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Safety and Reduction of Technology-Related Risks in the Process of Earth Dams' and Dams' Operation

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Safety and Reduction of Technology-Related Risks in the Process of Earth Dams' and Dams' Operation

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Abstract. Ground water-retaining structures belong to hydrodynamically dangerous objects, most of the accidents are due to errors made during the design, construction and operation of structures, including insufficient ridge stock above the water level in the reservoir.The reason of the pressure front breakthroughs of three hundred dams in various countries of the world for 175 years was the overflow of water through the ridge of the dam (35% of cases).The article provides the tasks for improving, creating more effective technological and constructive measures to combat defects and damages of ground water retaining structures based on known, positively proven and improved technologies and technological processes that take into account the technological and financial capabilities of local repair and construction organizations and farms having machines and mechanisms and local raw material base at their disposal.

1. Introduction

One of the most frequent and large-scale emergencies in the Russian Federation are floods. The urgency of tasks to ensure the safety of life and reduce of material losses from such emergencies is confirmed by annual large floods in the Far East, Primorye and the Volga region, which bring enormous economic damage, significantly changing the way of life and threatening the health of the population.

Unfortunately, it is impossible to prevent floods, but it is possible to significantly reduce their damag. The issues of increasing the earth dams and dams safety as the most widespread type of hydraulic structures, which will increase the security of settlements in the rural areas of the Russian Federation are studied in this paper.

2. Relevance

The current state of beam ponds and other small reservoirs is estimated mainly as degrading [1-9]. Their safe and efficient operation depends directly on the operational reliability of water-forming structures - weirs, dams, banks. Unfortunately, the decompaction and collapse of slopes, subsidence of the ridge, soil removal from the body of the structures, the formation of the gaps, and a number of other negative factors not only contributed to a two-fold increase in the average world level of their (constructions) accidents, but also predetermined siltation and overgrowing of basins, decrease of the ponds' and small reservoirs' useful capacity, their transfer to the category of non-economic and liquidation as a source of water for the needs of water supply, recreational purposes, etc.

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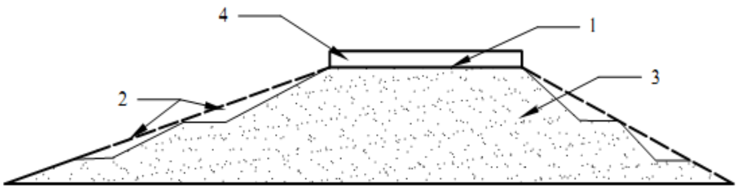
3. Technological proposal

The repair and construction works are aimed at increasing the height of the earth dams, the expansion of their profile and their build-up, thus the structure bodies are refered to overhaul and must be carried out with special responsibility. The technology for building the body of the earth dam is given below, the essence of which consists in the sequential execution of a number of operations.

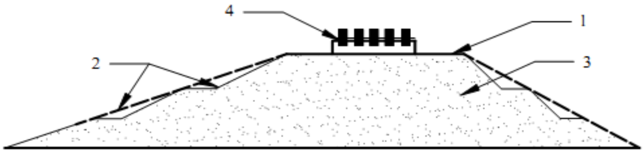
1. Removing uncultivated ground from the slopes and ridge of the dam.
2. Ledges arrangement with the movement of the soil to the ridge of the dam and its level-by-level spreading according to the scheme given in Figure 1.



1 - ridge; 2 - ledges; 3 - dam; 4 - ground, moved to the ridge while arranging the ledges

Figure 1. Scheme of the ledges location on the slopes of the dam.

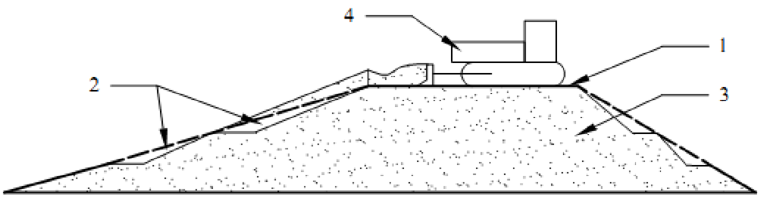
3. Stirring of soil with sifting, ash and cement, wetting the soil mix to the optimum moisture content on the ridge of the dam (Figure 2).



