Methods of Surveying the Inlet and Outlet Channels of the Spillway Dam at the Hydroelectric Power Plant

Sergey Evdokimov¹, Vladimir Seliverstov¹, Alla Orlova¹, Elena Rakova¹

¹Academy of Architecture and Civil Engineering of Samara State Technical University, Molodogvardeyskaya St 194, Samara, 443001, Russia

v.a.seliverstoff@yandex.ru

Abstract. The paper deals with methods of the hydroacoustic survey of the outlet, inlet channels of the spillway dam at the Zhigulevskaya hydroelectric power plant and waters adjacent to the earth-fill dam. The survey of underwater parts of hydraulic structures and the bottom of the Zhigulevskaya hydroelectric power plant was carried out with the help of the hydroacoustic method and included full coverage of all surfaces of underwater parts. All deformations of the surveyed surfaces and all foreign objects on them, the size of which exceeded 0.5 m in height, were recorded. The survey of the waters was carried out with tacks of basic coverage based on a system of parallel tacks oriented in parallel and perpendicular to the axis of the structures. The devices used for the survey allowed obtaining coordinate increments in the plan and along the height at the distances of the surveyed waters with an accuracy of not more than 0.1 m and a confidence coefficient of 95 %. When performing the set of works, it became possible to conduct the hydroacoustic survey and create a bathyorographical map for the inlet and outlet channels at the spillway dam. The hydroacoustic survey allowed making a sample-based assessment of the condition of concrete slopes of the outlet, inlet channels at the spillway dam, of the HPP as well as the condition of slope protection at the earth-fill dam in the waters of the upper pool. The analysis of the survey results helped to evaluate the dynamics of the deformation process taking place at the bottom of the outlet, inlet channels at the spillway dam, the HPP and in the waters around the earth-fill dam. As a result, measures for the operational reliability of structural elements in the outlet, inlet channels at the spillway dam, the HPP and in the waters around the earth-fill dam were developed. In addition, according to the results of the hydroacoustic survey of the outlet, inlet channels at the spillway dam of the Zhigulevskaya HPP, a new bathymetrical map was created.

1. Introduction

The scheduled acoustic surveys of the outlet, inlet channels at the spillway dam (SD), Zhigulevskaya hydroelectric power plant (HPP) and adjacent waters around the earth-fill dam resulting in creation of bathymetrical maps and profiles are conducted regularly every 5 years. Last time such works on the hydroacoustic survey were undertaken in autumn of 2013. The current survey was aimed at:

1) a sample-based video recording of the condition of concrete slope protection of the outlet, inlet channels at the SD and the HPP as well as the slope protection at the earth-fill dam in the waters of the upper pool made according to the results of hydroacoustic survey;

2) evaluating the deformation process that affects the bottom of the outlet, inlet channels at the spillway dam, the HPP as well as in the waters around the earth-fill dam, taking into account previous surveys;
3) developing and implementing measures aimed at increasing the operational reliability of structural elements in the outlet, inlet channels at the spillway dam, the HPP as well as in the waters around the earth-fill dam.

2. Materials and methods

The survey of underwater parts of hydraulic structures and the bottom of the Zhigulevskaya HPP was carried out with the help of the hydroacoustic method. It covered 100% of all surfaces. According to the results of the survey, all deformations of the surveyed surfaces and all foreign objects on them, the size of which exceeded 0.5 m in height, were recorded. Hydrographic surveying of the waters was conducted with the hydrographic complex AMC "SCAT" made by Scientific Production Association "Fort 21", including the following devices: the surveying echo sounder by the company LOWRANCE LMS-337CDF with a two-frequency emitter 50 kHz and 200 kHz; a side-scan sonar SportScan; satellite radio navigation systems "Trimble 5700" "Topcon" [1].

A detailed survey of the waters was carried out by tacks of basic coverage based on a system of parallel tacks oriented in parallel and perpendicular to the axis of the structure. To obtain the necessary full information about the condition of the surveyed underwater surfaces, extension of the tack system was conducted. It ensured the mutual overlap of the survey strips. The devices used for the survey allowed obtaining coordinate increment in plan and along height at the distances in the surveyed waters with an accuracy of not more than 0.1 m and a confidence coefficient of 95%. The correction of water level fluctuations in the lower pool was made at intervals of 3 minutes, and all depths were recalculated according to the Baltic System of Heights. Thus, the maximum total error of determining the planned and altitude position of surveyed objects was no more than 0.1 m.

When performing the above mentioned set of works, it became possible to conduct a hydroacoustic survey resulting in creating a bathyorographical map for the inlet and outlet channels at the SD.

