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STRENGTH OF COARSE-FRAGMENTAL SOILS OF RETAINING PRISMS OF PSKEM STONE-EARTH DAM

Abstract. The issues of the laying of stone material into the dam body are discussed in the paper; the control density of the laying is substantiated and the strength characteristics of the rock mass are roughly determined.

Keywords: sample, soil, coarse-fragmental soils, strength, shear coefficient, shear angle.

Uzbekistan has rich hydropower resources. Suffice it to say that the volume of hydropower resources of the Republic of Uzbekistan, technically suitable for the development, amounts to 27.4 billion kilowatt-hours of annual electric-power generation.

Given that hydropower resources are a natural, renewable and environmentally friendly energy source, the all-round increase in their use is in line with the modern development strategy of the Republic of Uzbekistan. This ensures guaranteed coverage of the growing electricity needs of industrial and municipal enterprises, agriculture and the population of the regions, it contributes to saving and rational use of organic fuel in the country and reducing emissions of harmful substances into the environment.

The main priorities of the development of the industry in this direction are determined by the approved Resolution of the President of the Republic of Uzbekistan dated May 2, 2017 No. PP-2947 "Program of measures for the further development of hydropower for 2017–2021. According to the program, 32 investment projects are being implemented in the system of JSC Uzbekgidroenergo to modernize and develop power plants and their networks for a total of $2.6 billion.

Investment projects include the construction of the Pskem hydroelectric power station on the Pskem river; it is one of the largest projects in the Republic. The Pskem hydropower plant (HPP) will be the second largest hydropower plant in Uzbekistan after the Charvak HPP. The zone of its influence will be the basin of the Chirchik river, the most economically developed and densely populated area of the republic and Central Asia.

The complex of the main tasks solved by this construction includes an increase in the share of hydropower facilities in the structure of the country's energy balance. Creation of new generating capacities in the electric power industry is connected to the wide use of the water-energy potential of the country's natural watercourses – renewable and environmentally friendly hydro resources, such as the Pskem river.

Considerate attitude to water potential of the republic consists in effective water management. The hydropower potential of the middle course of the Pskem river is used in order to:

– generate environmentally clean electric power and to save organic fuel;

– generate peak capacity to cover the deficit of regulatory power in the schedule of power system loads;

– implement seasonal regulation of river flow for guaranteed provision of water users of the Tashkent region in the agreed upon mode;

– develop the recreational potential of the Chimgan-Charvak resort area.

The volume and nomenclature of the estimated capacity of the Pskem HPP is 404 MW; the average annual electric power generation is 900 million kWh, the total capacity of the reservoir is 520.8 million m^3; the useful capacity is 486.5 million m^3.

The structure of the Pskem hydroelectric power plant includes the following main facilities:

– a dam built of earth materials of 195 m high with a core of loam (Fig. 1);

– a system of water discharge and water-energy facilities of the construction and operation periods;

– a building of hydroelectric station;

– a reservoir of seasonal flow regulation.

The main elements of the Pskem dam are a loamy core and retaining prisms built from the rock mass of pit No. 7. The issues of the laying of stone material into the dam body are considered in the paper and the control density of the laying is substantiated; the strength characteristics of the rock mass are roughly determined.

In working out the bedrock, a rock mass is obtained with different coefficients of inhomogeneity depending on the rock strength of the worked out package, its fracturing and interlayers of weaker rocks in the main massif.

