Strengthening bridge spans by composite materials

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Abstract. The modern effective method of reinforced concrete bridge superstructures reinforcement using composite materials is considered. The results of comparative analysis of physical and mechanical properties of materials used to strengthen the bridge spans that have received defects and damage during their operation are presented. The results of the performed analysis of experimental studies of building structures reinforced by similar methods are shown. Various options of fixing carbon lamellas on the surfaces of reinforced structures are investigated. An alternative method of fixing the carbon lamella using the anchor device, devoid of shortcomings of existing technical solutions, is proposed. The principle of operation of the proposed anchor device operating on the principle of tightening bar is described in detail. The article describes technological operations in strengthening the reinforced concrete beam of automobile and road bridge. Construction solutions of the organization of nodal connections are shown.

1. Introduction

Strengthening of reinforced concrete structures can be carried out with a change in the design scheme or without it [1].

Strengthening of construction structures by changing the design scheme is one the most efficient methods, especially for bending elements. The essence of the technique is in additional structures redistributing external stresses and internal forces to the less loaded elements of the bearing system of the structure. Depending upon the type of relieving structure, the redistribution of forces is achieved by reducing the design span and enhancing the bending stiffness of the reinforced cross-section. By the structural design, the strengthening by changing a structural scheme of bending elements is carried out with finger bars and supporting poles, gantries, beams, frameworks, strutted frames, tie-bars, etc.

Strengthening without changing a structural scheme can be done by widening the cross-section area of structural elements as well as by outer reinforcement without increasing the cross-section creating the prestressing of reinforcing members attached to the structure, including out of composite materials. This article considers in details one of such methods of strengthening of a reinforced concrete beam without changing its design scheme.

2. Main part

Strengthening of ferroconcrete structures by external reinforcement with prestressing has been used as a building technique since the 50-s of the 20th century.
The technique of strengthening structures providing the stress adjustment enables to reduce the internal forces occurring in the structure. The advantage of the given method also lies in the fact that the strengthening can be produced without reloading. The stress adjustment is achieved by the prestressing of reinforcing elements up to the set level.

In case of application in repairs and strengthening of structures by metal reinforcement, there is a risk of corrosion damage. The alternative to metal is the use of corrosion resistant composite materials based on high-strength fibers (carbon, aramid, glass, et al.).

At present, most bridges in the Russian Federation need major repairs with strengthening of bridge superstructures [2]. There are a lot of bridge structures in good operable technical state but which do not meet the changed regulations. In order to bring them in line with the safety and load requirements, the measures should be taken to strengthen them without traffic interruption. Along with the known methods of strengthening, the composite materials have been used in the recent decade.

The use of external reinforcement technology with carbon fiber-based composite materials makes it possible to restore emergency operation of emergency structures, eliminate concrete damage and reinforcement corrosion as a result of prolonged exposure to natural factors and aggressive media during operation, extend the service life of facilities, eliminate the consequences of construction defects, design errors, and also increase bearing capacity of structures with an increase in design loads [3].

The most important disadvantages of carbon composite materials are their rather high cost and temperature requirement during installation (above five degrees centigrade). However, these disadvantages are compensated by the following indisputable advantages compared with other materials and technologies [4,5]:

- low weight;
- small overall thickness;
- the possibility of using material of any length;
- ease of transportation and installation;
- economical installation (no heavy hoisting equipment and installation equipment);
- the possibility of obtaining very high tensile and bending strengths;
- high modulus of elasticity;
- excellent fatigue resistance;
- the possibility of painting and applied without any preparation;
- resistant to alkalis.

The strengthening of ferroconcrete bridge spans with composite materials is realized by external reinforcement – attachment to the existing structure with polymer adhesives or binding stuff on a mineral base. Composite materials can be obtained on the base of various binding stuff – polymer, ceramic, metal, mineral et al. [6].

To this end, bands of different width can be applied. However, to strengthen the bridge spans, these bands are inconvenient and in this case it is more efficient to use lamellas manufactured from bands. The lamellas have great thickness and stiffness typical for bands as well as they are more efficient in use [7-9].

Analysis of experimental research made abroad and in the Russian Federation [10] shows that in most cases the beams strengthened for bending moment were under the test. In this connection, the scheme of beam destruction strengthened by carbon plastic composite materials has been specified for the shear strength action and the methodology of their design by the critical loads has been corrected [11-14].

Due to high strength properties of carbon fibers, it is possible to increase the bearing capacity of the structure virtually without losing payload volume and increasing the dead load – the thickness of the strengthening member makes from 1 to 5 mm, as a rule. The beams are strengthened by fixing the carbon fiber at the most stressed zones: to accommodate the increased bending moment, it is usually done in the span center, bottom edge of the structure [15,16].
Herewith, by reference to the scheme of the structure behavior in bending, there is no need to fix the hydrocarbon bands to the lateral surfaces of beam webs, since this will result in the extra inefficient use of the material [17]. To solve such problems, all kinds of carbon stuff will do – bands, lamellas, and grids [18,19]. To increase the bearing capacity of the bridge beam to the effect of lateral forces, it is necessary to strengthen (reinforce) over support zones by fixing U-sturrups of carbon bands or grids. Such reinforcements should be located at the areas of increased lateral forces at over supports, but not uniformly over the length of the beam. The carbon bands and lamellas are basically used jointly, since their assembly technique and adhesive compositions are alike [20].

