Stress - strain state dams on a loess subsidence base

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Abstract. The article presents the calculation of the stress-strain state of an earthen dam on a loess base on a computer. The calculation of the joint operation of the dam with the foundation was carried out using finite difference methods using shifted approximating grids (displacements and velocities are determined at the nodes of one mesh; deformations and stresses at the nodes on the other). The use of the developed algorithm, on the one hand, and the improvement of the mathematical model of the soil, based on experimental studies of samples for expansion, on the other hand, make it possible to assess the formation of trenches by calculation methods. The obtained calculation results are compared with the data of experimental model studies of the stress-strain state of an earthen dam with a subsidence base on a centrifuge. The correctness of the previously stated position was confirmed that for calculations of crack formation, the values of the limiting extensibility of the soil should be taken. It is necessary to determine these values by simulating the complex stress state of soil samples in laboratories. The areas of the dam have been identified as potentially the most in terms of cracking (a ridge zone with low compressive loads, close to uniaxial expansion in terms of operating conditions, and near-edge buried in places of a sharp break in the slope of the banks with significant stresses and destruction of soil material in a complex stress state by tension with sliding).

1. Introduction

The stress-strain state of earth dams was investigated in order to ensure the stability of the structure as a whole, this was manifested in the study of the problem of cracking in dams. Solving this problem, a huge contribution was made by the founders of soil mechanics N.M. Gersevanov. [1], Florin V.A. [2], Abelev Yu M [3], Denisov N Ya [4] Mustafaev A A [5], Tsytochich N A [6], Teltel-baum A I [7], Radchenko V G [8], Shcherbina V I [9], Zaretsky Yu K [10], Goldin A L [11].

The calculation of the stress-strain state, given by us, is based on the analysis of world experience in dam building and taking into account the main features of the behavior of earth dams during their construction [1-18].

To predict the possibility and parameters of cracking in the soil dam of the Nizhne-Alaarchinsky reservoir, built on loess collapsible soils, we considered the characteristic sections of the dam, where the formation of cracks was most likely.

In the alignment of the investigated dam, the greatest danger from the point of view of the occurrence of tension cracks is represented by the areas where the dam adjoins the banks, folded to a great depth by loess highly subsiding loams.
Thus, the thickness of loess loams here is very significant and reaches 100 meters.

Studies have shown that only the upper zone of loams with a depth of about 20 meters has the greatest subsidence.

Therefore, for the study, a fragment of the left bank abutment of the dam with a coastal subsidence base was accepted.

The dimensions of the fragment (Fig. 2.8) are taken into account the possibility of subsequent (verification) testing of it in the carriage of the used centrifugal machine.

Taking into account the scale of modeling (1: 200), the dimensions of the computational domain correspond to a section of the dam in nature, equal to 55 meters in height and 160 meters in width.

2. Materials and methods

For the calculation, we used the data on the deformation properties of soils (broken and undisturbed structure) in a dry and wet state, obtained during compression tests in the odometer and by the method of centrifugal modeling [19].

In addition, the strength parameters of the loess soil of the disturbed structure, determined in the devices of the spatial stress state - “compression - extension” and uniaxial tension, were used.

The criterion for cracking is the limiting relative tensile deformation.

The calculation of the joint operation of the dam with the subsidence foundation was carried out by the finite difference method (FCD) using shifted approximating grids (displacements and velocities are determined at the nodes of one grid; deformations and stresses at the nodes of the other).

When solving the problem, an explicit temporal scheme is used - the "establishment scheme". The calculation algorithm is described in detail in the work [20].

3. Results and Discussion

At the first stage, the stress-strain state of the dam and subsidence foundation, which characterizes the construction period, was calculated.

The value of its own weight increased smoothly from zero to the calculated value, after which the deformations at the time of their stabilization were determined.

At this stage, the forecast showed the possibility of a surface crack formation at the left boundary of the computational domain (Figure 1).

![Figure 1. Residual sediments of a soil dam on a loess foundation during the construction period](image-url)

- pilots sediment at the depth of the dam before filling the reservoir
- precipitation by dam depth in cross section
At the second stage, the stress-strain state of the dam and subsidence base was calculated at a water-saturated state, which characterizes the filling of the reservoir during the operational period. The loading mode is similar to the first stage. At this stage, the uneven deformations of the dam crest were mainly due to deformations of the base (Figure 2).

Therefore, a significant subsidence of the basement stratum near the left-bank abutment led to large sediment of the body (up to 4 meters) in this zone, which, according to the forecast, resulted in the formation of two cracks 5 m. deep.

