Research on the Stress-Strain State of the Base of Operating Low-Pressure Hydraulic Structures

PaluanovDaniyar, KulanovJakhongir, GadaevSodik, SaidovFarid

Abstract---The analysis of the stress-strain state of one of the operated low-pressure hydraulic structures on weak soils is considered in the paper. Calculated model on estimation of technical condition of designed and operated HS (hydraulic structures) and their bases taking into account a load of own weight of structures and hydrostatic pressure of water of the upper high relief is offered.

Keywords: low-pressure hydraulic engineering structures, base, stress-strain state, weak soil, load, the hydrostatic pressure of water, weight of structure.

I. INTRODUCTION

Operation of low pressure hydraulic structures (HS) is an important task to ensure reliability and safety of their operation. Analysis of HS destruction shows that the accident rate of low-pressure HS is higher than for high and medium pressure structures. This is explained by the fact that there are no normative documents and research works, the necessary funds are not allocated for repair works, etc.

The most responsible GTS of I-III class safety requirements are satisfied in full, and for low-pressure structures of IV class are not satisfied in full and in some cases are not satisfied. The majority of low-pressure hydraulic structures in the republic were built in the middle of the XX century and by the present time have partially or completely exhausted their resource.

At present, due to the lack of monitoring studies and proper maintenance, there is a decrease in the level of safety of low-pressure hydraulic structures.

In recent years, a significant number of scientific papers in this area have been published [1-8]. Despite certain achievements of science in this area, there are still no well-founded methods for calculating the basis of low-pressure concrete HS. In the absence of methods for calculating the base of concrete low-pressure HS is of great importance to develop effective and economic methods of calculation to improve the reliability and safety of operating structures and their bases.

Revised Manuscript Received on 10 October, 2019.

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As an example, we give the water outlet structure of the Mezhdurechenskoye water reservoir of the Republic of Karakalpakstan. The selected structure is characterized by the following parameters: total capacity 450 million m3; NPU 57.00; mirror area 320.5 km2; 4-spillway regulator with a diaphragm and span length - 5 m; deep flat gates with a cross-section - 5x4 m; threshold mark - 51.8 m; head - 5.2 m; length of the structure - 87 m; construction height - 8.0 m.capacity - 360 m3/s, construction capital class - 3; seismicity of the construction area - 6 points (Fig. 1).

Fig. 1. The water outlet of the Mezhdurechenskoye reservoir on the downstream side

The selected section of the construction area is represented by alluvial sandy loam (0.3-3.8), loam (0.6-5.8 m) and dusty sands (0.4-4.5 m). Below these layers there is an overlaying of sandy loam, loam and dusty sands. Physical and mechanical characteristics of soils: modulus of elasticity (E): sand - 15,6 MPa; sandy loam - 24,2 MPa; loam - 5,5 MPa; density of sand and sandy loam - 1,81 t/m3; loam - 2,03 t/m3; angle of internal friction (hail.): sand - 17,3; sand - 20,4; loam - 11,6; cohesion (C): sand - 25 kPa, sand - 20 kPa, loam - 25 kPa [9].

In order to calculate stability and strength parameters of operated low-pressure HS, it is necessary to determine the stress-strain state of the dam base. At present, there are various methods; however, recently in Uzbekistan a method has been used, which establishes the deformation states of the HS base for monitoring the safety of structures. An example of this is the research conducted jointly with the Institute of Mechanics and Seismic Resistance of the Academy of Sciences of the Republic of Uzbekistan in some large HS on the territory of Uzbekistan. Geometric dimensions of the calculated model (Fig. 2): thickness of each ground layer is equal and makes up - 2,3 m; height of the structure - 8 m; length - 87 m; length of the base before and after the construction is accepted - 30 m; water depth of the upper reach - 7 m; density of the structure body - 2,5 t/m3. All physical parameters of the water outlet structure were used in the calculation.

