsk region.

Static laboratory tests of reinforced concrete elements were carried out on a WPM-300 press (Fig. 3). In total, more than 50 sample series were tested, differing in the design of the external reinforcement system and the type of FRP composite used. An additional factor for column specimens, the influence of which on the effectiveness of the reinforcement was investigated, was the value of the eccentricity of the load application to the structure – centrally and eccentrically compressed specimens were considered.

Beam specimen *Column specimen*

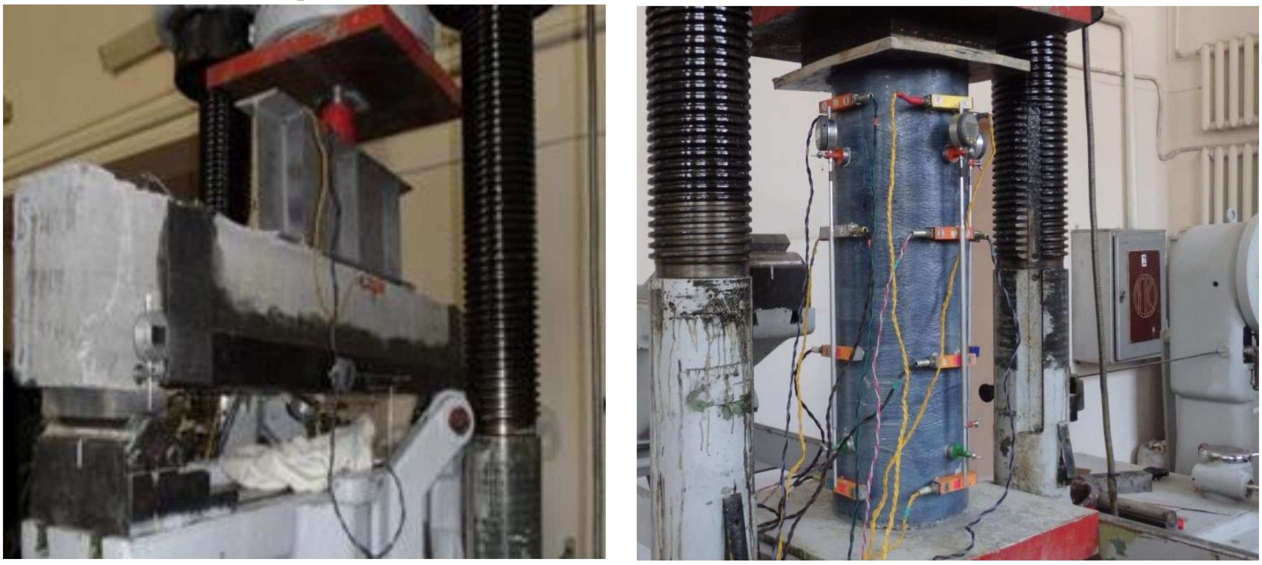

Fig. 3. *Reinforced concrete specimens during static testing*

Laboratory tests on beam-span models were performed on a power stand. The samples were T-beams with a length of 4 meters, a height of 30 cm, and a web and flange thickness of 7 cm.

To assess the degree of involvement of the external reinforcement system in the joint work with the beams of operating bridges (Fig. 4), static tests were carried out before the installation of FRP, after the completion of the epoxy binder polymerization process, and one year after the structure was operated in normal mode.

Fig. 4. *Bridge beams strengthened in the support section against shear force*

Triaxial and four-axle trucks, each with a total weight of 35 to 55 tons, were used as test loads. To assess the spatial behavior of the span structures, various loading schemes were implemented during the tests, differing in the location of the load across the bridge (Fig. 5). During the tests, the overall deformations of the span structures were recorded, as well as the local deformations of the elements of the external reinforcement system and the concrete of the beams at the closest possible points.

In all tests conducted, strain, displacement, and force sensors of the "Tensor MS" system, as well as mechanical strain gauges, were used as measuring instruments.

