Management of the technical condition of hydraulic structures

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Abstract. In the process of operation of hydraulic structures it is needed to study these structures for their technical condition, which affects the durability and other structures operational properties. Some defects are impossible or difficult to examine. This is due to the lack of open access for visual inspection. Such defects are cavities formed under reinforced concrete slabs, which protect the dam from erosion. Timely detection and elimination of cavities during repairs extends the service life of dams. Scientifically confirmed methods are proposed, by means of which the problem of finding the location and the volume of cavities under reinforced concrete of ground dams, dams and other hydraulic structures is solved. The research proves that with using the natural pulsed electromagnetic field of the Earth geophysical method it is possible to interpret in terms of the cavities which occur during the inspection of the reinforced concrete fastening of the upper slope of the dams. The authors propose to determine the depth of anomalies by the color of the equal level of the natural pulsed electromagnetic field of the Earth, which corresponds to the depth of the cavities obtained by the method of geoelectric tomography.

1. Introduction

In addition to the inspection of the technical condition of hydraulic structures, in some cases it is necessary to eliminate the causes that threaten the failure of these structures. This is due to the lack of open access for visual inspection. Sometimes such causes are harder to establish than to eliminate. Such reasons include the condition of the soil, which is in contact with the inner surface of the protective reinforced concrete slabs, which are usually laid on the slope of the summit pounds of the earth dam.

Under the influence of reservoir waves, such conditions as branching, erosion, and voids can be formed in the soil under the slabs. If measures to eliminate the cavities under the slabs are not taken, then eventually the dam may collapse under the pressure of pressure and waves of the reservoir. Currently, the problem is which method to determine the location of cavities and establish their volume rather quickly, with little labor efforts. Therefore, the purpose of this research is to develop an instrumental method of inspection of sections of reinforced concrete slabs, which protect the summit pounds of the dam from erosion, detection of voids and determination of their volume.
2. Materials and methods
The object of the inspection is a section of reinforced concrete slabs of the summit pounds of the dam of the cooling pond of Kryvyi Rih TPS of PJSC DTEK DNIPROENERGO within the limits of pickets 75-85 (length 1000 m). The purpose is to detect the location of the cavities under the reinforced concrete cover of the slope of the dam and to determine their geometry with the subsequent calculation of the volume.

2.1. Methods of inspection of reinforced concrete slabs
The most common method of inspection of the fastening of the slopes of dams is a visual method, which captures visible defects (cracks, potholes, concrete delamination, frost destruction, etc.) [1]. Methods of instrumental inspection are the method of non-destructive testing [2], which determines the strength of concrete and checks the integrity of the reinforcement. But what is the state of the system "reinforced concrete slab - bedrock" this method does not give an answer.

A common cause of defects and anomalies between the slabs is the destructive effect of water that occurs with the operation of the dam, when cracks appear, diverge temperature and deformation seams, reduces the layer of gravel under the slabs, and so on. First, the soil begins to be carried out from under the slabs through the seams and through the edges of the slabs. The upper part of the fastening near the crest of the dam is also washed away if there is no concrete parapet, which serves as a barrier to rain flows and no drainage. What is the danger of these phenomena? Over time, the reinforced concrete slab is covered with cracks and the destruction becomes avalanche-like. The earth dam becomes defenseless against pressure and waves of a reservoir.

2.2. Main provisions of research methods by different methods
The methods used in the inspection of reinforced concrete dams and described in scientific publications can be divided into two groups. The first is geophysical methods. These include georadar scanning, electrical exploration [2 - 5]. To the second - one known, it is a method of thermography [3, 6, 7]. When considering and analyzing the publications, we came to the conclusion that the first group uses the most common method is method of georadar [3]. Georadar is used for a wide range of technical tasks that are in one way or another related to the earth's crust. About a few dozen such problems are successfully solved using georadar [9, 12]. In the publication [3] it was found that georadar performed work to detect cavities under the protection slabs in earth dams. We witnessed the verification of the results of georadar by a company that performed a contract with the Kryvyi Rih TPS in 2013.

In research [3] V.V. Glazunov proves that georadar can overcome this trouble, but the interpretation in the article is not convincing enough. Desktop processing is complex, interpretations are ambiguous, the technical report is difficult for the customer to understand. In addition to these disadvantages, there is an economic one: the cost of the device is quite high. The thermal imaging method presented in the same article, which we assigned to the second group [6, 7, 12, 13], is based on distance measurements by a thermal imager. This method has more disadvantages than advantages and worthy results.

