Research of fracturing in the body of ground water dams

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Abstract. The basic principle of centrifugal modeling is given. The main similarity relationships when modeling earth dams using a centrifuge: density, relative deformation and stress are the same, which makes it possible to predict the assessm ent of cracking in more detail. Great attention is always paid to the reliability and safety of hydraulic structures. On the other hand, performing scientific research work, it is possible to understand that the reliability of underground water dams, their safety and serviceability are directly dependent on the dam's resistance to cracking. Scientific studies have confirmed the assumption that the main unevenness of the sediments is related to the manifestation of subsidence deformations of the coastal slope during the filling of the reservoir. Pre-moistening of the foundation makes only a part of the deformations of the settlement, therefore, when filling the reservoir, relatively large settlements of the foundation and their significant unevenness can be expected. The results of our scientific research will be reflected in future studies of the effects of lake sediments on water reservoirs.

Keywords. Dam, model, density, deformation, stress, sensor, crack, soil, filtration.

1 Introduction

Great attention is always paid to the issue of ensuring the reliability and safety of hydraulic structures. In turn, the reliability of groundwater dams, their safety and operational suitability are directly dependent on the crack resistance of the dam [1].

Knowledge of the causes of the crack is necessary both to determine its danger to the structure and to develop measures for healing cracks. As evidenced by the data of field observations [5,6,13,14], the most common and dangerous type of damage to groundwater dams is the formation of through transverse cracks on the crest of the dam due to uneven deformations of the dam body material or its base.

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For each specific case of dam design and construction, there may be specific measures to prevent cracking, consider them in relation to the operated groundwater dam of the Nizhne-Alaarchinsky reservoir (Republic of Kyrgyzstan). The maximum height of the dam is 41.5 m, the length along the ridge is 2.3 km, the slopes are laid from 1:3 to 1:10. The estimated density of the soil skeleton in the body of the dam is 1.75 t/m^3.

According to the engineering and geological conditions of the valley, the Ala-Archa River is composed mainly of sandy-gravel and gravel-pebble soils with layers of sandy loam and loam.

The sections of the base of the dam's abutment to the sides are composed of loess macroporous loam. Their total depth capacity reaches 100 m. Among the loams there are plastered horizons with gypsum interlayers up to 0.3 m. Gypsum is powdery, its amount does not exceed 10 ... 12%. In addition, individual small crystals and druses of gypsum are noted in the loam thickness [2, 7, 8, 9].

The depth of groundwater ranges from 8 m for floodplain areas and up to 40...50 m in the watershed.

According to laboratory studies in the granulometric composition of soils, the predominant fraction is pulverized, the content of which in the soil varies from 40.5 to 93.9%. The content of water-soluble salts in the soils of the aeration zone is 0.032...0.923%. The density of loess-like loam particles varies from 2.67 t/m^3 to 2.75 t/m^3, the density of the soil skeleton in its natural state ranges from 1.21...2.13 t/m^3,. The porosity of soils varies from 30.2 to 56.4%. The natural soil moisture does not exceed 6...8%. The filtration coefficient of loess-like loams in the vertical direction varies from 2.55 to 0.15 m/day and decreases with depth. The shear resistance of soils in the natural state is characterized by the values of the internal friction angle φ from 200 to 320 and the specific adhesion C from 0.1 to 1.44 kg/sm^2, in the water-saturated state respectively $\varphi = 21...280$ and $C = 0.02...0.88$ kg/sm^2.

2 Methods

The total amount of subsidence deformation of the soil at natural pressure varies depending on the thickness of the subsidence from 0.03 to 2.6 m. The total amount of deformation at an additional pressure of 4 kg/sm^2 varies from 0.45 to 5.35 m, at a load of 6 kg/sm^2 from 0.85 to 5.69 m. The deformation properties of loess-like loams vary significantly depending on the depth. According to stamp tests, if the modulus of linear deformation in the natural state at a depth of 1 m is 169 kg/sm^2, then at a depth of 6.0 m it is equal to 100 kg/sm^2. In the water-saturated state, it increases from 26 kg/sm^2at a depth of 4.0 m to 71 kg/sm^2 at a depth of 10.0 m.

In most cases, calculations of its stress-strain state and the values of the ultimate soil extensibility were used to assess the conditions for the occurrence of cracks in the dam. The analytical solution of very complex and completely unexplored issues of cracking in the body of earthen dams presents great difficulties. In connection with this, to solve the problems of cracking, to obtain the whole picture of the course of deformations over time, it seems promising to use the method of centrifugal modeling [10].