Scheme 1 (scheme 3 - mirrored) *Scheme 2*

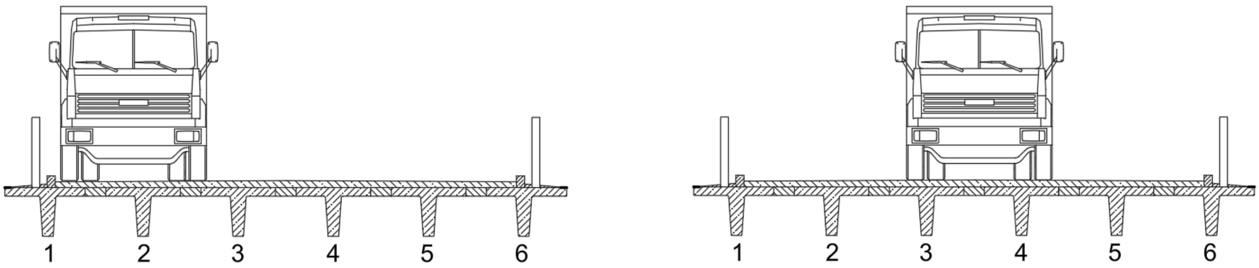

Fig. 5. *Test load arrangement schemes during testing*

The use of FRP in auxiliary structures. Laboratory static tests were performed to determine the holding capacity of the composite railing and to assess its suitability for use on bridges. The tests were carried out on railing sections made of fiberglass elements with a rectangular cross-section. The tests evaluated the bearing capacity and deformability of the railings under vertical and horizontal loads, with magnitudes corresponding to the requirements of current regulatory documents. The sections were fixed to a concrete base using metal studs in accordance with the manufacturer's recommendations. The load was applied using a hydraulic jack and transferred to the structure via a special traverse (Fig. 6). During the tests, both the applied load and the deformation of the railing elements were recorded.

Horizontal load test *Vertical load test*

Fig. 6. *Sample of the railing during static tests*

Results and Discussion

The use of FRP as bearing elements in bridge spans. The test results for the composite span showed that the construction coefficients (ratio of actual to calculated values of controlled parameters) for all trusses and gauges across all controlled sections ranged from 0.75 to 0.98. These values indicate good design performance and consistency of actual and estimated data.

The analysis of vibrograms of span oscillations showed that the structure at different points along its length vibrates in phase, with the same frequencies and intensity – no changes in the stiffness of the span along its length before and after the tests were detected. There are no significant changes in the frequency of the own oscillations after testing.

The results of monitoring the bridge’s technical condition, based on the values of general vertical deformations in the span’s farms, show that the initial arching of the farms, 15 cm at the end of all installation works, has decreased to an average of 8.2 cm. During the first year of operation, overall construction rose slightly, likely due to improved connections, but it returned to its previous level over time. This effect is due to changes in material properties, especially in concrete, where the rheological effects are noticeable in the first 2 years after laying. The deformation is now stable. Dynamic design parameters (natural frequencies and logarithmic decrement) are also stable for 10 years.

The use of FRP for strengthening of bearing structures. Tests of the rectangular cross-section beam samples showed that the bearing capacity of the reinforced elements was 40-190% higher for bending moment and 20-70% higher for shear force.

Column samples, reinforced with FRP, had a bearing capacity of 10-50% higher than unreinforced samples. The efficiency of the reinforcement depended largely on the location where the compressive force was applied – the farther from the gravity center of the cross-section it was applied, the smaller the increase in the sample's load capacity.

Tests on exploited road bridges showed that the elements of external reinforcement systems were well integrated into the joint work with beams under transport loads. The overall and local deformation of the beams did not exceed the calculated values. The structural coefficient values ranged from 0.8 to 0.9, indicating that the design assumptions were consistent with the actual design performance. The use of composite materials increased the bearing capacity of the spans for both bending moment and shear force, ensuring that active design loads A14 and H14 could pass through the bridges without restrictions.

The use of FRP in auxiliary structures. According to the test results for the railing sections, the loads causing sample destruction were significantly higher (by 50-150%) than the normative loads. The deformation of the railing under normative loads did not exceed 4 mm vertically and 34 mm horizontally. There are no defects caused by normative loads in the samples. The destruction of samples usually resulted from the rupture of anchor studs that secured them to the concrete base.

Summary

The use of FRP as bearing elements in bridge spans. Static and dynamic tests of the composite span showed, in general, satisfactory compliance of design assumptions taken into account and the actual operation of the installed structure. The technical condition of the span has remained stable throughout all 10 years of its operation. According to the results of the last inspection of the structure, no power or mechanical damage to bearing structures was found. There are no signs of degradation of the fiberglass and reinforced concrete elements of the span; the coating condition is good. There are no defects that reduce the structure's bearing capacity – the actual bearing capacity matches the design loads.

The results of tests and monitoring of the technical condition of a span show that such construction can be applied on pedestrian and road bridges. Large bearing capacity and stability in real operating conditions indicate the feasibility of its use in bridge construction and reconstruction.

The use of FRP for strengthening bearing structures. Research on FRP components of external reinforcement systems, as well as on reinforced concrete elements strengthened by these systems, has shown that this technology is efficient and cost-effective. Its use extends the service life of bridges by at least 25 years.

During the research, many normative documents were developed, which enabled the accelerated and expanded introduction of such external reinforcement systems in Russia's bridge construction industry.

Currently, research is being carried out in the SBRI to use FRP as an external reinforcement system for curved and stretched steel elements in spans.

The use of FRP in auxiliary structures. Tests of the fiberglass railings have shown that they fully meet the requirements of current normative documents for stiffness and bearing capacity. The operation of such railings, as well as the drainage channels made of FRP, demonstrates their sufficient durability.

It should be noted that the use of electric lighting poles, viewing and operating devices, and other auxiliary constructions made of FRP is possible on bridges. However, this requires additional research to confirm their reliability.

Conflict of Interest

The authors declare no conflicts of interest.

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