First, an expensive device, secondly, a long measurement procedure that requires separate requirements, thirdly requires unique weather conditions (only in summer, the presence of the sun, but when it is before sunset, so that there is no heat), fourthly, the results are such that not quite correct. Figure 1 [3] shows the cavities of the same color as the adjacent areas without anomalies. In general, thermogram analysis includes a proportion of subjective estimates. Any inaccuracy as a result leads to material losses of the customer of works. In research [14] it was also noted that this method is used in the United States as an approximate, evaluating in the early stages of the study, which shows in a fairly large area the affiliation of the anomaly. We completely agree with this conclusion.

One of the modern methods of geophysics is electrotomography as a component of a more general method of electrical exploration, and which is a more accurate and informative method than the georadar method [5 - 8]. This method solves many problems. Solutions to the problems of surveying the integrity of the dam are presented in figure 1. But the use of geophysical method of electrical...
exploration is not suitable for our needs, because the method involves immersing steel electrodes in the soil, which cannot be done through reinforced concrete slabs.

![Figure 1. Geoelectric section of the body of the earth dam.](image1)

Another geophysical method is the method of the natural pulsed electromagnetic field of the Earth (NPEFE). It seems that the method of NPEFE [7] is also not used by anyone for our purposes because it does not answer the question: at what depth are the cavities. No researches were found on this topic. But this method is very attractive because it has one significant advantage over other geophysical methods. It consists in the fact that the radiation waves propagate in the opposite direction, i.e., not from the day surface of the Earth, as in georadar scanning, or in electrical exploration, but from the middle of the Earth. The power of these electromagnetic waves is not large enough, but they penetrate everywhere. Wave frequency from 1 to 50 KHz. Here is a graphical representation of the state of flooding among the urban development of the city made using the method of NPEFE.

![Figure 2. NPEFE scheme in urban development.](image2)

In order to find out at what depth underground the phenomenon appeared, which is reflected in figure 2, it is necessary to drill wells and take soil tests to determine its condition. In other words, the method gives a qualitative assessment of the situation that worries us. Quantitative assessment of soil condition can be obtained by applying to the heap another method that will show this condition by section in depth. Of the more acceptable methods, in our opinion, the method of geophysical tomography is suitable as a component of electrical exploration. In order to apply the two methods together, it would be advisable to overlay one graphic image on the other and as a result have the desired 3D image.

But as mentioned above, the method does not involve working in water, and it is difficult, and virtually impossible, to drive steel electrodes into the ground through reinforced concrete slabs. Given these circumstances, we came to the conclusion that it is necessary to make surveys by both methods.
on a separate experimental site with a pre-known location under the reinforced concrete slabs of the cavities, and with their known geometric dimensions. And then determine at what depth and what size the cavities are depicted and then compare how the image coincides with the natural location and size of the cavities. Finally, make a color image of the depth of the desired cavities using lines of equal level. To ensure the efficiency of the method, a measurement method was developed to examine the upper slope of the dam - cooler with subsequent verification of the coincidence of the results of NPEFE method with the natural location of cavities by local, adjustable drilling holes in the ground through reinforced concrete surface.

3. Theory and calculations
A particularity of electrical tomography is the measurement by the system of electrodes, preliminary placed along the same profile at equal distances from each other. Switching of electrodes is done by a special channel switch-board. The main purpose of this technique is the simultaneous observation of the section along the profile and depth. When working on a limited area, where there are no conditions for placing unboundedness, a dipole configuration is used. For this installation with the same dipoles, the second image can be obtained by displacements the measure point based on the principle of reciprocity, without additional measurements. Modern multi-electrode systems allow increasing the interval of shooting in depth. To visualize the picture, in other words the inversion of field measurements, the res2Dinv program is used, which is based on the quasi-Newtonian optimization method.

3.1 Methods of work performance
A section of the upper slope with two temperature seams, around which cavities usually occur, was found on the dam of the cooling pond of Kryvyi Rih CHP-plant, which is about 6 kilometres long. These cavities could be seen visually through a fairly wide control joint. Cavities are formed just near the joints, because through them the exhausted soil is washed away. The geometry of the cavities was measured in advance with measuring instruments. Surveying was carried out by the method of the natural pulsed electromagnetic field of the Earth, for which there were determined the profiles on which the operator with the RDVINS device will move and fix indicators in measuring points were determined (figure 3).

