Some aspects of the bridges’ functional qualities restoration

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Abstract. The paper considers the reasons for reducing the load-bearing capacity of bridge structures. Factors affecting the feasibility of major bridge repairs are identified and some ways of their implementation are analyzed. An improvement of one of the modern methods of repairing bridge beams – pasting them with carbon lamellas is proposed. The improvement essence is the use of a device for tensioning reinforcing belts and the proposal to use carbon fiber lamellas as puffs, similar to Sprengel puffs. The method consists in stretching the lamella along the lower edge of the beam edge and fixing it using the developed anchor, not by gluing.

1. Introduction
In the modern world with the concentration of population and production in large cities, transport security issues are becoming more and more relevant. Not only security against terrorist threats and man-made disasters, but also security in the sense of ensuring sustainable, reliable, and uninterrupted operation of facilities and systems. Stable operation should be understood as trouble-free operation of the systems, including transport systems with possible external negative impacts on the system. Bridges are the most vulnerable link in the transport system. Restoring the consumer qualities of the bridge, its load capacity and safety, is disproportionately more expensive than restoring a highway section. And this process takes much longer. Therefore, the problem of restoring bridges that are in poor condition or have passed into poor condition is very urgent. The repair and reconstruction of a bridge in a state of disrepair, which makes it impossible to continue operating, usually requires serious investment comparable to new construction. However, due to irregular inspection, bridge structures are often in unsatisfactory condition and all measures for their repair are carried out even when their damage is already significant [1].

2. Factors influencing the choice decisions about restoring or dismantling bridge structures
The existing method of a bridge structure inspection involves a comprehensive study of its technical condition for all groups: the bridge deck, spans, supports and the bridge space [2,3]. This is done so that a decision about the future use of the bridge structure – major repairs, reconstruction or dismantling and new construction can be made. The determining factor here is the state of superstructures and their resource. Major repairs with the replacement of all load-bearing structures are not effective, as the price is comparable to the new construction, and sometimes exceeds it due to the old structures’ dismantling. It is also important to note that it is not possible to use modern methods of design and construction in case of a major repair bridge because the old bridge is made in accordance with a certain scheme, which on the one hand not be significant changes, and the other does not fully meet modern requirements for this bridge structure. For example, the breakdown into
spans, location and the obstacles’ intersection angle may be less well chosen for modern conditions than for the conditions in which this bridge was built. The possibility of making certain structures from certain materials may also have changed, as well as the possibility of using other, more modern materials.

Promising in terms of major repairs with relatively low costs are the bridge structures with span beams, the resource of which is not exhausted, but only reduced due to changes in load capacity standards and removable defects. Load capacity is a characteristic of the technical condition of a bridge structure that corresponds to the maximum impact of a temporary vertical load, at which there is no transition to the limit state in any of the main load — the construction bearing structures. The load capacity of the structure as a whole is determined by the load capacity of the weakest of the main load-bearing structures [4].

3. Some methods of bridge structures’ recovering

Figure 1 shows the bridges with reduced load capacity, mainly due to changed standards. The facade surfaces of the superstructure’s extreme beams are in poor condition and require either repair or replacement. In the first case, it will not be possible to increase the load capacity of the structure, but only to prevent further development of the reinforcement and concrete corrosion defect. Moreover, the beam reinforcement was previously performed. If the end beams are replaced with new modern ones, the load capacity of the bridge in this part of the superstructure will be increased to the required standard. The second pair of adjacent beams does not require replacement, since the forces in it are lower than in the extreme ones. The beams in the superstructure are loaded in accordance with the transverse installation coefficient [5]. The ordinates of the pressure influence line for the extreme beams are determined by the expression:

\[ y_1 = \frac{a_1^2}{2 \sum a_i^2 + \frac{n \cdot l_p^2 \cdot G_b \cdot I_b}{3 \cdot E_b \cdot I_k}} \]

and for the adjacent beams (second beams), the expression:

\[ y_2 = \frac{a_1 \cdot a_2}{2 \sum a_i^2 + \frac{n \cdot l_p^2 \cdot G_b \cdot I_b}{3 \cdot E_b \cdot I_k}} \]

The ratio of expressions will be \( \frac{a_1}{a_2} \), if \( a_1 = n \cdot a \) and \( a_2 = (n - 2) \cdot a \) then we get \( \frac{n}{n-2} \). Usually in the span structures of bridges beams from 6 to 10 pieces. Then the coefficient of transverse installation for the beams’ second pair is 40 percent less at n=6, and 20 percent less at n=10. The standard change in the time load of the mobile load from A11 to A14 corresponds to an increase in internal forces in the beam by 22 percent. Thus, this old part of the span structure is also out of danger.

