Experimental research on the determination of the filtration characteristic on the base of low-pressure hydraulic engineering constructions on complex multi-layer ground

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Abstract. In this study, the issue of studying the filtration flow characteristics of hydraulic engineering constructions designed by building a hydrodynamic grid for the filtration flow area using the method of electrohydrodynamic similarity is considered. Given there is complexity and diversity of filtration deformation problems in base of hydraulic engineering constructions, we conduct experimental studies to determine the filtration flow characteristics in base of low-pressure hydraulic engineering constructions in a special model to determine the overall picture and qualitative assessment of these processes. Before observing the filtration deformation processes in the construction soil, the filtration coefficients of the soils in the soil were determined using the Darcy device. The purpose of determining the filtration coefficients of soils is the importance of using the value obtained in the laboratory under experimental work. Based on the experimental studies, graphs of the average filtration flow rate and specific flow rate depending on the water pressure were constructed. The theoretical results obtained were compared with existing analytical methods.

1. Introduction

In recent years, in the context of water scarcity, much attention has been paid to the design and construction of low-pressure hydraulic engineering constructions (HEC), the rational use of existing ones. Low-pressure HEC, built from concrete and ground material, plays an important role in water use management not only for irrigating agricultural crops, but also in the socio-economic sectors of the country. World practice shows that the construction of low-pressure HEC is widely used as an effective solution in order to mitigate the supply of water resources in complex engineering-geological conditions and in areas with water shortages.

One of the biggest problems in low-pressure HEC today is the lack of regulatory documents for the design and construction of low-pressure HEC. However, the implementation of in-kind observations remains a very complex issue due to the fact that the installation of control-measuring instruments is not envisaged in the low-pressure HEC. In particular, these facilities face a number of difficulties in conducting research, in particular, in conducting experimental research, in determining the filtration characteristics of the soil of the structure [1-3].

In all cases, the design of the ground connection of HEC must take into account the possible changes in the filtration and strength characteristics and deformation of the base during the construction and operation of the structure. At present, the theoretical basis of hydraulics is not
sufficient to determine the filtration research processes in the base of the structure in solving many issues related to the design and construction of HEC. Therefore, experimental research is an important tool to fill the gaps in the theory and development of computational theory of HEC and their bases. In practical work, the design and construction of HEC on geologically diverse soils face very complex problems due to the presence of soft grounds [4-9].

Given there is complexity and diversity of filtration deformation problems in base of HEC, we conduct experimental studies to determine the filtration flow characteristics in base of low-pressure HEC in a special model to determine the overall picture and qualitative assessment of these processes. HEC usually have a relatively small width, so the flow conditions of the filtration current in their base require a spatial solution of the problem, which in the current state of filtration theory allows modeling only by the electrohydrodynamic similarity (EHDS) method.

2. Materials and methods

In practice, the characteristics of the filtration flow for dams (pressure, pressure gradient, flow rate) should be determined by the EHDS method, which confirms the need to perform filtration problems in this method. In the developed EHDS model, research is conducted to build a hydrodynamic grid in the dam floor and to determine the filtration rate and flow rate in the dam floor [10].

Using the EHDS method, it is possible to build a hydrodynamic grid of motion. In practice, they are often limited to finding lines of equal pressure (equipotentials), as well as flow lines perpendicular to lines of equal pressure are drawn graphically. It is the most convenient and simplest bridge-based measurement method for determining equipotential lines [11,12].

The study of pressure filtration processes in hydraulic engineering using computer programs is actively developed in foreign countries. This created an opportunity to adopt optimal design solutions, improve their quality, increase reliability and efficiency. One such program is the construction of a hydrodynamic grid of computer-generated filtration flow. The permeable floor is prepared on a scale covering the area of the filtration flow. The main criterion for the correct construction of a hydrodynamic grid is the equality of the flow rate in each selected flow line. Typically, in practice, the hydrodynamic grid is divided into ten belts (according to the number of divisions in a decade). The flow lines are constructed graphically according to the rules of hydrodynamic grid construction. We keep in mind that it is not advisable to prepare a model with an area of less than 200 cm.

