Improvement of metrological measurements of bridge crossings at waterworks when studying non-destructive testing methods

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Abstract. The article considers the main parameters of applying the modern methods of metrological measurements of bridge crossings on water channels during research with non-destructive testing methods. Instrumental surveys of water supply facilities in Russia showed that in some cases their effectiveness, operational quality and reliability are insufficient, which is associated with violations of normal water supply systems functioning. In modern conditions, with limited public resources allocated for the reconstruction of water facilities, problems of optimizing the requirements for metrological support of the developed non-destructive testing measuring instruments and the unification of observation technologies are of particular importance. The most common are defects of an internal nature, leading to the disruption of waterworks normal functioning. We can conclude that violations of the butt joints of prefabricated elements, breaking and breaching of walls in various zones, cracks, sliding and subsidence of elements relative to each other lead to disruption of the normal operation of bridge crossings. This raises problems such as the loss of scarce irrigation water, rising groundwater levels, waterlogging and salinization of irrigated lands. The solution to these problems should be based on the mandatory consideration of reliability requirements in design, construction and operation. The purpose of research with non-destructive testing instruments was to detect possible defects in concrete bridge crossings and determine the condition of reinforcing bars. These field studies were carried out using the OKO-2 GPR and the electronic concrete strength measurer IPS-MG4.01. Comparison of the vertical displacement profiles of bridge crossing bearing components through the waterworks horizontally along and across the bearing elements revealed insignificant internal changes. A metrological support system for research by non-destructive methods for monitoring bridge crossings at waterworks is necessary to achieve unity and the required accuracy, completeness, timeliness and efficiency of measurements.

1. Introduction

Instrumental surveys of the water supply facilities of the constituent entities of Russia have shown that in some cases their effectiveness, operational quality and reliability are insufficient, which is associated with violations of the normal water supply systems functioning, failure in their work. The most common are the defects of an internal nature, leading to the disruption of the normal waterworks
functioning [1].

In the Rostov Region alone, there are more than 50 bridge crossings being an integral part of the highway and representing complex and expensive structures are carried an asset of Rostovmeliovodkhoz. They need to be considered not only as transport, but also as hydraulic structures, and, therefore, the size and shape are largely justified by hydrological, hydraulic and channel calculations [2].

The predominant accidental defects are as follows: complete destruction, the formation of defects that violate the normal operation of the structure, violation of butt joints, as well as the destruction of a hinge part support. Cracks whose dimensions exceed the maximum permissible values, delamination of the protective layer of concrete, concrete reinforcement corrosion in the form of blooms and rusty streaks are the hazardous defects that cause deterioration in the performance of structural elements [3].

We can conclude that violations of the butt joints of prefabricated elements, wall breakings and breaching in various zones, cracks, sliding and subsidence of elements relative to each other lead to the disruption of the normal bridge crossings operation. This causes problems such as the loss of scarce irrigation water, rising groundwater levels, waterlogging and salinization of irrigated lands. The solution to these problems should be based on the mandatory consideration of reliability requirements in design, construction and operation.

When designing a bridge, it is necessary to solve the following problems:
- create optimal conditions for transporting goods and passengers by road;
- provide the possibility of reliable operation of the bridge over a long period of its service under the inconstancy of river flow, natural channel deformations, violation of the natural river behaviour by bridge crossing;
- get an economically sound design solution, which corresponds to the minimum construction and operating costs;
- minimize adverse environmental impact.

The technical condition of waterworks bridge crossings is assessed in winter, which impedes realistical safety indicators assessment. In most cases, the conclusions are based on visual examination data and a small amount of instrumental measurements.

The parameters subjected to non-destructive testing in concrete are strength, size of the protective layer, humidity, frost resistance, moisture resistance and others. In manufacturing, reinforced concrete products, the reinforcement tension and the amount of vibration during concrete mixture compacting are also controlled. However, compressive strength is the main controlled parameter for concrete [4].

