Modelling of horizontal pipe drainage for Sultansandjar dam

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Abstract. The article discusses the research work results for new type horizontal pipe drainage in earth fill dams, obtained from a physical model for Sultansandjar dam, made of natural sand with scale of 1:75. The main goal of the work is to determine the location and discharge from new drainage, as well as to determine the location of the phreatic surface in the dam body. The task was accomplished with the account of main factors, such as freezing depth, capillary rise height of water and the scope of work.

1. Introduction

According to the data from the International Committee on large dams, currently there are more than 45 thousand large dams around the world, and 60% of them are earth fill dams. In Uzbekistan 54 out of 55 total operated water reservoirs have earth fill dams, and 24 of them are equipped with horizontal pipe drains.

Earth fill dams are 3 times less reliable than concrete ones so the accidents in them mainly occur as the result of water filtration through the body and the base of these dams [1]. According to data from Japan Water Agency these numbers reach as high as 33% from the total number of accidents.

In the number of cases erosive leakage takes place through the dam body and the base, and the main reasons for that is the quality of drainage reverse filter installation, unsuitable type of earth fill material, irregular precipitation, mistakes in drainage pipe joints [2, 3, 4, 5, 6, 7].

These failures in drainage operation result in quite serious consequences, such as outflow of filtrated water on the downstream face of dams, decrease of its stability, dam downstream face creep [8, 9, 10, 11, 12, 13, 14] (Fig.1).

For example, during operation of Sultansandjar dam it was observed that sand was eroded out with filtrated water and the drainage pipe located between pickets PK57+80 and PK57+20 has been shut plugged with wood, which resulted in the rise of phreatic surface by 90 cm.

Figure 1. Failure craters on the downstream side of Sultansandjar dam
The existing restoration methods for operation of horizontal pipe drainage [15] requires uncovering of the drainage on the whole length of repair area, which requires significant material expenses. We have proposed a new design for horizontal pipe drainage, which provides the recovery of operating ability without dismantling of the new system. [7] (Fig.2).

![Horizontal pipe drainage for earth fill dams](image)

**Figure 2.** Horizontal pipe drainage for earth fill dams

Horizontal pipe drainage consists of nonfunctional (asbestos-cement or concrete) pipe 1 with perforated 3 horizontal plastic pipes 2 inserted in it, the plastic pipes are covered with artificial protection and filtrating material 4. Plastic pipe ends 5 as well as the ends of operating pipes 6 are plugged with temporary wooden plugs 7, and the nonfunctional pipe ends are plugged with concrete plugs 8. The concrete plugs are made using wooden forms 9. Plastic pipe ends are partially inserted 10 into the manholes 11.

It was required to check the operation of the new design in models.

2. Method

Despite the fact that physical modelling requires high expenses and much time, it is still the most important tool among all other options in checking spatial facts and events which take place under influence of various factors [16, 17].

For modelling we chose Sultansandjar dam of the off-river reservoir with the same name, which is a part of Tuyamuyun hydrosystem in Amudarya river. The total length of the dam is 19.6 km, maximal height is 24 m, width of the crest is 6 m, upstream and downstream slope are $m_1=4.0$ and $m_2=3.0$, respectively, water depth at normal water level of 130.00 is 21.8 m. The dam is erected of fine grained sand with the coefficient of filtration $K=1.5\div 2.5$ m/day.

Horizontal pipe drainage is made of perforated asbestos-cement pipes with diameter of 400 mm, the total length of the two lines is 17003 m.

Physical model is made of natural sand while maintaining the geometrical and kinematic similarity [16, 17]. The length, width and height of the filtration chute is 3.5 m, 0.38 m and 0.58 m respectively (Fig.3).
Figure 3. Laboratory flume and the model of an earth fill dam with horizontal pipe drainage

Steady filtration state was studied in the model. Geometrical similarity coefficient is $\alpha^1=75$. The dam model dimensions are: height $H_m = 32.0$ cm, crest width $b_m = 8.0$ cm, dam base width $l = 235.0$ cm, water depth at the upstream side $h = 29.1$ cm. Horizontal pipe drainage model is made of six plastic perforated pipes 16 mm in diameter, installed inside the existing drainage. Geotextile [18] 600-6.00 TSh 64-15808601-74:2010 was used as protective and filtration material. The material’s coefficient of filtration is 70 m/day at 2 kPa pressure. The flume has 12 piezometers, which were used to obtain the reading for phreatic surface in the dam body. Drainage pipe locations and water level in the reservoir were changed periodically during the process of laboratory observations. The location of drainage pipe with respect to the beginning of the dam were taken at the distances of: $l_{0\text{-drainage}} = 1.451$m for option 1, $l_{0\text{-drainage}} = 1.574$m for option 2, $l_{0\text{-drainage}} = 1.205$m for option 3.

