Possibilities of a dynamic survey method for hydraulic structures

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Abstract. Establishing the category of a hydraulic structure’s technical condition is an urgent task that constantly requires solutions during operation. Both the operating costs and the safe operation will largely depend on the choice of a survey method and its reliability and validity. The method of structural dynamic diagnostics, which is becoming more widespread, is promising and relevant, however, based on the relative novelty of the method, its application requires closer attention, including consideration from the standpoint of numerical modeling.

Introduction

Due to the presence of complex engineering and geological conditions at most of the proposed construction sites, the issue related to the provision of a workable and safe condition of a water structure during its operation is relevant. One of the key factors for the structures of this type is the soil base involvement in the distribution of horizontal forces arising from the shear mass (aquatic environment) located in the elevated basin. In this case, it is imperative that the work of hydraulic structures should take into account the changes in the actual forces acting on the structure, such as the changing the accumulated water mass, its possible dynamic effect during movement, and other factors. Analysis of the behavior of the elevated structure, taking into account the base and the soil foundation, is carried out in a nonlinear setting since the base is the subject to structural change (compaction) due to the alternate application of loads taking into account relaxation (unloading of the ground base) in an empty pool.

The hydraulic structures’ safe operation is impossible without timely diagnosis of their technical condition and it is most rational, that information about the state is received and analyzed constantly, or in accordance with a pre-established algorithm.

The choice of the optimal method, which will allow to establish the category of the hydraulic engineering structure’s technical condition as soon as possible is an urgent task [1, 2, 3, 4]. The dynamic method currently meets all the requirements. It examines the amplitude-frequency characteristics (AFC): frequencies and forms of natural vibrations, characteristics of the oscillations’ damping, as well as the dynamic stiffness analysis; dynamic geophysical parameters of structures. The dynamic method can be used both in express diagnostics of technical condition and as a method of a structure’s continuous monitoring [5, 6, 7, 8]. The dynamic control method allows to determine the category of the technical condition of the inspected object within a few hours, or just as importantly - this method allows remote control of the collecting, analyzing and transmitting data processes to the consumer.
Currently, an additional amount of theoretical and field studies is required to compare the damage degree to hydraulic structures depending on the frequency response for diagnosing defects and developing regulatory documents, as well as determining the category of the structure’s technical condition [9, 10].

**Material and technology**

Let us consider the influence of a defect (local decrease in the concrete elastic modulus, a change in concrete density, a change in the thickness of the structure) of a hydraulic structure on the amplitude-frequency characteristics (AFC). The calculation results obtained by numerical simulation are presented in Table 1. This defect has a significant effect on the structure’s bearing capacity, and it is assumed that the change in frequency response will be in the range of 31-60%, that is, the hydraulic structure will have severe damage and it will be awarded a limited working condition.

**Table 1. Frequency response of a hydraulic structure**

| AFC forms | Visualized views | AFC characteristics |
|-----------|------------------|---------------------|
| Form 1    | ![Form 1](image) | W = 25.23 [rad/s]  
             |                   | f = 4.016 [Hz]    
             |                   | T = 0.249 [s]     |
| Form 2    | ![Form 2](image) | W = 32.92 [rad/s]  
             |                   | f = 5.24 [Hz]     
             |                   | T = 0.1909 [s]    |
| Form 3    | ![Form 3](image) | W = 39.98 [rad/s]  
             |                   | f = 6.363 [Hz]    
             |                   | T = 0.1571 [s]    |

Figure 1 shows the results of a complete move based on the static calculation.
Max displacement = 9.21463 mm at node 10812

**Figure 1.** Full movement

Figure 2 shows the equivalent stresses according to the Huber-Mises theory calculated by the results of a static calculation.

Min SeM = 0.54364 kN/m², Max SeM = 10721.1 kN/m²

**Figure 2.** Equivalent stresses

Based on the dynamic calculation, a decrease in frequency was recorded with an increase in the number of the defective areas. There is also a change in the deformed oscillation pattern at the corresponding frequencies, however, it should be noted that the deformations in the first form are close to the structure’s deformations in the absence of defects, this indicates a significant redistribution of forces in the building structure. According to the static calculation results, we ascertain that the displacements from external influences increase (hydrostatic pressure), there is a significant increase in stresses, the need to increase the reinforcement cross-sectional area in order to ensure the structure’s bearing capacity [11, 12, 13, 14]. Based on the foregoing, it is necessary to appoint the measures aimed at strengthening and restoring the damaged structures’ bearing capacity.

Let us consider the effect of the defect (local decrease in the elastic modulus of concrete, changes in concrete density, changes in the thickness of the structure, exclusion of individual structural elements or the structure as a whole) on the frequency response. The calculation results are presented in Table 2. This defect has a significant effect on the structure’s bearing capacity, and it is assumed
that the change in frequency response will be in the range of 61–100%, that is, the hydraulic structure will have the critical damage and it will be conferred an emergency condition.

**Table 2.** Frequency response of a hydraulic structure

| AFC forms | Visualized views | AFC characteristics |
|-----------|------------------|---------------------|
| Form 1    | ![Form 1 Visualized](image1.png) | $W = 13.34 \text{ [rad / s]}$  
$\omega = 2.123 \text{ [Hz]}$  
$T = 0.4711 \text{ [s]}$ |
| Form 2    | ![Form 2 Visualized](image2.png) | $W = 21.44 \text{ [rad / s]}$  
$\omega = 3.411 \text{ [Hz]}$  
$T = 0.2931 \text{ [s]}$ |
| Form 3    | ![Form 3 Visualized](image3.png) | $W = 25.74 \text{ [rad / s]}$  
$\omega = 4.097 \text{ [Hz]}$  
$T = 0.2441 \text{ [s]}$ |

Figure 3 shows the results of a complete move based on the static calculation.
Max moving = 53.9553 mm in knot 13725

**Figure 3.** Full movement

Figure 4 shows the equivalent stresses according to the Huber-Mises theory calculated by the results of the static calculation.

Min SeM = 0.37612 kN/m², Max SeM = 12716.5 kN/m²

**Figure 4.** Equivalent stresses

Based on the dynamic calculation, a decrease in frequency was recorded with an increase in the number of defective areas. A change in the deformed oscillation pattern at the corresponding frequencies is also observed. According to the static calculation results, we note that the displacements from the external influences (hydrostatic pressure) are critically increased, there is a significant increase in stresses, the need to significantly increase the cross-sectional area of the reinforcement or change the structure’s design to ensure the load-bearing capacity of the structure. Based on the foregoing, it is necessary to appoint the measures aimed at immediately stopping operation, overhaul or demolition.

**Summary**

The use of the dynamic method for the hydraulic structures’ study is appropriate and justified, since a dynamic examination makes it possible to quickly establish the presence or absence of the structure’s defects, including the hidden ones, based on the simulation; the AFC frequency response are confirmed to the defects in the building structure.
The proposed degree of damage to hydraulic structures depending on the changes in frequency response can be used to diagnose the defects and assign a category of the structure’s technical condition.

There is a need to expand the existing regulatory documents in the field of a dynamic survey method for hydraulic structures.

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