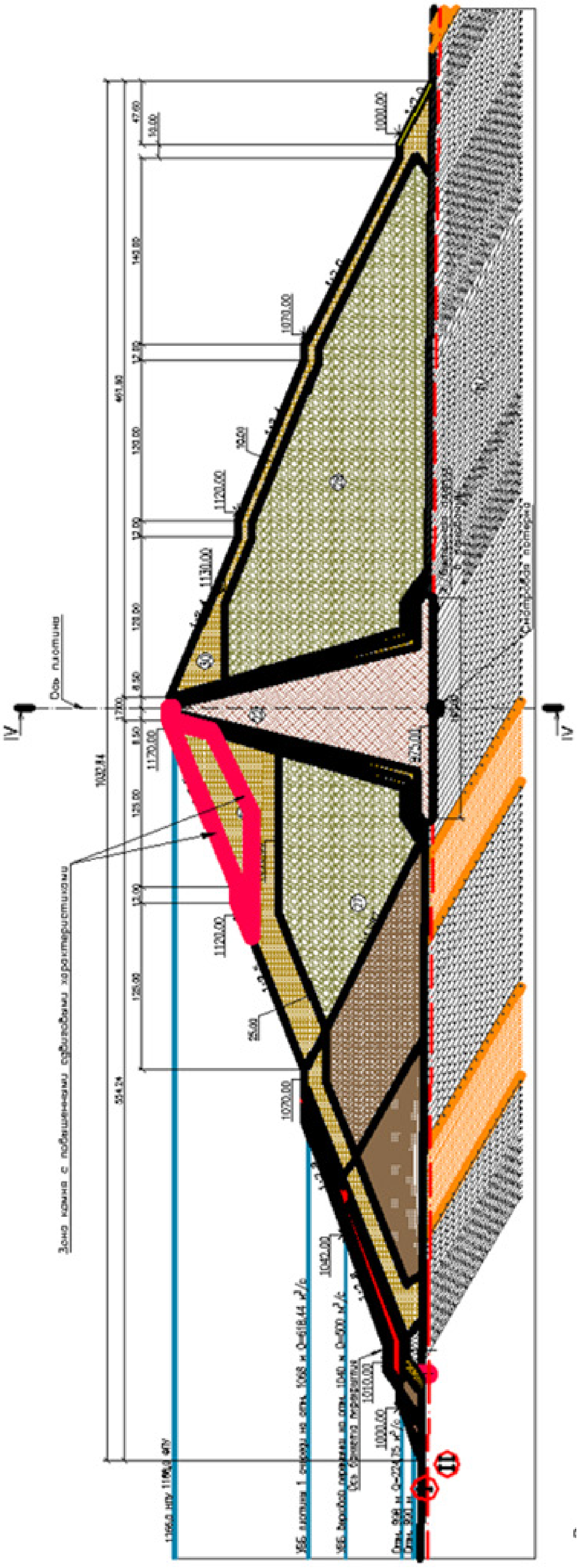

Figure1. Longitudinal profile of the dam, M 1: 2000

The strength of coarse-fragmental soils, used as materials of retaining prisms, is one of the main parameters that determine the design, dimensions and, to some extent, the technology of construction of stone-earth and rock-fill dams. In mass construction, the effective use of any materials is possible only with the standardization of their properties, and this fully applies to the strength.

This is due to the fact that despite the wide studies of the strength on each object, they are all carried out on different devices, according to different methods and are interpreted by different methods. All this leads to a low reliability of results.

In this regard, with account of ever-increasing volume of earthworks in hydro-engineering construction, the problem of the strength of coarse-fragmental soils is now one of the most pressing.

Studies have shown that the strength of coarse-fragmental soils can vary in a very wide range. The shear coefficient for one type of soil in different experiments varied by a factor of three and more (68, 97, 98).

The recommended grain compositions of the rock mass for the laying of retaining prisms of the Pskem dam are divided into three zones by the summation curves of the grain compositions. These compositions differ in terms of the content in the mix composition of fine earth (fr. < 5 mm), coarse fractions, coefficient of inhomogeneity. Therefore, in each case, it is necessary to establish experimentally the design characteristics put into the project.

Given that in the grain composition of the rock mass when conducting drilling and blasting operations (limestone) to get the minimum amount of fine earth (fr. < 5mm) ~ 5% is very difficult, the range between curves 1–3 is taken as the main composition. The curve of grain composition No. 2 is an average one for this range, for which the calculated characteristics for the corresponding number of shears are determined according to regulatory requirements.

The experiments have been carried out on a large-scale device, the use of which made it possible to carry out material tests with the inclusion of 140 mm fractions satisfying conditions $5D_{max} \le d_{min}$ of the device. The presence of 500–900 mm fractions in the full-scale material necessitates the switching to a model composition of material.

The calculation of the regulatory and calculated characteristics of "*tgφ*" and "c" is carried out using the formulas of the least squares method of the straight-line dependence of the form $\tau = Ptg\phi + c$ for the whole set of experimental data. The calculation of the regulatory values of tgφn and sn is given in (Table 1).

Table 1.

No	σ_i, kg/cm²	σ_i^2, kg/cm²	τ_i, kg/cm²	$\sigma \cdot \tau_i$ kg/cm²
1.	2	4	2.20	4.40
2.	2	4	2.30	4.60
3.	2	4	2.15	4.30
4.	2	4	2.10	4.20
5.	2	4	2.35	4.70
6.	2	4	2.25	4.50
7.	4	16	3.80	15.20
8.	4	16	4.0	16.40
9.	4	16	3.96	15.84
10.	4	16	3.71	14.84
11.	4	16	4.30	17.20
12.	4	16	4.00	16.00
13.	8	64	7.0	56.0
14.	8	64	7.75	62.0
15.	8	64	7.20	57.6
16.	8	64	6.80	54.4
17.	8	64	7.36	58.88
18.	8	64	7.30	58.40
19.	12	144	9.45	113.40
20.	12	144	10.75	129.0
21.	12	144	10.50	126.0
22.	12	144	10.00	120.0
23.	12	144	10.50	126.0
24.	12	144	10.20	122.4
Σ	156	1368	142.03	1206.26

The calculated strength values are obtained by dividing the regulatory values by the safety factor for soil, the physical meaning of which is that the actual values of the strength characteristics will not exceed the limit strengths of soil at an appropriate confidence probability.

