FORCES IN THE CASING OF THE AGGREGATE SHAFTS OF THE DNESTROVSK WATER-STORAGE ELECTRIC POWER PLANT

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1. The aggregate shafts proposed for the Dnestrovsk water-storage electric power plant (WEPP) will be located at the foot of a tall (~130 m) steep slope consisting of horizontal layers of limestone, several types of earth, argillite, aleurolite, and sandstone. The mass of semi-excavated rock is intersected by cracks of various degrees of magnitude, and include thin clay interlayers with reduced shear characteristics. The engineering and geological conditions of the Dnestrovsk WEPP site are considered in more detail in [1-3].

The location of the aggregate shafts at the base of the slope in a stress-concentration zone and the geological characteristics of the rock necessitate design solutions corresponding to minimum change in the stress state of the rock around the shafts. This ensures stability of the slope, the state of which is close to limiting equilibrium, according to estimates. Such solutions include:

- choice of the aggregate-shaft positions so that the width of the blocks between the shafts is equal to the shaft diameter;
- the use of downpipes to pass through the layer of solid rock in the upper part of the shaft;
- adoption of a procedure for each shaft within the semisolid rock such that removal of the earth is by blasthole drilling with a 2-m shoulder (overhang) and an annular concrete is extended downward as the depth of the shaft increases;
- the use of counterfiltrational and drainage measures to ensure that the position of the depressional groundwater surface within the slope is no higher than the natural level;
- reinforcement of the lower part of the slope in regions of possible collapse.

The upper part of the aggregate shaft consists of a ferroconcrete downpipe for passage through a layer of solid rock of thickness ~16 m. The pipe is of diameter 31 m with a wall thickness of 1.2 m. A shaft of depth 34 m and internal diameter 26 m with a ferroconcrete casing of thickness 1.8 m is cut in the semisolid rock mass. The structure of the aggregate shaft is described in more detail in [4-6].

To estimate the strength of the aggregate-shaft casing in these conditions, the stress-strain state of the system consisting of the casing and the surrounding rock must be calculated as a three-dimensional problem of the theory of elasto-plastic bodies with creep, taking account of the following factors. First, the natural stress state of the earth in the region of the shafts prior to drilling must be estimated, since the forces in the casing cross section depend significantly on this stress state. Second, account must be taken of the order of shaft drilling, the sequence of earth excavation in each shaft, the order of casing production, and the placement of the concrete in the lower part of the shaft; the influence of drilling of the supply and drain pipelines and the access tunnels must be taken into account, since this has considerable influence on the stress-strain state of the casing and the surrounding rock. Third, the influence of the filling of the upper reservoir, the increase in water level in the lower reservoir of the WEPP, and the increase in groundwater level (taking account of the influence of the counterfilter measures contemplated) must be considered. Fourth, the influence of various holes and other structural features of the casing must be taken into account.

To permit the solution of this complex three-dimensional problem, certain simplifications are introduced. First, the natural stress field in the rock and the transformation of this field after sinking the downpipe are estimated. Then, the force in the casing of the aggregate shaft and the change in the stress field of the surrounding rock in the systematic excavation of the rock and concreting of the casing are determined from the solution of the axisymmetric elasticity problem for an inhomogeneous rock.
geneous body with varying configuration and rigidity. Next, the influence of the creep of the rock on the pressure variation over time in the rock at the casing is taken into account. Finally, the influence of adjacent shafts on the force in the casing cross section is approximately calculated.

2. Consider the formation of the natural stress field of the rock in the region where the aggregate shafts will be constructed. As shown by geophysical studies of the stress state of semisolid rock,* the experimental horizontal stress greatly exceeds the theoretical value based on the Dinnik–Terzaghi hypotheses. In the present work, the natural stress level is estimated on the basis of the Rast–Herget hypothesis [7–9], taking account of the formation of such stress. According to this hypothesis, the natural stress in the rock is determined by first finding the stress in a layer of sedimentary rock prior to the formation of the Dnestr river valley. This stress must be determined according to the Geim hypothesis, i.e., the vertical and horizontal stress is equal to the weight of the overlying rock (Fig. 1a).

\[
\sigma_{x,1} = \sigma_{y,1} = \sigma_{z,1} = \rho g Z_1, \tag{1}
\]

where \(\sigma_{x,1}\), \(\sigma_{y,1}\), and \(\sigma_{z,1}\) are the stress at depth \(Z_1\); \(\rho g\) is the density of the rock. Then the change in stress in the rock associated with erosion of the upper layer (the formation of the Dnestr valley) is estimated from the Dinnik–Terzaghi hypothesis (Fig. 1b)

\[
\Delta\sigma_z = \rho g H_{er}, \quad \Delta\sigma_x = \Delta\sigma_y = \frac{v}{1-v} \Delta\sigma_z, \tag{2}
\]

where \(H_{er}\) is the thickness corresponding to erosion of the upper soil layer; \(v\) is Poisson’s ratio of the rock. Taking this into account, the natural stress in the rock is found, according to the Rast–Herget hypothesis, as the difference in the stress given by Eqs. (1) and (2) (Fig. 1c). Stress curves for the conditions relevant to the Dnestrovsk WEPP are shown in Fig. 2.

The Rast–Herget hypothesis is probably correct at sufficiently large depths. Close to the surface, plastic deformation must be taken into account. This may readily be demonstrated in the present case. When the principal stresses \(\sigma_1 = \sigma_2 = \sigma_x = \sigma_y\) and \(\sigma_3 = \sigma_z\), the Coulomb plasticity condition may be written in the form (see [10] and elsewhere)

\[
s_1 \leq 2c \frac{\cos \varphi}{1 - \sin \varphi} + \sigma_z \frac{1 + \sin \varphi}{1 - \sin \varphi}, \tag{3}
\]

where \(\tan \varphi = 0.7\) and \(c = 0.01\) MPa are shear parameters for the conditions of the cracked rock surrounding the aggregate shafts. Curves of the horizontal natural stress, taking account of Eq. (3), are shown in Fig. 2.

The natural stress field obtained in this way is transformed as a result of sinking the downpipe and removing the layer of unexcavated rock within the area of the pipe, which corresponds to removing the vertical load over the area of a 31-m circle. The corresponding curve of the natural horizontal stress along the axis of the aggregate shaft is shown in Fig. 2 (curve 3).

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