The durability of a reinforced concrete structure is significantly affected by the size of a concrete protective layer and the presence of defects, specifically, cavities, pores, cracks, etc. The protective layer keeps the reinforcement safe from moisture, oxygen, aggressive substances and gases. Reinforcing rods having a small protective layer or significant defects in it undergo corrosion in the first place [5].

2. Materials and methods

The purpose of the research with non-destructive testing instruments was to detect possible defects in concrete of bridge crossings and to determine the condition of reinforcing bars. These field studies were performed using OKO-2 GPR and the electronic concrete strength measurer IPS-MG4.01 [6, 7]. The bridge crossings of the Lower Don and Right Egorlyk irrigation systems were studied with non-destructive testing devices. (Figure 1).
Figure 2a shows a fragment of georadar sounding profile No. 17, passed across the water flow along the bridge crossing. When interpreting the radarogram, the concrete pavement thickness and the state of the under pile space were determined. Two reflecting boundaries were distinguished in the radarogram in the upper part of the section in the region of 0-3 m and 6-9 m. They corresponded to the sole of reinforced concrete slabs and the air-ground interface. The thickness of the reinforced concrete slabs was 9-10 cm, the thickness of the air gap was from 0 to 10 cm. Below was the layer of the embankment of the main body mixed with washed rocks [8].

Figure 2b shows a fragment of a radarogram obtained from profile No. 11. Parts with intense dimming correspond to the portions of the medium with a higher energy of the reflected signal in comparison with the bright parts. The part with low energy of the reflected signal corresponds to a more homogeneous medium than the part with high energy of the reflected signal [9]. It can be seen that in the sector of 0-3 m and 6-9 m, the heterogeneity of the medium reaches the depth of 40 cm.

Figure 3a shows a fragment of profile No. 14, georadar sounding along the length of the bridge crossing pier with highlighted fittings and a zone of contact with water. Below is a layer with reflections from various voids and decompressions. Reflections from reinforcing bars are highlighted on the fragment of the radarogram in the upper part of the section. Figure 3b shows a fragment of profile No. 15 of georadar sounding along the width of a level crossing pier with highlighted fittings and a zone of contact with water. On the fragment of the radarogram, the zone of concrete corrosion in the places of contact with water is highlighted. Below lies a layer with the reflections from numerous local objects [10].
Fig. 3. Fragments of georadar sounding along the length of the bridge crossing pier of waterworks with dedicated fittings and a zone of contact with water: a is profile No. 14 along the length of the bridge crossing pier; b is profile No. 15 of georadar sounding across the width of the bridge crossing pier

When examining the bridge crossing, it was found that the supports have characteristic destruction of the protective concrete, exposure of the reinforcement mesh in places of contact with water ($R_{\text{com}}=35.4$ MPa, concrete class B 30), on the top of the side ($R_{\text{com}}=43.2$ MPa, concrete class B 35). The study of the columns showed the detachment of concrete, its corrosion in the area of bearing on the foundation slab ($R_{\text{com}}=39.4$ MPa, concrete class B 30) [11].

During operation, the properties of water supply structures are changed under the influence of aggressive environmental factors. Untimely detected and eliminated defects often develop into serious structural violations. It is proposed to model the technical condition of bridge crossings using the SCAD office software package in combination with studying the technical condition of their construction according to external signs [12].

As a result of the experiment, a solid-state model of the supporting elements of the bridge crossing through water channels was built. The stress-strain state of reinforced concrete bearing elements under various combinations of loads was considered.

The number of elements and the number of nodes of the complex were 479021 and 32901, respectively. The source information was encoded in terms of the increment method with regards to the fragmentary representation of the bridge crossing load-bearing elements in the form of objects with simple geometric shape and made of reinforced concrete of grade B 45.

The bridge crossing bearing elements coming through the water supply channels without defects formation were numerically calculationed with the objective to establish the adequacy of the solid-state model of the stress-strain state.

