To the Safety of Small Reservoirs Ground Structures

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Abstract. There are several hundred low-pressure soil structures, which belong to the IV and III classes of building on the territory of the Russian Federation. In recent years, the maintenance of normal operation and the maintenance of dams in satisfactory condition has become quite an acute problem. The decrease in the water objects' security level of this kind is due to the long period of facilities' operation, the reduction of the maintenance staff, the complete or partial lack of project documentation in this field and even the absence of owners. The main damaging factor in a hydrodynamic accident is a breakthrough wave. The flow of water moving at high speed damages to some extent buildings and structures, floods vast areas, and in the event of a breakthrough in a large reservoir, it can lead to the death of people. This article proposes constructive solutions that improve the safety of low-lying ground structures, and thus reduce the risk of accidents and flooding of the underlying areas.

1. Introduction

The current technical condition of the earth dams on a number of Rostov region reservoirs poses a potential danger to the population, economic and cultural-historical objects, agricultural lands [4-11]. Meanwhile, many defects and damages can be prevented, using improved and new design solutions for their main elements - anti-filtration slope devices.

Anti-filtration devices (screens, cores, etc.) reduce the piezometric slopes of the filtration flow, reduce the depression curve, increase the stability of the bottom slope and the filtration strength of structures as a whole. Thus, they minimize dangerous defects and deformations - suffusion, formation of strokes and voids, erosion, forcing, freezing, etc.

Ground screens are usually made of low-permeability soils, layered and compacted parallel to the base of the dam (Figure 1). Being a barrier to the filtration flow path and because of the compacted soil layers parallel to the dam's base, screens often do not provide the necessary reduction of the depression curve in the lower part of the dam, the safe height of the filtration flow seepage to the bottom slope and the required reduction in the filtration flow.
2. **Constructive proposal**

It is suggested [2] to incline the condensed layers of the screen ground toward the lower tail at an angle to the surface of the dam base, and the angle is determined by the admissible values of the filtration flow parameters (Figure 2).

The usefulness and efficiency of the proposed technical solution (patent No. 120423) is explained by the fact that the upper zones of the layers are more effective in resisting the movement of the filtration flow through the lamellar-compacted layers of the screen ground, which, in comparison with the lower (plantar) layers, are more compacted and involved in the work in the oblique position of the layers.

3. **Calculation justification**

The effectiveness of the proposed solution will be shown on a concrete example. Given: the coefficient of soil filtration of the dam body $K_T = 0.5 \text{ m/day}$; screening coefficient of the screen ground $K_Z = 0.005 \text{ m/day}$; angle of screen inclination to the base of the dam $\theta = 18^\circ 30'$; thickness of the screen on top $\delta_v = 1.0 \text{ m}$; thickness of the screen below $\delta_n = 2.0 \text{ m}$; average screen thickness $\delta_{sr} = 0.5(\delta_v + \delta_n) = 1.5 \text{ m}$; projection of the screen thickness on the vertical $Z = \delta_{sr} \cdot \cos \theta = 1.5 \cdot 0.95 = 1.42 \text{ m}$; ratio of filter coefficients $n = K_T / K_Z = 100$. Other data (parameters) are on the filtering scheme (see Figure 1) [2].

The calculation of filtration through a dam with a screen is made by the formulas:

$$
\frac{q_T}{K_T} = \frac{H_1^2 - h_e^2 - Z^2}{2 \cdot \delta_{sr} \cdot n \cdot \sin \theta};
$$

$$
L = \left(H_{pl} - h_e\right) \cdot m_1 + b_{pl} + m_2 \cdot H_{pl} - \frac{\delta_{sr} + t_{zah}}{\sin \theta};
$$

$$
\frac{q_T}{K_T} = \frac{h_e^2 - h_1^2}{2 \cdot \left(L - m_2 \cdot h_1\right)};
$$

where $h_e$ is the initial ordinate (behind the screen, the first) of the depression curve; $h_1$ - the final ordinate (at the point of exit to the downstream face) of the depression curve, or the altitude of the seepage; $q_T$ - specific filtration flow; $L$ - distance from the origin to the bottom of the downstream face.
The equality of the left-hand sides of formulas (1.1) and (1.3) implies the equality of the right:

$$\frac{H_1^2 - h_c^2 - Z^2}{2 \cdot \delta_{sr} \cdot n \cdot \sin \theta} = \frac{h_c^2 - h_1^2}{2(L - m_1 \cdot h_1)};$$  \hspace{1cm} (4)