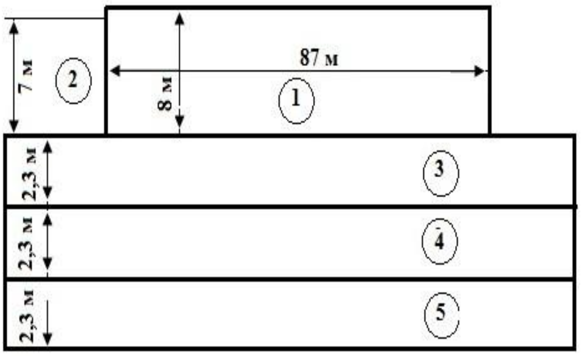


Fig. 2. Calculation model for the base of low-pressure HS

1-concrete structure; 2-upper tailrace of the structure; 3,4,5-ground base, sand, loam and sand, respectively

The model was calculated using the finite element method (FEM). The initial equation in calculating FEM is the variation equation of the principle of possible equations, according to which the sum of all the forces on the possible displacements is equal to 0 [10,11].

$$-\int_{V_n} \sigma_{ij}\delta\varepsilon_{ij}dV_n + \int_{V_n} \vec{f}\delta\vec{u}dV + \int_{\Sigma} \vec{P}\delta\vec{u}d\Sigma = 0,$$

$$i, j = 1,2, \; n = 1...3 \qquad (1)$$

Here: ε_{ij}, σ_{ij} - respectively, deformation and stress tensors; $\delta\vec{u}$, $\delta\varepsilon_{ij}$ - isochronal variations in displacements and deformations; $\vec{f}$ - mass force vector; $\vec{P}_1$ - vector of external forces (hydrostatic water pressure) applied to the surface [11].

The following boundary conditions for the model under consideration are accepted:

- the lower boundary of the model is rigidly fixed, i.e. there are no possible movements along the axes

$$y = 0; \; \delta u = \delta v = 0 \qquad (2)$$

- there are no horizontal movements on the side borders of the base, only vertical movement is possible

$$x = \pm L; \; \delta u = 0 \qquad (3)$$

- on the surface of the upper tailrace, including the bottom of the upper tailrace of the structure, hydrostatic water pressure acts;
- There is no load on the tailrace and above the structure.

In general, it should be noted that the value of tangential stresses is significantly lower than normal stresses in the model at a given load from its own weight and hydrostatic pressure of water. It is the normal stresses that form the main (tensile and compressive) stresses in the system under consideration, as shown in Fig. 3 и 4.

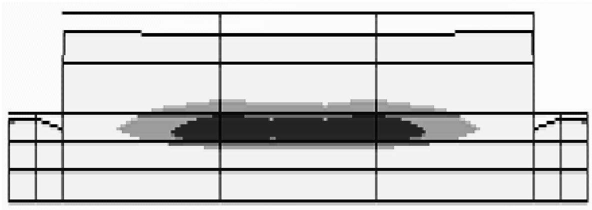
Figure 3 shows the main voltages. These positive stresses are small and only occur at the border of the concrete structure and weak soil.

a) Main voltages $\sigma_{1max} = 0{,}08$ MPa

0÷0,009 (light area)

0,009÷0,0267 (darker area)

0,0267÷0,044 (dark area)



б) Main voltages $\sigma_{1max} = 0{,}054$ MPa

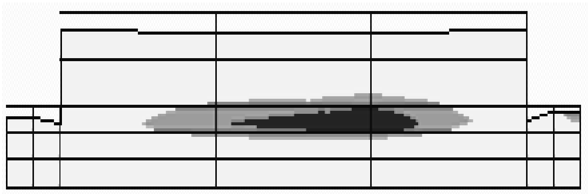


Fig. 3. Deformation state of the base under the influence of its own weight (a), weight and hydrostatic pressure of water (b)

Thus, the applied load leads to tensile stresses only in the area of direct contact of the ground with a rigid structure. And the effect of hydrostatic load, the maximum horizontal component of which falls just on the contact zone stretched under the influence of the structure weight, causes reduction of this zone and, accordingly, reduction of tensile stresses in it from $\sigma_{1max} = 0{,}08$ MPa (Fig. 3a) to $\sigma_{1max} = 0{,}054$ MPa (Fig. 3b).

RESULTS & DISCUSSIONS

The analysis shows that only the weight of the structure (Fig. 3a), the weight of the structure and the hydrostatic pressure of the water (Fig. 3b) cause minor deformation in the middle of the first layer of soil. This is explained by the fact that the safety of the structure and its foundation is ensured taking into account the safety of the body itself and the foundation of the structure.