1 - ridge; 2 - ledges; 3 - dam; 4 - milling cutter

Figure 2. Scheme of work while mixing the materials by a milling cutter on the ridge of a dam.

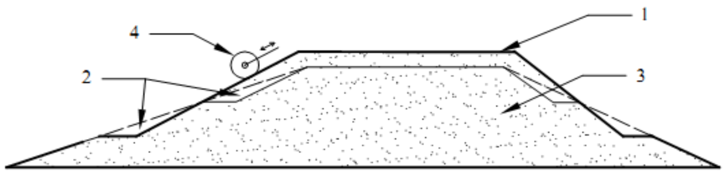
4. Scheme of leveling the soil mixture on the ridge and the slopes limited by ledges is illustrated in Figure 3.



1 - ridge; 2 - ledges; 3 - dam; 4 - bulldozer

Figure 3. Scheme of leveling the soil mix.

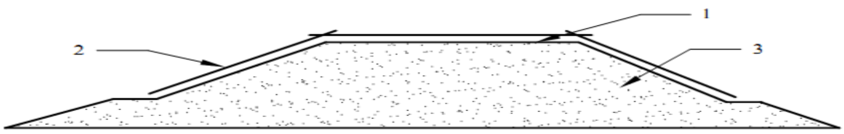
5. The layer-by-layer compaction of a soil mix with an optimum moisture to the design density is realized by means of rollers (Figure 4).



1 - stackable ridge of the dam; 2 - ledges; 3 - dam; 4 - roller ramming

Figure 4. Scheme of work with layer-by-level compaction of a soil mix.

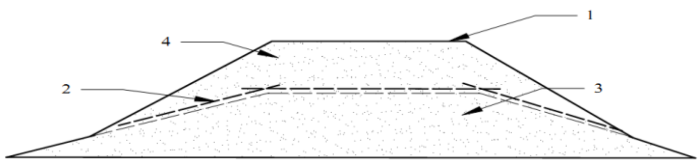
6. Laying the geonet on the dam slopes and ridge (Figure 5)



1 - stackable crest of the dam; 2 - geonet; 3 - dam

Figure 5. Geogrid position on the dam profile.

7. Extension of the ridge and body of the dam, layer by layer leveling and compaction of the soil mix. As a result, we obtain the body of reconstructed dam, the cross-cut profile of which is shown in Fig. 6.



1 – filled up ridge of the dam; 2 - position of geonet; 3 - dam before repair; 4 – filled up part of the dam

Figure 6. Scheme of the reconstructed dam.

The above schemes and compositions of technological operations make it possible not only to restore the deformed earth dams, but also to reconstruct them in order to increase the capacity of ponds.

4. Experimental research

The most effective restoration and reconstruction of earth dams is made not with the ground, but with the ground mixtures containing soil, cement, seeding and ash, taken in certain proportions [10]. Strictly speaking, the above proposed technology presupposes the use of such soil mixtures, but not soil, in the repair and construction work.

The compositions of soil mixtures were selected by means of laboratories in the following way. Materials (components) with the following parameters were used for their preparation:

Novorossiysk portland cement grade 400; soil – light, slightly water-permeable loam; sifting - waste stone crushing of limestone fraction 0-5 mm with the size module M_{kr} =2,98; flue cinder of dry removal from Novocherkasskaya GRES electrofilter. At the same time, the following ratios were observed: Cement + Ash = 15%, Soil + Sifting = 85%.

The conditions for coding and varying the factors of the planned experimental research are presented in Table 1.

Table 1. Coding and Variation of Factors.

Factors	Code X_i	Ground level, X_0, %	Variability interval, ΔX_i ΔX_i	Lower level, «–»	Upper level, «+»
Cement	X_1	9,0	6,0	3,0	15,0
Soil	X_2	62,5	22,5	40,0	85,0

The graphic design of the experiment is shown in Figure 8.