Figure 1. Figure with short caption (caption centred).
This solution was proposed to restore the capacity of the overpass in the city of Volgograd on Mendeleev street. The technical condition of the overpass on Mendeleev street is far from the standard. The survey showed the presence of defects in load-bearing structures, destruction of the protective layer of concrete, corrosion damage to working fittings, unsatisfactory condition of sidewalks—there are no slopes, separation of the railing (Figure 1). Corrosion of bridge reinforcement occurs due to the penetration of chlorides and carbon dioxide into concrete [6,7]. The destruction of the beams was facilitated by the passage of vehicles exceeding their standard load [8]. The structures have cracks, supporting parts and expansion joints in unsatisfactory condition [9]. The destruction of the waterproofing layer contributes to the concrete reinforcement and carbonation corrosion. The structure has a load capacity limit of 10 tons, which does not meet modern standards. Removing the end beams will allow you to use a new beam that meets all the requirements of the project. Replacing the pavement with reusable layers of asphalt concrete will reduce the constant load, restore the waterproofing layer and make traffic comfortable.

There is another solution to the problem of restoring the bridge’s load capacity. They are less costly. If the span beams are in good condition and the physical reduction in load capacity is 10 percent, then it is possible to use a high-strength composite-carbon slats glued from carbon fibers. Due to the high strength characteristics of carbon fiber, it is possible to increase the load-bearing capacity of the structure almost without losing the useful volume and increasing the own weight of the structures—the thickness of the reinforcing elements is usually from 1 to 5 mm. Beams’ reinforcement is performed by applying carbon fiber in the most stressed areas: for the perception of increased bending moment—usually in the center of the span along the lower face of the structure [10].

Composite reinforcement consists in the fact that the carbon lamella glued to the surface of the structure takes a part of the effort from the temporary load, thereby increasing the load-bearing capacity of the reinforced element (Figure 2). The disadvantage of the new type of reinforcement is its cost—it is more expensive than conventional reinforcement, but this is only at first glance. First, it is necessary to take into consideration that the durability and strength of the material increases the service life, and, therefore, potentially increases the inter-repair period and the cost of subsequent repairs. Second, the composite material itself is more expensive, and the technology of the amplification device is simpler. A small difference in the cost of metal and composite reinforcement can be beneficial later on.

![Figure 2](image1.png)

**Figure 2.** Reinforcement of the superstructure beams with carbon lamels.

a) execution of work; b) finished structure.
The disadvantages of reinforcement with carbon lamellas include: first, the possibility of detachment of the reinforcement tapes and difficulties with diagnostics; second, the inability to perceive a constant load acting on the structure; third, when installing the reinforcement without stopping traffic on the bridge, the non-hardened adhesive will allow the tape to shift slightly under the influence of a temporary load and not work for part of this load in the future.

The calculation of the required composite cross section is made from the condition $M \leq M_{ult}$, where $M$ – is the bending moment from the external loads; $M_{ult}$ – is the maximum bending moment that can be perceived by the reinforced section of the element. $M_{ult}$ value for bendable rectangular, t-shaped, and i-beam elements that have a shelf in the compressed zone with $\xi = \frac{x}{h} \leq \xi_{R,f}$ determine depending on the position of the neutral axis of the section.