The main voltages repeat both the distribution pattern and the numerical values of the vertical voltages. This is confirmed by the fact that as the vertical load increases, the structure and base itself are deformed (Fig. 4).

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a) Main voltage σ_3 (MPA)
0,05÷0,134 (white area)
0,134÷0,213 (grey area)
0,213÷0,292 (dark area)

б) $\sigma_{3\max} = 0{,}296$ MPa

в) $\sigma_{3\max} = 0{,}297$ MPa

Fig. 4. Deformation state of the base under the influence of own weight (b), weight and hydrostatic pressure of water (c)

In this case, the safety of the structure and the base cannot be ensured, as the specific safety measures for their operation are not taken into account.

As it is known, the analysis of the stress-strain state of the base can be performed by a numerical characteristic called the equivalent voltage, defined by the formula

$$\sigma_{экв} = \frac{1}{\sqrt{2}}\sqrt{(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{yz}^2+\tau_{xy}^2+\tau_{zx}^2)} \quad (4)$$

and with flat deformation. $\tau_{xz} = \tau_{yz} = 0$; $\sigma_z = \mu(\sigma_x+\sigma_y)$ by the formula

$$\sigma_{экв} = \sqrt{(\sigma_x-\sigma_y)^2+\sigma_y\sigma_x+3\tau_{xy}^2} \quad (5)$$

Figure 5 shows comparative values of equivalent voltage, which serves as a characteristic indicating the possibility of transition of the area to a plastic state.

a) Equivalent voltages (MPa)
0÷0,1 (whitearea)
0,1÷0,2 (greyarea)
0,2÷0,3 (darkarea)
б) Maximal values 0,263 MPa

в) Maximal values 0,264 MPa

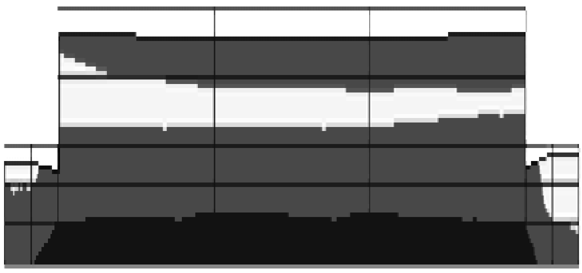

Fig. 5. Deformation state of the base under the influence of own weight (b), weight and hydrostatic pressure of water (c)

The flat system distribution $\sigma_{экв}$ practically repeats the conclusions made in the analysis of vertical stresses, not only in qualitative but also in quantitative terms. This is due to the fact that the system experiences vertical loads, mainly due to the gravity of the concrete structure, as the horizontal - hydrostatic water pressure on the upper embankment - is low due to low water levels.

If the value $\sigma_{экв}$ is found, the problem about the measure of danger of the stress state for certain parts of the model can be considered solved, because the criterion of transition from elastic to plastic state is the largest shear stress at the point $\tau_{\max}$.

$$\tau_{\max} = \frac{\sigma_{экв}}{2} \quad (6)$$

In this case, the most dangerous, plastically deformed zone is the lower zone of the loamy layer system, which experiences the greatest vertical loading. The maximum $\sigma_{экв}$ is achieved here (compare with Fig. 3). The increase in the grey area of the upper tailwater zone means an increase in stress caused by hydrostatic loading.

II. CONCLUSIONS

1. One of the most important problems in hydrotechnical construction is the design, construction and operation of low-pressure hydraulic structures and their bases in the absence of so far developed regulatory documents. These regulations, which have been developed so far, do not economically meet the requirements or increase the cost of construction or operation of low-pressure HS. Research is done only to alleviate this problem, or the results of research do not reflect the true picture of the actual site. The model being implemented is widely used in the implementation of the State Programs in this area to address the problems of low-pressure HS.

2. Different components of the stress-strain state of the base of low-pressure HS are determined and analyzed taking into account their own weight and the influence of additional load from hydrostatic water pressure on them is estimated.

3. In general, the influence of hydrostatic load on the stress-strain state of the base of the considered object in this problem is relatively insignificant. It is explained by the small depth of water of the upper high relief, forming hydrostatic load, the value of which is insignificant in comparison with the load from own weight of the structure.

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Retrieval Number: A2953109119/2019©BEIESP
DOI: 10.35940/ijeat.A2953.109119

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