The application of carbon grids usually excludes the use of bands and lamellas in connection with the so-called «wet» work. The quality of the prepared base (surface on which carbon fiber will be fixed) affects directly compatibility of the structure operation with strengthening element. The assembly of carbon bands can be done both with a «wet» or a «dry» technique. The carbon bands can be laid in several layers, however, when fixing to the ceiling surface, it is not recommended to fix more than two layers in one period – the stuff becomes removable by gravity [21].

The drawbacks of both kinds of the carbon bands assembly are as follows: risk of delamination of strengthening bands and problems with diagnostic operations; incapability to take up constant load affecting the structure; while performing the reinforcement assembly without traffic interruption on the bridge, the unhardened adhesive will allow the band to move a little under the temporary loading and later it will not work under partial load.

The method of strengthening carbon lamellas proposed by the authors is their anchorage in order to avoid negative aspects of their fixing.

The proposed new type of reinforcement of bridge span structures solves most of the shortcomings of the methods used in modern practice. It is proposed to use carbon-fiber lamella as an inhaling by analogy with a trussed inhaling. The method consists precisely in stretching the lamella along the bottom edge of the beam edge and securing it with the help of the developed anchor.

Figure 1 shows the solution for strengthening a ferroconcrete beam using carbon lamella and tensioning devices.

Figure 2 shows the construction of the tension anchor. Fixed anchor 2,a is a steel plate with glued lamella, sandwiched between two plates with tension of the bolts. Tension anchor 2,b is a welded part made of steel plates and an angle bar.
The strengthening of a reinforced concrete beam with composite carbon fiber provides the following process steps:

1. The beam of the superstructure is prepared: cracks are sewn, old destroyed concrete is bounced, rebar is cleaned of rust, torn shear is welded and treated with inhibitors, and then all defects are removed with repair solution.

2. The non-movable part of the anchor, shown in Figure 2, a, is fixed in a certain designed location. For installation, it is required to remove the protective layer of reinforcement and clean the reinforcement itself from concrete and rust.

   Two high-strength bolts (4) are inserted into the plate (2) and then the plate (2) is welded by electric welding to the bottom row of the reinforcement package (1). The fixed part of the tension anchor (7) is fixed in a similar way. The places of welding anchors to the fixture are sealed with repair compound, the protective layer of concrete is restored.

3. The necessary carbon fiber tape is cut with a margin of 80 ... 100 cm, 40 ... 50 cm on each side. The steel plate (3) and the movable anchor (13) are covered with adhesive, wrapped with tape, compressed and left under the press until the glue is completely solidified.

4. After that, the plate (3) is placed in place in the fixed part of the anchor (Figure 2, a), putting holes on the bolts, and secured with nuts. The movable part of the tension anchor with the glued lamella is inserted into the groove formed by the angle bar number 16 (12) and the steel plate (7). High-strength bolts are inserted into the existing holes in the tension anchor and nuts are baited. The force created by the tightening of the nuts tightens the lamella, which makes the design similar to the shear bolt, but the bridge clearance is not involved and the structure does not become heavier.

5. After creating the effort, the metal parts of the anchors are protected from atmospheric corrosion by painting. The lamella on top is covered with adhesive to protect against weathering and mechanical damage.

   Designs of mobile and fixed anchors are presented in Figures 3 and 4.
3. Conclusions

Based on the experience of exploitation of these structures, the conclusion can be drawn that the use of composite materials is an efficient and safe method to increase the bearing capacity of automobile bridges and can be recommended for using on other similar structures.

The proposed strengthening scheme can be used not only in the repair and reconstruction of bridges, but can be extended to the berthing constructions, tunnels, tanks, structures of industrial, public and residential buildings.

In most cases, the use of this method provides a significant economic effect due to the following factors:

- reduction of time, laboriousness of repair and costs for further operation;
- the ability to perform work without decommissioning facilities;
- strengthening of structures without reducing the working space, since the thickness of the reinforcement elements usually does not exceed 5 mm;
- reducing or eliminating the cost of using special construction equipment;
- increase in durability of structures and turnaround time.

Strengthening by composites is considerably easier than in the conventional way, which enables not to stop the bridge traffic movement and cuts repair period. The drawback of the proposed strengthening technique is its cost – it is more expensive than the conventional reinforcement.

However, if we make allowance for high strength and durability of the material, the lifetime is extended, hence, a number of subsequent repair works and their costs are potentially reduced. Moreover, the composite material itself is more expensive, but the strengthening process is easier. The minor difference in the cost of metal and composite strengthening can save considerable resources later.

This will allow to considerably cut the expenditures and to enhance the serviceability of structures.

The application of composite materials enables to drastically accelerate and facilitate the reconstruction of the exploited automobile bridges, and hence, offers an opportunity to pass high traffic numbers and to increase their road speed.

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