3. Results

The order of the experiment. The concrete dam model is drawn on a scale based on a computer program along with the permeable floor (Figure 1). The water pressure H (difference between the levels of the upper and lower pools) is divided vertically into 10 equal parts and horizontal lines are drawn according to 0.9H, 0.8H, and so on. By connecting the obtained points, the state of the flow line is drawn. Equipotentials (lines of equal pressure) are constructed. Flow lines are constructed using the properties of a hydrodynamic grid. Conditions for building a hydrodynamic grid [11] are:

a) flow lines and the lines of equal pressure must be orthogonal, i.e. they intersect at right angles;
b) lines of equal pressure shall be orthogonal at the points of connection to the contour of the structure and the waterproof line;
c) flow lines at the points where the upper and lower pools meet the base lines must also be orthogonal;
g) grid should be formed by curved squares;
d) if the waterproof line is located at a significant depth, then the flow line located at the depth of the active filtration zone is considered to be a waterproof line.

Before observing the filtration deformation processes in the construction soil, the filtration coefficients of the soils in the soil were determined using the Darcy device. The purpose of determining the filtration coefficients of soils is the importance of using the value obtained in the laboratory under experimental work. The soil of the first layer is loamy, its filtration coefficient $k = 0.007$ m/day. The second layer of soil is sand, the filtration coefficient of which is $k = 71$ m/day [1].
Procedure for calculating experimental data. 1. In Figure 1, the characteristic values of $\Delta L$ and $\Delta S$ are taken from the initially constructed hydrodynamic grid and converted to natural values. The value of $\Delta L$ is the average value of the rectangle along the length of each consumable strip; $\Delta S$ is the average value of the rectangle along the vertical.

2. According to the rules of construction of a hydrodynamic grid of motion, an equal pressure line divides the filtration area into an equal pressure belt ($\Pi$). The intervals between two adjacent flow lines are called consumption tapes ($L$) and, according to the construction conditions, the consumption passes through each tape, which does not interfere with the consumption passing through the other consumption tape.

3. The speed of movement is determined by the formula of the Darsi:

$$V = k \cdot i = k \cdot \frac{H}{\Pi \Delta L}$$

where $k$ – ground filtration coefficient, m / day.

4. Filtration consumption is equal to one meter of soil length (perpendicular to the drawing plane) through a single strip, namely the specific consumption is as follows:

$$q = V_{mid} \Delta \omega = V_{mid} \Delta S \cdot l = k \cdot \frac{H \cdot \Delta S}{\Pi \cdot \Delta L}$$

The comparison should be summarized by the number of consumption tapes.

5. Graphs of average motion filtration rate and specific consumption are constructed.

6. According to the analytical formula of academician N.N. Pavlovsky [13], the value of filtration consumption at the dam floor is determined:

$$q = \frac{H}{k \cdot \zeta_{ent} + \frac{l}{T} + \zeta_{exit}}$$

where $q$ is the specific filtration consumption, m$^3$/s; $\zeta_{ent}$ and $\zeta_{exit}$ – coefficients of resistance of input and output elements of the underground contour; $l$ is the length of the underground contour; $T$ is the active layer of the ground.
Based on the results of the calculations, we construct graphs based on the results of the average filtration rate and specific consumption for each pressure values (Figures 2 and 3).

The relative consumption and velocity values in the sandy ground and sand layers of the construction ground are represented in the graphs.

We determine the value of the filtration rate at the dam floor by the theoretical formula (4), where $\zeta_{ent} = \zeta_{exit} = 0.44$, $T = 6$ m. Then the filtration cost is equal to:

- $q = 0.000104 \text{ m}^2/\text{s}$.

This explains the closeness of the filtration costs determined theoretically and experimentally, and the correctness of the calculation procedures.

**Figure 2.** Graph of relative consumption dependence on pressure

**Figure 3.** Graph of dependence of filtration speed on pressure

4. Conclusion

In the computer-developed EHDS model, the filtration flow characteristic (pressure, pressure gradient, flow rate, specific flow) in the base of low-pressure HEC was determined by constructing a hydrodynamic grid. The specific consumption of the filtration flux detected in the experimental studies was compared with the value determined using theoretical methods, and the results showed that $q_{eks} = 0.0001 \approx q = 0.0001 \text{ m}^2/\text{s}$.

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