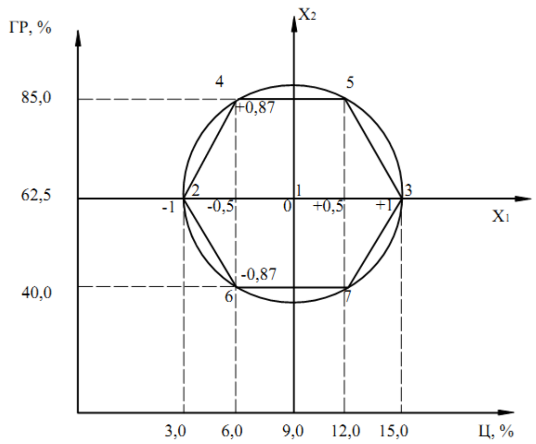


Figure 7. Experimental plan for a hexagon.

Fig. 7 shows that the points of the accepted experimental plan have the coordinates of a regular hexagon vertices, constructed within the variation of factors ± 1 in coded form. The chosen plan is convenient because the transition from coded values of factors to natural ones and vice versa can be performed graphically on the corresponding axes (see Figure 8).

Based on the results of seven experiments (six vertices and the center of a hexagon), unknown coefficients of the second-order regression equation are calculated:

$$\hat{y}_R = b_0 + b_1 X_1 + b_2 X_2 + b_{11} X_1^2 + b_{22} X_2^2 + b_{12} X_1 X_2,$$

where

$$b_0 = (0y) - \sum_{i=1}^{k} (iiy); \; b_i = 1/3(iy); \; b_{ij} = 4/3(ijy);$$

$$b_{ii} = 2/3(iiy) + 5/6 \sum_{i=1}^{k} (iiy) - (0y). \quad (1)$$

Using formulas (1.1), the coefficients of the second-order regression equation were calculated.
For the strength of the samples after 28 days of hardening and full water saturation, a regression equation was obtained in the form below:

$$\hat{y}_R = 13{,}21 + 4{,}90 X_1 - 2{,}09 X_2 - 3{,}2 X_1^2 - 1{,}56 X_2^2 + 0{,}83 X_1 X_2. \quad (2)$$

We'll analyze the model (3.2) after determining its type and constructing the corresponding geometric image. For this, we use the general theory of surfaces of the second order [3], taking:

$$b_0 - y = a_0; \quad b_{ij} = 2a_{ij}; \quad b_i = 2a_i; \quad b_{ii} = a_{ii}. \quad (3)$$

Invariants of the quadratic curve are:

- the coefficients sum of the quadratic terms:

$$S = b_{11} + b_{22} = -3,20 - 1,56 = -4,76$$

- a determinant composed of the highest terms coefficients:

$$\delta = \begin{vmatrix} b_{11} & 0,5b_{12} \\ 0,5b_{12} & b_{22} \end{vmatrix} = \begin{vmatrix} -3,2 & 0,415 \\ 0,415 & -1,56 \end{vmatrix} = 4,82 \quad ; \qquad (4)$$

- the determinant of the third order, made up of all the coefficients:

$$\Delta = \begin{vmatrix} b_{11} & 0,5b_{12} & 0,5b_1 \\ 0,5b_{12} & b_{22} & 0,5b_2 \\ 0,5b_1 & 0,5b_2 & b_0 \end{vmatrix} = \begin{vmatrix} -3,2 & 0,415 & 2,45 \\ 0,415 & -1,56 & -1,05 \\ 2,45 & -1,05 & 13,21 \end{vmatrix} = 74,42 \quad . \qquad (5)$$

Using the invariants (1.3), (1.4) and (1.5), we reduce equation (1.2) to the canonical form convenient for analysis and geometric interpretation:

$$\lambda_1 \bar{X}_1^2 + \lambda_2 \bar{X}_2^2 + C = 0 \quad . \qquad (6)$$

We calculate the coefficients of the canonical form in terms of invariants:

$$C = \frac{\Delta}{\delta} = \frac{74,42}{4,82} = 15,44 \quad ; \qquad (7)$$

$$\lambda_{1,2} = \frac{S}{2} \pm \sqrt{\frac{S^2}{4} - \delta} = -2,38 \pm 0,92 \quad ; \qquad (8)$$

$$\lambda_1 = -1,46; \qquad \lambda_2 = -3,30 \quad .$$

From the geometric point of view, the transition to equation (1.6) means the transfer of the point of origin to the center of the curve (surface) and turning them by some angle until they coincide with the principal axes of the quadratic curve.