When conducting a full-scale experiment, the highest values of normal stresses at full load were $102.4 \times 10^5$ N/m$^2$, during modeling they were numerically equal to $98.7 \times 10^5$ N/m$^2$, which made a difference of less than 7% and emphasized the adequacy of the solid-state stress-strain state model [13].

Comparison of the diagrams demonstrating the movements of the bridge crossing bearing elements through the waterworks vertically and horizontally along and across the bearing elements revealed insignificant internal changes. The most interesting was the diagram of vertical movements (Figure 4, a), which showed the change in the position of horizontal elements due to the applied loads as well as the displacement of the column heads. Those results indicated the the high coefficient of safety of horizontal elements [14]. As the results of comparing the diagrams of the equivalent stresses von Misés (Figure 4, b), the greatest stresses arose along the vertical sides of the bridge crossing supporting elements, namely, at the extreme columns and horizontal beams supported on them. This indicated the occurrence of critical stresses in the extreme columns, a quarter larger than the ones in other columns of the bridge crossing.
Horizontal promotions along the load-bearing elements showed insignificant displacements of the bearing zones of the reinforced concrete beams, and horizontal promotions of the load-bearing elements show the displacements of the extreme columns and reinforced concrete beams supported on them.

The epures of the equivalent stress von Mises horizontally along and across the load-bearing elements of the bridge crossing (Figure 5, a) also showed the greatest stresses that arose in the area of the column supporting the foundation caused by deformations of the load-bearing elements. Stresses are also present in horizontal reinforced concrete elements. The conducted simulation induced a substantial coefficient of safety of reinforced concrete bearing elements of the bridge crossing.

At the second stage, the load-bearing elements of the bridge crossing were modeled with the formation of defects and damage, namely, the formation of destruction and decompaction zones of reinforced concrete on the column. The most characteristic and dangerous defect is the loss of the bearing capacity of one of the bridge crossing columns, namely, the edge one, as it is mostly exposed to external influences and experiencing the greatest equivalent stresses von Mises [15].

The vertical movement diagram (Figure 5, b) shows a critical change in the position of the column and the beams resting on it due to a decrease in its bearing capacity caused by the formation of defects. A column head is critically displaced, which results in the loss of stability of the beams resting on it. These results indicate the loss of the bearing capacity of the vertical element being the column [16]. Horizontal promotions along the load-bearing elements show insignificant transitions of the bearing zones of the reinforced concrete beams, and horizontal promotions across the load-bearing elements show the critical transitions of the extreme column, which pulls along the reinforced concrete beams supported on it.
When comparing the diagrams of the equivalent von Mises stress and transitions, the greatest stresses arise along the vertical parts of the supporting elements of the bridge crossing, namely, on the head of the extreme column and horizontal beams supported on it. These results indicate the critical stresses at the points of support being twice as large as in other columns of the bridge crossing [17, 18], which leads to the destruction of the elements under consideration and the loss of the bearing capacity of the entire structure.

As a result of metrological measurements of bridge crossings at waterworks during research using non-destructive testing methods, zones of the formation of defects and damage on the bearing elements of bridge crossings through waterworks were identified, which might contain the same types of characteristic damage. This enabled to streamline the process of laying GPR profiles and determine the points at which it is necessary to measure the strength of concrete during field surveys. In this regard, the defects on the column in the form of voids and decompaction of reinforced concrete with sizes from 50 mm to 100 mm in diameter were modelled. An intensive threshold for the danger of the formation of voids and decompaction of reinforced concrete starting with the diameter of 100 mm was established.

3. Conclusion
In modern conditions, with limited public resources allocated for the reconstruction of water facilities in Russia, the optimization of the requirements for metrological support of the developed non-destructive testing measuring instruments and the unification of observation technologies are of particular importance. The creation of a metrological support system for research with non-destructive methods for monitoring bridge crossings at waterworks is necessary to achieve unity and the required accuracy, completeness, timeliness and efficiency of measurements.

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