Assessment of the hydraulic structures’ technical condition by means of the amplitude-frequency characteristics’ analysis

G V Degtyarev1*, F K Abdrazakov2, N P Lavrov3

1Kuban State Agrarian University, 13, Kalinina Str., Krasnodar, 350044 Russia
2Saratov State Agrarian University Named After N.I. Vavilov, 1, Teatralnaya sq., Saratov, 410012, Russia
3Peter the Great St.Petersburg Polytechnic University, 29, Polytechnicheskaya, St.Petersburg, 195251, Russia

E-mail: cst2007@mail.ru

Abstract. Based on the numerical simulation of the structure, a decrease in the frequency was revealed with an increase in the number of defective sections. A change in the deformed oscillation pattern at the corresponding frequencies is observed. The method clearly makes it possible to increase the hydraulic structures’ efficiency.

Introduction

The hydraulic structures’ safe operation is impossible without timely diagnosis of their technical condition [1, 2, 3, 4].

Assignment of the technical condition categories to structures, buildings, including soil base, is carried out on the basis of the inspection results and verification calculations, depending on the type of object. At the same time, the following control methods were widely used:

– method of evaluating structures by the external features;
– mechanical methods for determining the strength of concrete;
– ultrasonic method for determining the strength of concrete;
– magnetic and radiation control methods;
– laboratory control methods.

The structures of the building, including soil base, are divided into:

– in normative technical condition;
– in working condition;
– in limited working condition;
– in disrepair.

Recently, the dynamic method has been actively developing [5, 6, 7, 8]. This method examines the amplitude-frequency characteristics (AFC): the frequencies and forms of natural vibrations, vibration damping characteristics, as well as the dynamic stiffness analysis; dynamic geophysical parameters of structures. The dynamic method can be used both in express diagnostics of a technical condition and as a method of continuous monitoring of a structure [10, 11]. The dynamic control method makes it possible to determine the technical condition category of the object under examination within a few hours, while the performers group composition is minimal and can consist of 3 specialists - the work manager, engineers for measuring the frequency response and photo fixation works.
Material and technology

However, today there is a significant drawback that limits the widespread adoption of the amplitude-frequency response method - insufficient knowledge of the structures interacting with the liquid, including their amplitude-frequency characteristics, while the regulatory documents establish restrictions of no more than 10% for the frequency response of the structure, this range of 10% is clearly does not allow to determine the presence of damage, because based on the numerous hydraulic structures’ field vibration dynamic studies, in most cases, when the frequency response changes from 0–10%, damage or defects are absent or are insignificant.

In order to develop a classification of the damage degrees depending on the change in frequency response, as well as the criteria for assessing the technical condition of hydraulic structures, we perform the mathematical modeling of the hydraulic structure [12, 13, 14].

Let us consider the types of the most common damage (defects) of the supporting structures for this type of structure:

a) individual small chips, hair cracks;

b) force cracks, presence of decompression of reinforced concrete structures caused by corrosion of concrete, reinforcement;

c) partial or complete structural failure.

The following degrees of damage to the hydraulic structures are proposed for consideration, depending on the changes in amplitude-frequency response:

– no damage – 0 – 10 % – regulatory technical condition;

– permissible damage – 11 – 30% – working condition;

– severe damage – 31 – 60% – limited working condition;

– critical damage – 61 – 100 % – emergency condition.

Methods of modeling defects of the type (a) - we carry out by the local reduction of the elastic modulus of concrete; type (b) - a local decrease in the elasticity modulus of concrete, a change in the density of concrete, a change in the thickness of the structure; type (c) - a local decrease in the elastic modulus of concrete, a change in the density of concrete, a change in the thickness of the structure, with the exception of individual structural elements or the structure as a whole.

It should be noted that the lowest form is the most indicative for the damage analysis.

We determine the frequency response of the hydraulic structure in the absence of defects, the analysis is performed for the first three forms.

The amplitude-frequency characteristics and the visualized deformed model of the structure for various forms are presented in the following Figures 1-3.

The AC characteristics: \( W = 53.38 \text{ rad/s}; f = 8.495 \text{ Hz}; T = 0.1177 \text{ s} \)

Figure 1. Frequency response and visualized deformed model of the structure for form 1
The AC characteristics: $W = 79.66 \text{ rad/s}; f = 12.68 \text{ Hz}; T = 0.07888 \text{ s}$.

**Figure 2.** Frequency response and visualized deformed model of the structure for form 2

The AC characteristics: $W = 84.34 \text{ rad/s}; f = 13.42 \text{ Hz}; T = 0.0745 \text{ s}$

**Figure 3.** Frequency response and visualized deformed model of the structure for form 3

Based on the presented deformed schemes, we can conclude that the weakest zones in the structure for these zones are characterized by the greatest deformations in the corresponding shapes. Based on the foregoing, the defects presented above will be assigned precisely in these areas.

Max displacement = 2.08349 mm at node 13292

**Figure 4.** Full movement
Min SeM = 0.658903 kN/m², Max SeM = 6466.32 kN/m²

**Figure 5.** The equivalent stresses

Let us consider the effect of the defect (a) on AFC, the calculation results are presented in Table 1.

**Table 1.** The results of the impact calculation of the defect (a) on AFC water structures

| AFC forms | Visualized deformed water structures | AFC characteristics |
|-----------|-------------------------------------|---------------------|
| Form 1    | ![Form 1](image)                     | W = 44.93 [rad/s]   |
|           |                                     | f = 7.151 [Hz]      |
|           |                                     | T = 0.1398 [s]      |
| Form 2    | ![Form 2](image)                     | W = 69.78 [rad/s]   |
|           |                                     | f = 11.11 [Hz]      |
|           |                                     | T = 0.09004 [s]     |
Form 3

W = 75.38 [rad/s]
f = 12 [Hz]
T = 0.08335 [s]

Max moving = 2.52233 mm in knot 13292

Figure 6. Full movement

Min SeM = 0.373806 kN/m², Max SeM = 6945.57 kN/m²

Figure 7. Equivalent stresses

Summary
It follows from the presented data, that the previously considered assumption about the effect of defect (a) on the change in frequency response in the range of 11–30% is confirmed by the numerical simulation. It should be noted that there is a decrease in frequency with an increase in the number of defective areas. A change in the deformed oscillation pattern at the corresponding frequencies is observed. Analysis of the stress-strain state (SSS) indicates a slight increase in displacements and stresses in the building structures, which indicates the possible operation of the structure and the statement that damage (defects) of this type are permissible. Based on the foregoing, it is necessary to assign the intermediate repair measures.

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