![Figure 2. Residual sediments of a soil dam on a loess foundation after filling the reservoir - pilots sediment along the depth of the dam- precipitation by dam depth in cross section II-II](image)

It is not possible to verify the reliability of the forecast of cracking, obtained by computational studies using a computer, in full-scale conditions due to the incompleteness of the construction of the investigated dam.

In this regard, in order to verify the obtained results of the calculation on a computer, experimental studies of the cracking of this soil dam were carried out by the method of centrifugal modeling.

The main advantage of the centrifugal simulation method is the ability to create operating conditions and stresses in the model that are identical to those in the field.

This circumstance is of decisive importance in the case when the self-weight factor is decisive for the operation of the structure.

The object of modeling was a fragment of the left-bank abutment of the dam with the basement massif, where the greatest non-uniformity of deformations was expected, and, consequently, cracking of the dam body (i.e., a previously theoretically investigated fragment was checked).

The model was manufactured in the following way. In the test cassette, 400mm high, 200mm wide and 800mm long, pre-cut monoliths of undisturbed loess soil, selected at the base of the dam under construction, were placed.

The monoliths were installed in such a way that there was a 1 sm gap between them. Then this gap was clogged with dry loess soil of the same density as in the monoliths.

Then the design profile of the model was applied and the base model was cut out and the first stage of centrifuge tests was carried out - the compression of the model base, simulating the natural pressure.

To measure the settlement and horizontal displacements on the surface of the model and on the side of it, a network of surface and side marks was installed with a step in height and horizontally equal to 5 sm.

The loam was broken up and moistened to the design moisture content; the soil of the dam model was compacted using a manual trenching machine.

The model prepared in this way was retrofitted with lateral and surface marks, strain gauges were installed on it, and the second stage of testing was carried out: compression of the dam body and
foundation, simulating the construction period.

Finally, at the third stage of testing, the model was saturated with water through the sand filling to a level corresponding to the water horizon in the reservoir, after which the experiment simulating the operational period was continued.

The comparison of the residual displacements of soil in the body of the investigated dam, obtained by calculation according to the previously described method and in the experiment on a centrifuge, is given in Figures 1 - 2.

Figure 1. shows the settlement for the construction period. The figure shows that in the central part of the dam, the calculated settlements are in good agreement with the settlements in experimental studies.

Closer to the boundaries, there is some discrepancy in the results. This discrepancy can to some extent be explained by the difference in the boundary conditions adopted in the calculation and realized in the experiment.

The comparison of the distribution of sediment over the height of the dam in section 1-1 is presented in Figure 1 “b”. It shows a qualitative difference in the results obtained. In the calculation of the plot, the sediment is a smooth curve, varying from zero at the base to the maximum at the ridge.

At the second stage (Figure 2), which simulates the soil soaking as a result of filling the reservoir, the main variable precipitation is high both according to the calculated forecast and according to the experiment data, were observed in the area of the coastal abutment of the dam due to uneven subsidence of the foundation soil.

The latter led (as predicted by the calculation and confirmed in the experiment) to the formation of two cracks with a depth of about 5 m. respectively, at a distance of 55 ... 100 m. from the landfall. The relative limiting deformation of the dam body, at which cracks were formed, are, respectively, \( \varepsilon = 0.02 \) ... 0.03. The latter is assessed as more stringent in terms of safety requirements, as already noted earlier, can be recommended as a criterion for the limiting value of the relative settlement in the design of such soil dams according to group 2 of limit states for cracking conditions.

### 4. Conclusion

Based on the above mentioned aspects, the following conclusions can be drawn:

1. The developed method for calculating the stress-strain state of the body of an earth dam using a computer in relation to the operation of these dams on subsidence foundations makes it possible to effectively solve the problems of cracking in them, including establishing the location, direction, size and development in time.

2. The use of the calculation method makes it possible to clearly identify the peculiarities of the joint operation of an earth dam and subsidence base, depending on the loading history (the schedule for the construction of the dam body, filling the reservoir).

3. A criterion for cracking for such bulkhead structures was established when calculating them according to the 2nd group of limiting states (by deformation) - the limiting relative settlement \( \varepsilon = 0.0 \). conducted studies of the lead-tin-base bronze structure of the Br010S10 grade, it is possible to conclude that the modification with super dispersed powders influences considerably its structure. It is particularly typical for low concentrations of the modifier (up to 0.25 %).

When introducing a small amount of the aluminum oxide powder, the distance between the axes of the second-order dendrites and the average grain size reduces. This implies that a considerable part of the powder particles is effective crystallization centers. When increasing the Nano powder content, the structure starts coarsening relatively that, which was obtained using low powder concentrations. Introduction of the large quantity of the modifier leads to its coagulation and reduction of its influence on the structure.

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