3. Results and discussions

The inlet channel of the Zhigulevskaya HPP is designed to pass the estimated flow rate of more than 29 thousand m$^3$/s, which must flow through the water passages of all units of the HPP building and bottom discharges. In the upper pool of the hydroelectric complex above the HPP building there is a trash-rack structure (TRS), resting on the foundation slab, which is connected with the HPP building by the anchor blanket (Fig. 1). The length of the inlet channel along the axis is 400 m. The average flow rate during the flood period is 1.5 m/s [1, 10].
The channel is formed by cutting off the right bank and deepening the Volga riverbed. The left bank of the inlet channel is an earth levee. The channel has a curvilinear outline with a concave right bank. The shape and size of the channel in the plan are defined by the location of the HPP building, two-thirds of which are embedded in the right bank of the Volga river, and by the hydraulic conditions of the flow approach in the upper pool to the HPP building. In the inlet channel, the wide ledge of the right bank’ rock mass emerges into the riverbed, thereby slightly constraining the living section of the channel during the summer period [2, 3, 4].

The right bank of the inlet channel in the area, adjacent to the HPP, cuts into the non-rock soils of the gully sediments and from any height has the coefficient of slope \( m = 4 \) (Fig. 2). On the slope there are two berms 6 m wide at level marks of 26.0 and 44.5 m.

To protect the slopes against wave action and flow velocities, they are covered with concrete slabs sized 10x10 m in the plan, whereas the thickness of the slabs within the marks of 58.5 - 44.5 m equals 0.5 m, and below the mark of 44.5 m it is 0.35 m.

Along the slope toe at the bottom of the channel there is a basis made from concrete slabs sized 9.6x6.0x0.35 m and a stone prism 2 m thick. In the area, adjacent to the HPP, this basis is abutted with the blanket fixing.

In the input section, the right slope of the inlet channel cuts into the rock mass. The ratio of underwater slope below 50.0 m is taken to be \( m = 1 \) (Fig. 3). At this mark point, there is a berm 10 m wide, above which the slope is made with the gradient of \( m = 5 \). Every 15 m along the slope height there are berms 5 m wide.
To give a smooth outline to the channel entrance a soil dump is formed upstream the right bank, which is outlined in the plan along the curve. The top of the dump is taken at the level of 44.5 m. To protect it against erosion caused by the flow passing during the construction works, the dump at the section adjacent to the inlet channel is protected by a banked earth from quarry waste [5, 6, 7].

In the zone of water level fluctuations between the mark points of 44.5 - 58.5 m, the slope is protected with concrete slabs 0.5 m thick, and below with a layer of stone 1 m thick. The width of the inlet channel at the bottom is 500 m.

Earlier, a survey of the inlet channel was carried out by a specialized Department of Underwater Engineering Works. According to the results of the survey, a plan was drawn up in the contours of the inlet channel. 19 longitudinal and 4 transverse profiles, as well as 3 characteristic profiles along the riverbed of the inlet channel were made.

The analysis of these surveys showed that the overall condition of the channel is satisfactory. In the area of the former excavation pit the bottom level points vary from 18.0 m to 20.0 m, i.e. fluctuate near the design level which is equal to 19.0 m [8, 9].

The narrowest strip of the non-stabilized bottom of the channel is located on one of the slots of the upstream cofferdam of the HPP pit, where the bottom level marks vary from 18.0 m to 15.85 m. These lowered bottom level marks are located at a distance of 400 m from the axis of the HPP unit.

From the left bank the channel bed is cramped by the remains of the upstream cofferdam of the HPP pit, the maximum level marks of which are in the range from 24.0 m to 24.42 m.

The second lowered section of the channel is located at a distance from 170 m to 330 m from the axis of the HPP building units. The minimum bottom level marks of this section are in the range from 16.0 m to 15.12 m. The main body of the water stream flows along this strip of the inlet channel. Consequently its rate is higher in here than outside this channel bed which is located between the marks of 20.0 m.

The third section of the lowered channel bottom is located near the sloping abutment of the longitudinal part of the levee № 49 and the channel bottom. This section is limited by a strip of sediments which is about 140 m long and 25 - 30 m wide. The bottom level marks of this section are lowered from the level of 19.0 m at a distance of 210 m from the axis of units to 16.50 m at the end of the channel.

The approximate volume of sediment in the 20 m strip in front of the TRS is about 11000 m$^3$. At present, this sediment has virtually no impact on the operation of TRS and its hydro-mechanical equipment.

The survey has shown that the right slope of the channel causes no concern.

According to the results of the diver survey conducted on concrete slopes at a depth of 3.0 m there are sediments consisting of a dense layer of silt, stones and shells. Visible destruction of concrete slopes and displacement of retaining wall slabs were not detected. Temperature seams are in a satisfactory condition.

The outlet channel of the HPP building (Fig. 4) is formed by cutting into the right bank and deepening of the Volga riverbed. On the left, the channel is limited by a levee, the length of the outlet channel is 300 m. In the outlet channel at a design flow rate of 29600 m$^3$/s above the spillway apron, a surface mode is formed with velocities at the surface of 10.0 - 12.0 m/s. In the unprotected part of the outlet channel the velocities are aligned vertically and reduced to an average value of 2.5 - 3.0 m/s.
Fig. 4. The outlet channel of the HPP

The bottom level mark of the outlet channel is defined by conditions of water flow passage during the riverbed closure and is equal to 15.0 m. The axis of the outlet channel at the output section is located at the angle of about 37° with respect to the bank. The width of the channel at the bottom varies from 600 m at the HPP to 520 m at a distance of 300 m from the levee of the left bank.