The principle of centrifugal modeling is that by reducing the geometric dimensions of the structure (to a certain size of the model that fits into the centrifuge carriages) and preserving the basic properties of the material, it is possible to create large centrifugal forces, observe the equality of the stressed state of nature and the model at similar points, i.e. $\sigma_n = \sigma_m$ (where σ_n are stresses in the full-scale structure, σ_m are stresses at similar points in the model).At the same time, in the model itself, the deformation processes proceed as in reality, in accordance with the real patterns between stresses and deformations [11-14].

Thus, it is required that when the height of the structure decreases, the volumetric (γ_n) density of the material of the structure increases.
If

$$\gamma_n = \rho g \quad (1)$$

Where ρ-is the density of the material in kind; g-is the acceleration of gravity, then:

$$\gamma_n = \rho \alpha \quad (2)$$

where α is the total acceleration acting on the model in the field of centrifugal forces.

If the model is "n" times smaller than a full-scale structure, then the stress equality will be obtained when $H\gamma_n = \frac{H}{n}\gamma$ or $n\gamma_n = \gamma_m$.
Where n is the linear scale of the simulation.

According to the formulas (1) and (2) it turns out that $n\rho\alpha = \rho\alpha$ or

$$\alpha = ng \quad (3)$$

The value of the total acceleration (α) from the conditions of consideration of the force field in a centrifugal machine is equal to [11]:

$$\alpha = \sqrt{g^2} + \omega^4 R^2 \quad (4)$$

and the required angular velocity of rotation of the centrifuge to obtain the appropriate scale will be:

$$\varpi = \sqrt{g / R}\sqrt{n^2} - 1 \quad (5)$$

In accordance with [11,12], the main similarity ratios for (M-model, H-nature) when modeling earthworks on a centrifuge are as follows: density $\rho_m = \rho_n$; bulk mass $\gamma_m = \gamma_n n$; linear dimensions $H_m = H_n / n$; vertical and horizontal displacements $\upsilon_m = \upsilon_n / n$, $u_m = H_n / n$; relative deformations $\varepsilon_m = \varepsilon_n$; stresses $\sigma_m = \sigma_n$.It should be noted that these ratios are valid if the materials of the model and nature are the same or identical in their properties.

Another advantage of the method, which is very important in the modeling of groundwater structures, is that filtration and filtration consolidation processes are accelerated by a factor of "h_2" when tested in the field of centrifugal forces. For example, one hour of testing the model at an acceleration of 100 g corresponds to the period of operation of a real structure equal to 10,000 hours, which is approximately 14 months. The time dependence is expressed as follows:

$$t_m = t_n / n^2 \quad (6)$$

The accumulated research results currently allow us to speak quite definitely about the great possibilities of this method, in particular, in relation to the study of deformations, strength and cracking of dams made of local materials.

3 Results and Discussion

The base of the dam under study is highly sedimentary loess soils, therefore, when preparing such a base for the body of the dam, preliminary soaking was taken as an event. The latter circumstance potentially poses a significant danger in the direction of cracking in the dam.

The dam body itself is built by mechanical rolling at optimal humidity $W = 16 - 18\%$ and density $\gamma = 1.75\ t/m^3$. Due to the large length of the dam along the longitudinal axis, to study the conditions of cracking in the body of the dam, we tested flat models of its individual fragments. During the test, vertical and horizontal movements on the ridge were measured using specially designed deformation sensors. Experiments have shown that stretching zones arise at the side junctions of the dam crest, where transverse cracks form. When examining a fragment of the dam from the soil laid at the design density and humidity, the criterion of fracturing by precipitation (relative deformation of the dam body) was 0.01. Experiments have shown that with a decrease in the moisture content of the soil deposited in the body of the dam, the formation of cracks occurs with significantly less uneven precipitation. Thus, at a humidity of $W = 13.5\%$, cracks in the model were formed already with a relative unevenness of precipitation equal to 0.005. Therefore, in order to reduce the risk of cracking in the dam of the Nizhne-Alaarchinsky reservoir, it is recommended to lay the soil in its upper zone with a humidity of at least 16% (Fig.1.).

