Assessment of the damage impact to particular water structures on their performance

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Abstract. Identifying the type of damage in which the structure’s performance is not ensured is one of the most critical tasks in assessing the structures’ performance. The necessity of assessing the structure’s behavior for operability in the base - foundation - elevated system is proved.

Introduction
The material of water structures is reinforced concrete, which has certain tolerances during operation. With the prolonged load action, the inelastic deformations of concrete increase over time, that is, the zones of plastic hinges form [1, 2, 3, 4]. The property of concrete, characterized by an increase in inelastic deformations during the prolonged load action, is called creep of concrete. These properties lead to structural damage [5, 6, 7, 8]. There comes a time when the water structure cannot be operated safely. To understand and prevent the problem, a sufficient theoretical amount of knowledge that determines the behavior of the structure under certain conditions is needed. Modern software products make it possible to simulate a situation taking into account various conditions. As a result of the simulated situations’ analysis, it is possible to develop the recommendations for the safe operation of the structure, including the subject to the development of special measures [9, 10, 11, 12]. The damage analysis of the water structures and their impact on operability is assessed in the base - foundation - elevated system.

Material and technology
The types of damage that affect the water structures’ performance were identified:
– the formation of plastic deformations’ (cracking) zones in the designs of buttresses under the prolonged load action;
– the formation of the plastic deformations’ zones in the water structure under the prolonged load action;
– buttress construction failure;
– local subsidence.

The water structures’ operability analysis was carried out taking into account the following types of damage:
– the formation of plastic deformations’ (cracking) zones in the designs of buttresses under the prolonged load action;
– the formation of plastic deformations’ zones in the water structure under the prolonged load action;
– buttress construction failure;
– local subsidence.

To solve the goal of analyzing the water structure’s operability for various damages, the software products [13, 14] using the finite element method STARK ES version 2019 and the specialized geotechnical software complex GTS NX version 2019 were used.

At the initial stage, when analyzing in STARK ES version 2019, a numerical analysis was performed to assess the strength (analysis of the design scheme individual finite elements safety margin for given loads; the elements’ strength is analyzed by the forces arising from the static loads) of the water structures for two design cases: the plastic deformations’ formation in the water structure are not taken into account; the plastic deformations are present in the water structure.

The next step was the determination of strength, the calculation results are presented in Figure 1.

![Strength assessment of elements. Statistics](image)

**Figure 1.** Assessment of the water structure’s strength: a) the plastic deformations’ formation in the water structure is not taken into account; b) plastic deformations in the water structure are present
Based on the presented data, the force factors’ redistribution during the plastic deformations’ formation the water structure is clearly traced, and as a result, a significant reduction in effort. The water structure’s operability is not impaired.

Let us consider the type of structural damage in the form of the buttress structure’s destruction.

The simulation of the buttress destruction is implemented by excluding the construction of this structure from work. Figure 2 shows a plan diagram with the stages’ designations of shutting down the buttress structure construction from work.

**Figure 2.** The stages’ plan diagram of shutting down the buttress structure construction

The results of the water structure reinforcement calculation and their visualization are presented in Table 1.

**Table 1.** The results of the water structure reinforcement calculation

| Characteristic Values | Visualized water structures | Design Values |
|-----------------------|-----------------------------|--------------|
| Top axial reinforcement «r» | ![Visualization](image) | Min Asro = 0 cm²/m, Max Asro = 16.0816 cm²/m |
| Top axial reinforcement «s» | ![Visualization](image) | Min Asso = 0 cm²/m, Max Asso = 18.3962 cm²/m |
The design scheme of the elevated structures for stage I is presented in Figure 3.

**Figure 3. Calculation scheme for stage I**

The calculation results for reinforcing the water support structure for stage I are presented in Figures 4–7.

The results of calculating the upper reinforcement along the “r” axis and its visualization are presented in Figure 4.
Design Values: Min Asro = 0 cm²/m, Max Asro = 16.1017 cm²/m

**Figure 4.** Visualization and calculation results of the upper reinforcement along the axis «r»

The results of calculating the upper reinforcement along the s axis and its visualization are presented in Figure 5.

Design Values: Min Asso = 0 cm²/m, Max Asso = 18.4834 cm²/m

**Figure 5.** Visualization and calculation results of the upper reinforcement along the axis «s»

The results of the lower reinforcement calculation along the “r” axis and its visualization are presented in Figure 6.

Design Values: Min Asru = 0 cm²/m, Max Asru = 30.76 cm²/m

**Figure 6.** Visualization and calculation results of the lower reinforcement along the axis «r»
The results of the lower reinforcement calculation along the “s” axis and its visualization are presented in Figure 7.

Design Values: Min Assu = 0 cm²/m, Max Assu = 32.692 cm²/m

Figure 7. Visualization and calculation results of the lower reinforcement along the axis «s»

Summary
Based on the presented data, we note that upon destruction of the buttress construction provided for by stage I, there is a slight increase in the required cross-sectional area of the reinforcement for the upper reinforcement. For the lower reinforcement during the destruction of the buttress structure provided for by stage I, there is a significant lack of the reinforcement cross-sectional area. It should be noted that the maximum hydrostatic pressure in the plane of the excluded buttress structure is 84 kH/m². The location of the reinforcement (upper / lower) is regulated by the local coordinate axes’ orientation.

Thus, a type of damage in which the structure’s performance is not ensured - the destruction of the buttress structure was revealed. Other types of damage do not make a significant contribution to the performance of the structure; operability with these types of damage is provided.

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