The safety factor for soil is calculated from a set of paired measurements of vertical stresses and shear loads from σ_{min} to σ_{max} and depends on the variation of these values, that is, on the coefficient of variation "V".

$$\Delta = n\sum_{i=1}^{n}(\sigma_i)^2 - \left(\sum_{i=1}^{n}\sigma_i\right)^2 = 241368 - 24336 = 8496$$

$$tg\phi = \frac{1}{\Delta}(n\sum_{i=1}^{n}\tau_i\sigma_i - \sum_{i=1}^{n}\tau_i\sum_{i=1}^{n}\sigma_i =$$

$$= \frac{1}{8496}(241206.26 - 14203.156) = 0.798$$

$$c = \frac{1}{\Delta}\left(\sum_{i=1}^{n}\tau\sum_{i=1}^{n}\sigma^2 - \sum_{i=1}^{n}\sigma_i\sum_{i=1}^{n}\tau_i\sigma_i\right) =$$

$$= \frac{1}{8496}(14203 \cdot 1368 - 156 \cdot 1206.26) = 0.720$$

Calculation of the safety factor for soil

Initial data: $n = 24$; $\sum_{i=1}^{24}\sigma_i = 156.0$; $\sum_{i=1}^{24}\tau_i = 142.03$;

$\sigma_{\frac{\min}{\max}12} = 2.0; tg\phi^н = 0.798; c^н = 0.72; \bar{\sigma} = 65; \sum(\sigma_i - \bar{\sigma}) = 354.0;$

$$S_i = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}(c^н + \sigma_i tg\phi^н - \tau_i)^2} = \sqrt{\frac{1}{22}(2.076)} = 0.307;$$

$$G = \frac{\sigma_{\min} - \bar{\sigma}}{\sqrt{\sum_{i=1}^{n}(\sigma_i - \bar{\sigma})^2}} = \frac{2.0 - 6.5}{\sqrt{354}} = -0.239;$$

$$D = \frac{\sigma_{\max} - \bar{\sigma}}{\sqrt{\sum_{i=1}^{n}(\sigma_i - \bar{\sigma})^2}} = \frac{12.0 - 6.5}{\sqrt{354}} = 0.292;$$

$$\lambda = \sqrt{\frac{1}{2}\left[1 - \frac{1 + nGD}{\sqrt{(1+nG^2)(1+nD^2)}}\right]} = 0.566;$$

The confidence interval

$T_{min} = c^н + G_{min} tg\phi^н = 0.72 + 2 \cdot 0.798 = 2.316;$

$T_{max} = c^н + G_{max} tg\phi^н = 0.72 + 12 \cdot 0.798 = 10.296;$

$$S_{\frac{\min}{\max}} = \frac{V_T S_i}{\sqrt{n}} \sqrt{1 + \frac{n(\sigma_{\frac{\min}{\max}} - \bar{\sigma})^2}{\sum_{i=1}^{n} (\sigma_i - \bar{\sigma})^2}} = \frac{0.197}{0.223};$$

V_{T-} is the coefficient at $\kappa = 2$ and α is the confidence probability 0.95 (81, 82, 83) $V_T = 2.04$; $S_{\frac{\min}{\max}} = \frac{0.197}{0.233}$;

$$\gamma_\partial = \frac{T_{\min} + T_{\max}}{T_{\min} - S_{\min} + T_{\max} - S_{\max}} =$$

$$= \frac{2.316 + 10.296}{2.316 - 0.197 + 10.296 - 0.233} = 1.034;$$

According to the Building norms and codes, a safety factor for soil is 1.05: then the calculated values are:

$tg\phi^P = \frac{tg\phi^н}{\gamma_\partial} = \frac{0,798}{1,05} = 0,76$; $c^P = \frac{c^н}{\gamma_\partial} = \frac{0,72}{1,05} = 0,686$, kg/cm^2.

Using the calculated characteristics of the strength of the rock mass for the average curve of the grain composition No. 2. and the methodological guidelines for account of strength characteristics dependence on the static stress state, we get:

$$tg\psi = tg\phi^P + \frac{c^P}{\sigma}$$

Table 2.

σ, MPa	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
tgψ	1.103	0.932	0.874	0.846	0.828	0.817	0.809	0.803	0.798	0.794
ψ°	47.8	43.0	41.2	40.2	39.6	39.2	39.0	38.8	38.6	38.4

As follows from the table a decrease in strength occurs with an increase in stresses, which allows us to conclude that the retaining prism of the dam should be erected with the requirements of their stressed state. To obtain the homogeneity in physical and mechanical properties of material, the requirements should be imposed on the laying of material in different zones of the dam body that ensure the homogeneity of strength properties.

Conclusions

In material obtained after the explosion it is recommended to sort out the rock mass by shoveling and dumping of fine-grained material, i.e. to produce a capping inside a pit, by segregating the rock mass. The possibility of using a material with a high content of fine earth above the upper curve T.U. is limited to a load of 0.4 MPa.

According to the results of numerous strength tests of the coarse-fragmental soils of theTupalang, Pskem, and Rezaksay dams, the following aspects have been determined:

– shear angle φ, used in calculating the slope stability depends both on the grain composition of material and on the density;

– with an increase in the size of material characterized by a average weighted diameter, in the experiments $d_{ср.взв}$.–36.4 and $d_{ср.взв}$–56.56 the shear angle increases as well;

– as the density increases, the shear angle increases as well;

– shear angle is a variable value, it decreases with an increase in normal stress.

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