Taking into account (1.7) and (1.8), the canonical form of equation (1.2) takes the form:

$$-1,46\bar{X}_1^2 - 3,30\bar{X}_2^2 + 15,44 = R_{28} \quad , \qquad (9)$$

and the coordinates of the response surface center are determined by the formulas:

$$\bar{X}_{01} = \frac{\begin{vmatrix} -0,5b_1 & 0,5b_{12} \\ -0,5b_2 & b_{22} \end{vmatrix}}{\begin{vmatrix} b_{11} & 0,5b_{12} \\ 0,5b_{12} & b_{22} \end{vmatrix}} = \frac{\begin{vmatrix} -2,45 & 0,415 \\ 1,05 & -1,56 \end{vmatrix}}{\begin{vmatrix} -3,2 & 0,415 \\ 0,415 & -1,56 \end{vmatrix}} = 0,702 \quad ;$$

$$\bar{X}_{02} = \frac{\begin{vmatrix} b_{11} & -0,5b_1 \\ 0,5b_{12} & -0,5b_2 \end{vmatrix}}{\begin{vmatrix} b_{11} & 0,5b_{12} \\ 0,5b_{12} & b_{22} \end{vmatrix}} = \frac{\begin{vmatrix} -3,2 & -2,45 \\ 0,415 & 1,05 \end{vmatrix}}{\begin{vmatrix} -3,2 & 0,415 \\ 0,415 & -1,56 \end{vmatrix}} = -0,486 \qquad (10)$$

The tangent of the new axis rotation angle with respect to the original axis:

$$\text{tg}\alpha = \frac{\lambda_1 - b_{11}}{0,5b_{12}} = \frac{-1,46+3,2}{0,415} = 4,193.$$

By the canonical form (1.9), the semiaxes of ellipses are determined by the following relations:

$$a = \sqrt{\frac{15,44 - R_{28}}{1,46}}; \qquad b = \sqrt{\frac{15,44 - R_{28}}{3,3}}. \qquad (11)$$

The geometric image of the model $\hat{y}_R$ (R_{28}) is shown in Figure 8.

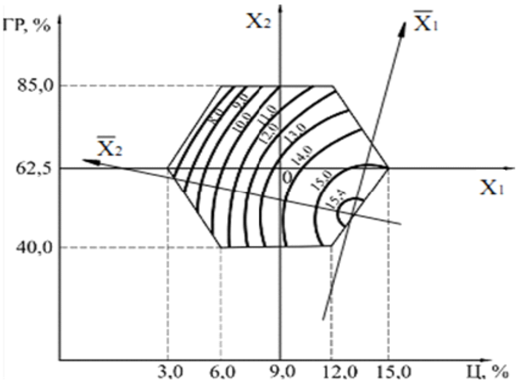


Figure 8. Geometrical image of the concrete strength model after 28 days of hardening and full water saturation.

5. Conclusion

The analysis of the mathematical model and its graphical representation according to Figure 8 allows us to make the following conclusions.

1. The strength of the soil mixture (ground concrete) hardened after 28 days increases with a decrease in the amount of soil in the composition of the soil mix and an increase of cement and sifting.

2. The dosage of cement and sifting in high-strength (13-15 MPa) soil mixes (cinder concrete) should be, respectively, not less than (8.0-10.0)% and not less than (25-30)% of the soil mix mass.

3. Reducing the dosage of cement in equal-strength primer-concrete should be compensated by an increase in the rate of sifting in the composition of the soil mix. Consolidated soil mixtures have the same strength properties with the following expenditure of components (cement, soil, sifting, ash):

C = 9,0 %; S = 46-48 %; Sif = 37-39 %; A = 6,0 %;
C = 10,5 %; S = 63-65 %; Sif = 20-22 %; A = 4,5 %;
C=12,0 %; S = 69-71 %; Sif = 14-16 %; A = 3,0 % ect.

4. The use of sifting and fly ash for economical consumption of cement in equal-strength soil-mixes (cinder-concrete) in an amount, (20-40)% and (4-6)% of the soil mix mass respectively, should be considered optimal.

5. Reducing the sifting amount below 20% and increasing the dosage of ash by more than 6%, do not provide a hardened high-strength soil mix without increasing cement consumption.

6. References

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