Equality is valid at $h_c = 8.6$ m and $h_1 = 2.28$ m:

$$L = (15 - 8.6) \cdot 3 + 8 + 2 \cdot 15 - \frac{1.5 + 2}{0.32} = 46.26 \text{ m;}$$

$$\frac{12.5^2 - 8.6^2 - 1.42^2}{2 \cdot 1.5 \cdot 100 \cdot 0.32} = \frac{8.6^2 - 2.28^2}{2(46.26 - 2 \cdot 2.28)};$$

$$0.83 = 0.83.$$  

Define the specific filtration flow rate:

$$q_T = K_T \cdot \frac{h_c^2 - h_1^2}{2 \cdot (L - m_2 \cdot h_1)} = 0.5 \cdot \frac{8.6^2 - 2.28^2}{2 \cdot (46.26 - 2 \cdot 2.28)} = 0.412 \text{ m}^3/\text{day}.$$  

$$q_T = 0.412 \text{ m}^3/\text{day} > q_T(dop) = 0.35 \text{ m}^3/\text{day}.$$  

Consequently, the specific filtration flow $q_T$ exceeds the permissible value $q_T(dop)$ and, in order to increase the operational reliability of the dam, it must be reduced. It can be reduced (see the formula) by decreasing the seepage height $h_1$ and the initial ordinate $h_c$ of the depression curve, that is, reducing the depression curve, which is achieved by oblique performance of the soil screen layers (hereinafter "screen layers").
We'll show how $h_e$, $h_1$ and $q_T$ are decreased in the oblique performance of the compressed soil screen layers (Figure 2).

Example. With an inclination angle of the layers $\alpha = 10$ degrees. When the compressed layers of the screen are parallel ($\alpha = 0$) to the base, the filtration factor (see above) of the screen is $K_Z = 0,005$ m/day. If they are inclined, the filtration coefficient is determined from the expression [3]:

$$K_{Z\alpha} = K_Z \cdot \beta,$$

where $\beta$ is the coefficient that takes into account different degree of the upper and lower (plantar) zones compaction of the screen layers, determined by the formula:

$$\beta^2 = \frac{1 + \tan^2 \alpha}{1 + (\varepsilon \cdot \tan \alpha)^2},$$

where $\alpha$ is the angle of condensed layers inclination of the screen to the surface of the base of the dam, $\varepsilon$ is the ratio of the filtration coefficient of the lower (less dense) zones of the screen layers to the filtration coefficient of the upper (densest) zones of the layers. Depending on the type of soil, the thickness of the layer, the number of compacting means passes (roller, for example) on one track, $\varepsilon = 5 \div 20$. Accept $\varepsilon = 10$.

Define:

$$\beta^2 = \frac{1 + \tan^2 10}{1 + (10 \cdot \tan 10)^2} = \frac{1 + 0,1763^2}{1 + 3,109} = 0,251,$$

The permeability coefficient of the ground in the inclined performance of the compacted layers is equal to:

$$K_{Z\alpha} = K_Z \cdot \beta = 0,005 \cdot 0,5 = 0,0025 \text{ m/day}.$$

Setting successively several times the ordinate $h_e$ of the depression curve behind the screen ($h_e = 2,4,6,8,10$ m), from the formula (1.2) we define the distance $L$ from the origin to the bottom of the downstream face. The ordinate $h_1$ of the depression curve at the point of exit to the downstream face (i.e., the altitude of the seepage) is calculated by the formula:

$$h_1 = h_0 + \frac{L}{m_2} - \sqrt{\frac{L^2}{m_2^2} - (h_e - h_0)^2}.$$

Denoting the right-hand side of equation (1.1) as

$$\frac{H_1^2 - h_e^2 - Z^2}{2 \cdot \delta_{sr} \cdot n \cdot \sin \theta} = F_1(h_e),$$

and equations (1.3) as

$$\frac{h_e^2 - h_1^2}{2(L - m_2 \cdot h_1)} = F_2(h_e)$$

we calculate their values. All calculations are presented in tabular form (Table 1).
Table 1. Determination of the depression curve ordinate behind the screen.

| $h_e, \text{м}$ | $L, \text{м}$ | $h_1, \text{м}$ | $F_1(h_e)$ | $F_2(h_e)$ |
|----------------|-----------|-------------|-------------|-------------|
| 10,0           | 42,06     | 3,02        | 0,28        | 1,26        |
| 8,0            | 48,06     | 2,04        | 0,47        | 0,68        |
| 6,0            | 54,06     | 1,47        | 0,62        | 0,33        |
| 4,0            | 60,06     | 1,15        | 0,72        | 0,13        |
| 2,0            | 66,06     | 1,02        | 0,79        | 0,02        |
| 7,25           | 50,31     | 1,79        | 0,53        | 0,53        |

It follows from the table that at $h_e = 7.25 \text{ m}$, $F_1(h_e) = F_2(h_e)$.

Graphical interpretation of the calculation results is shown in Figure 3.

Figure 3. Graph for $h_e$ determination.

Define the specific filtration flow rate:

$$q_T = 0.5 \cdot \frac{7.25^2 - 1.79^2}{2 \cdot (50.31 - 2 \cdot 1.79)} = 0.264 \text{ m}^3/\text{day}.$$

$q_T = 0.264 \text{ m}^3/\text{day} < q_{T(dop)} = 0.35 \text{ m}^3/\text{day}.$

The obtained value of specific filtration flow rate $q_T$ is less than permissible, therefore $h_e = 7.25 \text{ m}$, $h_1 = 1.79 \text{ m}$, $q_T = 0.264 \text{ m}^3/\text{day}$ are within the range of permissible values and ensure reliable operation of the dam.

Let us compare the results of the calculation at $\alpha = 0^\circ$ and $\alpha = 10^\circ$:

$\alpha = 0^\circ - h_e = 8.6 \text{ m}; \quad h_1 = 2.28 \text{ m}; \quad q_T = 0.412 \text{ m}^3/\text{day}.$

$\alpha = 10^\circ - h_e = 7.25 \text{ m}; \quad h_1 = 1.79 \text{ m}; \quad q_T = 0.264 \text{ m}^3/\text{day}.$

From these results it follows that performing the compacted layer screen at an angle of $\alpha = 10^\circ$ to the bottom surface of the dam, the position of the depression curve (based on its initial and ultimate $h_e = 7.25 \text{ m}$ and $h_1 = 1.79 \text{ m}$ ordinates) decreases. The filtration flow seepage height on the
downstream face $h_1 = 1.79\, m$ (at $\alpha = 0°, h_1 = 2.28\, m$) decreases (it becomes relatively safer). The specific filtration flow rate is also reduced - $q_T = 0.264\, m^3/\text{day}$ (at $\alpha = 0°, q_T = 0.412\, m^3/\text{day}$). Thus, there are provided - increased filtration strength and stability, and hence increased operational reliability of the dam.

4. Conclusion

Thus, the calculated evaluation of the antifiltering device (screen) effectiveness from the oblique of low-permeability soil is held. When compared to a horizontally filled soil layers, 1.5-2.0 times decrease in filtration flow rate and not less than 1.2-1.5 times decrease of the seepage height at the downstream face was found. It provides a high level of filtration strength and stability, prevents damage and defects, and thus reduces the cost of repairs, reconstruction and emergency work on the clay dam of ponds and reservoirs reclamation purposes.

5. References

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