![Figure 3. Diagram of the location of profiles and measurement points on them.](image)

Operating conditions are satisfactory. The surface of the reinforced concrete pavement along the entire length of the site is smooth, not moistened. On profiles close to water the step of measuring points of 1 meter is accepted, on profiles of 3 and 4 it is 3 meters. Profile 1 is above the water surface. During the measurements, two horizontal components of the method of the natural pulsed electromagnetic field of the Earth were registered: Ex, which coincides with the direction of the profiles, and Ey, orthogonal to the extension of the dam. The results were processed independently for each measurement point. The standard program "surfer" was used for visualization. The results were presented in the form of isoline maps of components Ex and Ey in imp / s.

Zones of high inhomogeneity (flooded and accommodating cavities) are marked in bright yellow. The result is shown in figure 4. Anomalies indicate the belonging of cavities that are selected graphically. The slope width in meters starts from the profile of the 4th dam (figure 3).
Figure 4. Map of lines of the same level of the natural pulsed electromagnetic field of the Earth on the experimental site.

To confirm the values of the depth of the anomalous zones, an experimental study was carried out in the same area by the method of electro geological tomography on the profile with a measurement step of 1 meter.

The measurement technique is as follows:

The EIHN-209M meter was used as an electric field receiver at a frequency of 1.22 Hz in the dipole MN. The ГЕР -1/300 generator is used as a current source (figure 3).

![Figure 3](image)

![Figure 4](image)

Figure 5. a) Scheme of the field installation. AB - supply dipole; MN - receiving dipole. b) The layout of the recording points on the pseudo section.

According to the results of field measurements, pseudo sections are obtained, the construction features of which can be understood from figure 5 b). The extreme left dipole is used as a supplier, and located next to the right of it is as a recipient. The recording point refers to the middle of the installation and to the depth Z, which can be found when drawing lines from the centers of the dipoles at an angle of 45° to the intersection at the recording point.

The measurement technique involves the use of electrodes that are driven into the ground and connected to a conductive wire. We used metal cutter arms as electrodes, which rested on a foam substrate irrigated with aqueous saline solution. The general view of the location of the cutter arms electrodes is shown in the photo (figure 6).

Comparing the results shown in figure 4 and figure 7 we determine that the cavity in the middle of the section (between 8 and 12 meters) corresponds to the depth on the profile of the geoelectrical section of 0.5 meters, area - 0.35 m², volume - 0.175 m³. The entire geometry of the cavity coincides with the previous measurements with an endoscope and measuring instruments. Thus, with the help of this study, we proved the possibility of using two methods of geophysics to accurately assess the state of the underlying layer of earth under reinforced concrete slabs.
Figure 6. General view of the location of the electrode cutter arms on the profile.

Figure 7 shows the tomography profile of the section of the reinforced concrete slab of the dam between the temperature seams with a pre-known location of large cavities under the slabs.

Figure 7. Geoelectrical section.

4. Study of the site of reinforced concrete pavement of the upper slope of the dam

The study was conducted according to the method of the natural pulsed electromagnetic field of the Earth described in the section above. According to the results of this study, the images of the natural pulsed electromagnetic field of the Earth are shown in Fig. 8 by segments of 25 m. Below these images are comments. Counting the width of the site in meters starts from the parapet of the dam.

Figure 8. The image of the natural pulsed electromagnetic field of the Earth:
  a) PC 75+75 – PC 76+00, b) PC 76+00 – PC 76+25.
Selected anomaly is 4, soil erosion at a depth of up to 0.5 m, anomaly 5 is the second part of the void from the previous section (it is located at the junction of sections).

4.1 The results of geophysical survey of the upper slope of the dam of the cooling pond by the method of the natural pulsed electromagnetic field of the Earth

The results of volumes on significant anomalies are shown in the diagram in figure 9.

![Diagram of the estimated volume of anomalous zones in the area from the picket PC 75+00 up to PC 85+00.](image)

**Figure 9.** Diagram of the estimated volume of anomalous zones in the area from the picket PC 75+00 up to PC 85+00.

5. Conclusions

It is established that with the help of the geophysical method of the natural pulsed electromagnetic field of the Earth, it is possible to recognize in the plan of a branch cavity which meets at the study of reinforced concrete fastening of a top slope of dams. The depth of the anomalies is determined by the colour of the equal level of the natural pulsed electromagnetic field of the Earth, which corresponds to the depth of the cavities obtained by the method of geoelectrical tomography (figure 8). Thus the important economic task on timely detection and elimination of destructive defects of dams during their operation in the aggressive water environment is solved.

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