If the neutral axis passes in the shelf (Figure 3), then the condition is met,

$$R_s A_s + R_f A_f \leq R_b b_f h'_f + R_{sc} A'_s, \tag{1}$$

The bending moment should be determined by the formula:

$$M_{ult} = R_b b x (h_0 - 0.5 x) + R_{sc} A'_s (h_0 - a) + R_f R_f a$$

The height of the compressed zone should be determined by the formula:

$$x = \frac{R_s A_s - R_{sc} A'_s + R_f A_f}{R_b b} \tag{2}$$

**Figure 3.** Cross-section of the beam: a) under normal loading (the neutral axis passes in the shelf); b) overloaded (the neutral axis passes through the edge).

If the neutral axis passes through the edge (Figure 4), then the condition is met,

$$R_s A_s + R_f A_f > R_b b_f h'_f + R_{sc} A'_s, \tag{1}$$

The bending moment should be determined by the formula:

$$M_{ult} = R_b b x (h_0 - 0.5 x) + R_b (b'_f - b) h'_f (h_0 - 0.5 h'_f) + R_{sc} A'_s (h_0 - a) + R_f A_f a, \tag{2}$$

The height of the compressed zone should be determined by the formula:
\[ x = \frac{R_s A_s + R_f A_f - R_{sc} A_s - R_b (b_f - b) b_f}{R_b b} \]

When calculating the strength of the superstructures’ bending beams in formulas (1) and (2) of the elements, it is recommended to observe the condition \( \xi = \frac{x}{h} \leq \xi_{R_f} \). Then the maximum bending moment \( M_{ult} \) can be determined by replacing the calculated resistance of the external reinforcement made of composite materials \( R_f \) with the stress in it \( \sigma_f \), determined by the formula:

\[ \sigma_f = \left[ \varepsilon_{b2} \left( \frac{wh}{x} - 1 \right) - k \varepsilon_{bc}^0 \right] E_f \] (3)

The problem of eliminating the disadvantages of simply gluing carbon tapes with an adhesive composition is solved. For this purpose, a patented device for tensioning reinforcing belts is used [11,12]. It is proposed to use a carbon fiber lamella as a tightening by analogy with a Sprengel tightening. The method consists precisely in stretching the lamella along the lower edge of the beam edge, and fixing it with the help of a developed anchor, and not by gluing. The fixed anchor is a steel plate with a glued lamella clamped between two plates by the tension force of the bolts. The tension anchor is a welded part made of steel plates and a corner. The carbon fiber composite reinforcement device provides for the following technological operations: the span beams are repaired – the cracks are expanded, old destroyed concrete is beaten off, the reinforcement is cleaned of rust, the torn cross reinforcement is welded and treated with inhibitors, and then everything is sealed with a repair solution.

The fixed part of the anchor is fixed in the place determined by calculations. To install, you need to break off the protective layer of reinforcement and clean the reinforcement itself from concrete and rust. Two high-strength bolts are inserted into the metal plate, then the plate is welded by electric welding to the lower row of the reinforcement package. The fixed part of the tension anchor is attached in the same way. Places where anchors are welded to the reinforcement are sealed with a repair compound, and the protective layer of concrete is restored. The required length of carbon fiber tape is cut off with a margin of 80 - 100 cm by 40 - 50 cm on each side [13]. The steel plate and the movable anchor are covered with adhesive, wrapped with tape, crimped and left under the press until the glue is completely cured. After that, the plate is placed in place in the fixed part of the anchor by putting the holes on the bolts and fixing them with nuts. High-strength bolts and nuts are inserted into the existing holes in the tension anchor. The force created by tightening the nuts is pulled on the lamella, which makes the structure similar to the Sprengel tightening, but the bridge dimension is not engaged and the load-bearing bridge structure is not weighted. After creating forces, the metal parts of the anchors are protected from atmospheric corrosion by painting. The lamella top is covered with an adhesive to protect it from weather and mechanical damage.

4. Summary
1. Major repairs of reinforced concrete bridges with the replacement of all load-bearing structures are not effective, it is relevant only when to achieve the standard load capacity of the bridge, it is enough to replace only the extreme beams of the superstructure.
2. Effectively increase the load capacity of bridge structures, composite materials such as carbon fiber lamellas can be used, but the lamellas should not be glued, but stretched along the lower edges of the beam ribs, and fixed with the help of developed anchors. The use of a tensioning device increases the durability and reliability of the structure.

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