HORIZONTAL DISPLACEMENT AND SETTLEMENT OF THE SHELLS
OF EARTH DAMS WITH A CORE FOLLOWING RESERVOIR FILLING

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In recent years dams utilizing coarse-fragmental materials in the shells and watertight elements in the central part as a core have become popular in the USSR and abroad. Examples of such dams are the Nurek, Charvak, Sarsang, etc., having a height of more than 100 m, which are under construction in the USSR.

When designing such dams it is quite important to predict their deformations during construction and operation, in particular the horizontal displacements of the impervious elements upon filling of the reservoir. Without touching on the problems of settlements of the core and shells during construction, longitudinal deformation parallel to the dam axis, etc., which have been analyzed in other studies [1, 2, and 4], in this article we will examine the problem of horizontal displacements of the core and downstream shell from the water pressure of the upper pool and settlements of the coarse-fragmental soil masses when flooded.

Horizontal Displacements of the Downstream Shell

The problem of displacement of the core of an earth dam by water pressure reduces to a determination of the compaction and displacement of the downstream shell. In view of the complexity of this problem and the lack of appropriate theoretical solutions, it can be solved approximately if we made certain assumptions concerning the soil properties, conditions of deformation of the material of the downstream shell, distribution of stresses, etc. [5-7].

The stress state of the downstream shell is taken to be unknown (on the assumption of a linear law of stress distribution in the horizontal cross section) and is subject to determination. The displacements are calculated with consideration of the character of embedment of the dam in the foundation without enlisting artificial hypotheses concerning the immobility of the downstream slope or the outer part of the downstream shell, absence of misalignments in the shell, etc.

Laboratory experiments to study the active and passive pressure of shells on the core of a dam [7] have shown that the active pressure reaches a maximum with a core displacement many times less than the displacement at which the passive earth pressure reaches a maximum. On the basis of this, we have adopted the following scheme for the action of the forces on the core (Fig. 1). With a rapid rise of the water in the reservoir up to the design level, small displacements of the core toward the lower pool occur and active earth pressure of the upstream shell acts on the core. We can consider that with a rise of water level in the reservoir the core transmits the pressure from the upstream to the downstream shell. However, in view of the appreciable size of the core it will partially absorb the pressure from the upstream shell. This part of the pressure can be determined approximately on the basis of the shear strength along the base for a core weight reduced by the magnitude of the piezometric pressure along the contact with the base.

The stresses $\sigma_x$, $\sigma_y$, $\sigma_{xy}$ within the downstream shell, for simplification, are assumed to vary linearly from the maximum at the boundary with the core to zero on the downstream slope, with consideration that the relation between deformation of the shell material and the stresses in it is expressed by the relations of the elasticity theory.

Various cases of embedment of the downstream shell in the foundation, cases with constant and variable moduli of deformation of the soil over the height of the shell, with different values of the Poisson ratio, with consideration of not only elastoplastic but also creep strains, with consideration of various schemes of behavior of the core, etc., have been examined. The indicated problem was examined in detail in [8]. The final equations without their derivation follow presently.

We will examine a symmetrical triangular profile of a dam (Fig. 1), considering that the core and the shell are composed of different soils, each of which is characterized by its own angle of internal friction, modulus of total deformation, Poisson ratio, and unit weight.


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Fig. 1. Calculation scheme.

TABLE 1

<table>
<thead>
<tr>
<th></th>
<th>Before water level rise</th>
<th>After water level rise</th>
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<tbody>
<tr>
<td>( \lambda = 0 )</td>
<td>-1.05</td>
<td>-1.24</td>
</tr>
<tr>
<td>( \lambda = 1 )</td>
<td>-1.18</td>
<td>-1.24</td>
</tr>
</tbody>
</table>

The approach to solving the formulated problem is as follows. First we determine the stresses in the downstream shell, assuming their linear distribution, then we calculate deformation by equations of the theory of elasticity for the case of plane strain, after which the expected displacements are determined on the basis of the Cauchy equations and conditions of embedment of the dam in the foundation. This procedure leads to an equation describing the distribution of horizontal displacements in the downstream shell

\[
\bar{u} = \frac{a_x}{2} \bar{u} + b_{xy} \bar{u} + \bar{y} + d,
\]

where \( \bar{u} = \frac{uE}{H^2} \) is the adjusted displacement, \( u \) is the true displacement, \( m; E \) is the modulus of deformation of the shell material, \( \text{kg/cm}^2; H \) is the height of the dam, \( \bar{x} = \frac{x}{H}, \bar{y} = \frac{y}{H} \) are the dimensionless coordinates; \( b, d \) are coefficients characterizing the conditions of embedment of the shell in the foundation; \( a_x, \ldots, b_{xy} \) are coefficients characterizing the distribution of strains in the downstream shell.

The coefficients \( b \) and \( d \) can be determined from the relations

\[
b = (a_{xy} - b_x) \bar{x}_0 + a_y
\]

and

\[
d = -\frac{a_x}{2} \bar{x}_0 - a_{xy} \bar{x}_0 \frac{a_y}{2} - \frac{b_{xy}}{2},
\]

where \( \bar{x}_0 \) is an arbitrary point of embedment of the downstream shell selected at the place of intersection of the calculation vertical with the base.

To determine the coefficients \( a_x, \ldots, b_{xy} \) we have equations derived from conditions of equilibrium and physical relations of the elasticity theory.