The bottom of the channel is composed of dense clays and loams. The right bank slope of the outlet channel near the HPP building is located in non-rock soils, consequently the ratios of slope are defined by the stability condition $m = 4$ from the bottom level mark to the level mark of 34.0 m and $m = 3$ from the level mark of 34.0 m to the level mark of 42.0 m.

On the slope there are berms 3 m wide at 27.0 m and 34.0 m levels. The channel slope in this section within the fluctuation of water levels is protected with concrete slabs. Along the length of the channel, the slope protection is elongated to 50 m over the apron plunge pool. In the lower part of the slope from the bottom of the channel to the level of 34.0 m slabs are from 1.25 m to 0.75 m thick. The thickness of slabs decreases in the direction of the flow. From 34.0 m to 42.0 m level marks, slabs are 0.5 m thick. In the section with concrete reinforcement along the slope toe there is a basis made of concrete slabs sized 15,0x7,5x1,25 m, which lengthens into a flexible up-stream slope protection of the plunge pool made of slabs sized 3,0x3,0x0,3 m.

50 m below a plunge pool of apron and to the end of outlet channel the lower part of the slope passes through the rocky soils (Fig. 5) and the upper part – through fragmental rocks and non-rock soils (Fig. 6).

Fig. 5. The right slope of the outlet channel in rocky soils
Fig. 6. The right slope of the outlet channel in soft soils

The base of the apron is composed of dense clays and loams. The length of the horizontal part of the apron is 110 m, and the width is 520 m. The final section of the apron serves as an anchor for flexible protection of the plunge pool’ upper slope. The slabs of the apron are laid on a concrete mat, underlain by a three-layer reverse filter 0.9 m thick. The level mark of the apron horizontal section is equal to 15.0 m.

The ratio of the upper slope of the plunge pool is m = 4. The slope is protected with flexible slabs sized 2x2x0.3 m. Slabs are laid on a stone layer 0.85 m thick, underlain by a three-layer reverse filter 0.5 m thick.

Surveys of the outlet channel of the HPP building showed that on the large part of the horizontal apron the bottom level marks are higher than the design ones and they are in the range from 15.1 - 15.2 m to 15.6 - 16.0 m, whilst on the right bank they are below 1st and 2nd HPP sections – up to 18.0 - 18.55 m.

On the horizontal apron there are separate sections where the level marks of its surface are below the design marks. These sections of the apron are located behind the 4th, 8th and 9th sections of the HPP building. On the plunge pool’ upper slope the lowering of marks reaches up to 0.4 m behind the 4th section of the HPP, and behind 8th and 9th sections – up to 0.10 - 0.15 m.

Along the length of the plunge pool sediment deposition or stone rip-rap can be observed. All lower slopes of the apron are eroded mainly in the upper part to a depth of 0.2 m on the profile № 15 to 3.4 m on the profile № 6. Only on the profile № 5 no erosion is observed but there is sediment deposition or stone rip-rap 1.6 m thick.

Thus, the comparative analysis of data obtained after surveying sections at the Zhigulevskaya HPP and hydroacoustic surveys allowed concluding that alternating-sign reforming of the bottom outside the plunge pool is taking place. To prevent the increase in the depth and planned dimensions of the erosion pit, it is necessary to follow the design procedure of operating the HPP units and spillways. At the same time, the mode of flow passage through the spillway front of the HPP building should be uniform along the entire length. Behind sections 2 and 4 it is necessary to reduce the level of the banked earth, which will reduce the swirling areas in the stream: along the current up to 50 m and against – up to 50 m. These deposits should be leveled to the average bottom level mark of 12 - 13 m in this section, which is about 12500 m³ of soil, and they should be moved downstream behind section 3. In addition, it is necessary to dump rock behind sections 2, 3 between the profiles 4, 5 and 6, raising the top of the dumping to the level of 12 - 13 m. According to the results of the diving survey, the visible destruction of concrete slopes and the displacement of the retaining wall slabs were not detected, the temperature seams are in satisfactory condition.

According to the results of the hydroacoustic survey of the inlet and outlet channels of the spillway at the Zhigulevskaya HPP, a bathymetrical map was created.
4. Conclusions
1. The results of the survey made it possible to evaluate the dynamics of the bottom deformation of the outlet, inlet channels of the spillway at the Zhigulevskaya HPP. In addition, the results allowed assessing the condition of concrete slabs of the outlet, inlet channels of the spillway at the HPP as well as the condition of slope protection at the earth-fill dam in the waters around the upper pool.
2. The revealed process dynamics made it possible to develop measures aimed at increasing the operational reliability of structural elements in the outlet, inlet channels of the spillway dam, the HPP and in the waters around the earthen dam.

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