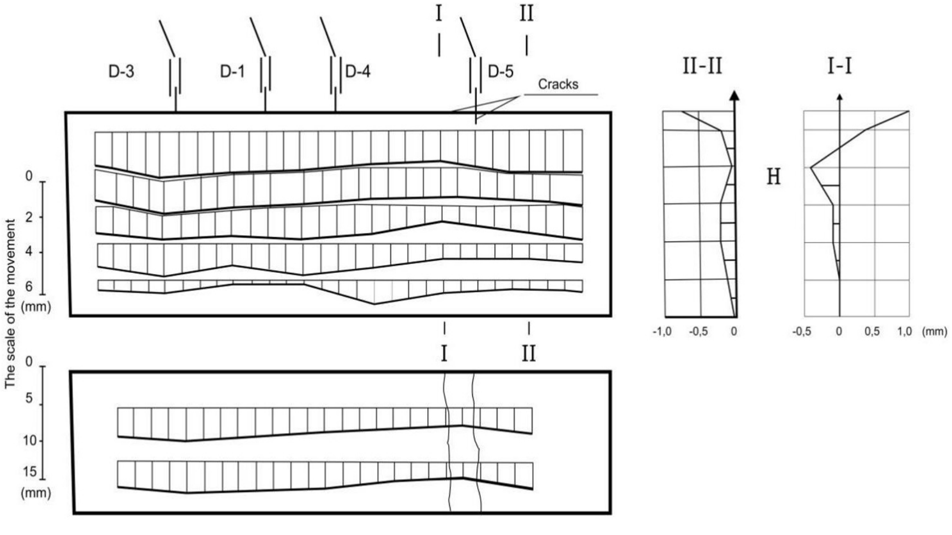

Fig. 1. Sediment of a model of a loess-based soil dam corresponding to the construction period before filling the reservoir.

At the second stage of testing (with completion of the reservoir and flooding of the foundation) on the crest of the model one crack of the construction period closed, but two new, deeper (up to 10 cm) and widely opened cracks appeared. These cracks were located much closer to the bank abutment of the dam (at a distance of 90 cm from the edge). The cracks opened already at an acceleration of 50 g, so the experiment was stopped and measurements of all deformations were carried out. In all cases, unevenness of horizontal moving soil models in the vicinity. Despite the strong slope of the channel to the bank, horizontal displacements cause directions directed back to the side - to the bank. The crack of the dangerous location zone is located at a distance of 35 ... 75 cm from the bank. Cracks were constantly observed within its limits. A similar zone was also found in the experiment simulating the construction period, it was located only at a distance of 65 ... 80 cm from the shore (or 130 ... 160 m when converted to natural conditions). The criterion for crack formation in the lower cases was the value of tensile relative deformations equal to 0.02. Since in most cases only dam settlements are observed, it seems appropriate to determine the criteria for crack formation in the dam as a function of the unevenness of precipitation. The processed experimental results indicate that the limiting relative unevenness of settlement, at which crack formation occurs in the model, is on average ε_5 = 0.03 (ε_5 is the difference in precipitation on the dam surface area, related to its length). The latter value can serve as a criterion when calculating any earth dams for the second group of limiting phenomena (for deformations).

In the last experiment, since cracks in the dam were already formed at an acceleration of 50 g and the substance content in terms of natural conditions was about 5 m, the section of the dam model damaged by cracks was cleared and the cracks were again filled with soil. After this model, a test was carried out up to the calculated acceleration of 245 g.

After the experiment was completed and the centrifuge was stopped, only a hairline crack less than 2 cm deep was found on the surface of the model at the place where the soil was replaced.

From this point of view, it is worth mentioning the work carried out in the Research Institute of the Hydroproject [1,2,16], the VODGEO Research Institute [7,11,12], Dnepropetrovsk Institute of Railway Engineers [3, 4], Moscow Institute of Transport Engineers [15], etc. which were aimed at a detailed study of sediments, stability of the body and slopes, deformability and cracking of cores and screens of stone-earth dams.

One of the first works to study the conditions of cracking in dams made of local materials is the experimental work of V.I.Vutsel and V.I.Shcherbina [1], who investigated the conditions of cracking in the model of the core of a stone-earth dam.

Studies have confirmed the calculated assumptions that the main unevenness of sediments is due to the manifestation of subsidence deformations of the coastal slope during the filling of the reservoir. Pre-soaking of the base implements only a part of the subsidence deformations, therefore, when filling the reservoir, relatively large sediments of the base and their significant unevenness can be expected.

4 Conclusion

In conclusion, it should be noted that the experimental method of centrifugal modeling is a very convenient method for solving problems about the deformed state of dams made of local materials. This method makes it possible to make a qualitative assessment of the behavior of the structure not only during construction and operation, but also to obtain a number of very important data necessary to assess cracking in the body of groundwater dams.

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