We have determined the location and piezometer reading for each option with laboratory model, then calculated real quantities for natural conditions as follows:

$$l_{iN} = l_{iM} \cdot \alpha_L; \quad h_{iN} = h_{iM} \cdot \alpha_L; \quad Q_{iHN} = Q_{iM} \cdot \alpha_L^{2.5}$$

\section*{3. Results}

The research results are given below in Table 1 and Figure 4.

\begin{table}[h]
\centering
\caption{Experimental data for determining the phreatic surface at normal operating level of 130.00, $H_m=21.8$m, $H_m=29.1$cm}
\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|c|c|}
\hline
Piezometer locations & $l_{1,1}$ & $l_{1,2}$ & $l_{1,3}$ & $l_{1,4}$ & $l_{1,5}$ & $l_{1,6}$ & $l_{1,7}$ & $l_{1,8}$ & $l_{1,9}$ & $l_{1,10}$ & $l_{1,11}$ & $l_{1,12}$ \\
\hline
Model $l_{iM}, \text{ m}$ & 0.763 & 0.117 & 0.115 & 0.117 & 0.112 & 0.115 & 0.112 & 0.123 & 0.145 & 0.115 & 0.11 & 0.115 \\
\hline
Field $l_{iH}, \text{ m}$ & 57.2 & 8.8 & 8.6 & 8.8 & 8.4 & 8.6 & 8.4 & 9.2 & 10.8 & 8.6 & 8.25 & 8.6 \\
\hline
Piezometer readings & $h_1$ & $h_2$ & $h_3$ & $h_4$ & $h_5$ & $h_6$ & $h_7$ & $h_8$ & $h_9$ & $h_{10}$ & $h_{11}$ & $h_{12}$ \\
\hline
Model $h_{iM}, \text{ m}$ & - & - & - & - & 0.272 & 0.258 & 0.25 & 0.27 & 0.23 & 0.22 & 0.19 & 0.02 \\
\hline
Field $h_{iH}, \text{ m}$ & - & - & - & - & 20.35 & 19.45 & 18.85 & 18.1 & 17.35 & 16.6 & 14.35 & 1.5 \\
\hline
\end{tabular}
\end{table}
We can see from Figure 4 that:
- for the first drainage location option the phreatic surface is quite low from the surface of the slope and the installation of the drainage requires large amount of work, so this option can be recommended if there is a need to increase the downstream slope stability;
- for the third drainage location option the phreatic surface is very close to the downstream slope surface;
- for the second drainage location option the phreatic surface is at the distance of 4.4 meters from the slope surface, which can be considered as the optimal option.

Fig. 5 shows the comparison of the phreatic surfaces in Sultansandjar dam for upstream water level 129.15 and $H_H=20.95$ m with experimental data, obtained in laboratory conditions.

It is known that the depth of buildings and structures is set according to the soil freezing depth [19]. Maximum soil freezing depth is determined according to the location of the structure [20] and is accepted with 10% or 2% probability depending on the service life of the structure.

We consider that setting the depth of drainage system in the dam only by soil freezing depth like with civil structures and buildings is not quite enough, and since the phreatic surface is the level of filtrating water in the dam body, it is necessary to take into account the factor of capillary water rise [21].

Based on the mentioned facts it is reasonable to set the minimal distance from the downstream slope surface to the phreatic surface by the following relationship:

$$d_n = d_s + d_k + a$$  \hspace{1cm} (2)
where

- \( d_\gamma \) - soil freezing depth on the downstream slope, m;
- \( d_\kappa \) - height of the capillary rise, m;

\( a \) – reserve factor, depending on the dam significance level, reliability and stability of the slopes, it can be initially set as \( a = 0.5 - 1.0 \) m.

Based on model research of Sultansandjar dam the following results were obtained: \( d_\gamma = 11.85 \) m, \( d_\kappa = 4.40 \) m, \( d_a = 0.88 \) m for the 1st, the 2nd and the 3rd options, respectively.

From (19, 20) for conditions in Karakalpakstan and Khorezm regions the soil freezing depth \( d_\gamma = 1.38 \) m, height of capillary rise for desert sand \( d_\kappa = 0.6 \) m. Then with (2) we have \( d_\gamma = 1.38 + 0.6 + 0.8 = 2.78 \) m.

Filtration discharge on the model was 0.0000482 l/sek with upstream water level 130.00; 0.000042 l/sek with upstream water level 129.15; 0.0000323 l/sek with upstream water level 123.1. The corresponding field discharge values, determined with equation (1) are 0.0313; 0.0273; 0.021 l/sek, these maximal values are close to maximal discharge observed in the section of Sultansandjar dam under study and is equal to 2.2 l/sek.

4. Discussion

Earth fill dams are the most common type of dams because of their simple design, ability to use local materials, aseismic stability and cost. The main disadvantage of such dams is the presence of filtration through the body and the base. In order to catch and extract filtrated water they build drainage system, including the ones with horizontal pipe drainage. The developed structure allows to restore the operation of horizontal pipe drainage without dismantling the existing system by installing it inside of the existing pipe.

Model research was conducted on a physical model of Sultansandjar dam maintaining the geometrical and kinematic scale of 1:75. The research is carried out with three water levels in the reservoir and with three options of new drainage model location on the downstream slope. The laboratory model drainage consist of six piece 16 mm perforated plastic pipes installed inside of the existing drainage pipes.

Results obtained from the model were recalculated for field data and showed that the most suitable location of pipes is the second option according to the state of phreatic surface and to the depth of installation requiring less work, which is 4.4 m under the surface of the downstream slope.

It was proposed that setting the installation depth of the drainage system by the analogy of civil structures accounting only the freezing depth is not sufficient and it is necessary to take into account the capillary rise of water above phreatic surface, significance level, reliability of the drainage system. With the account of these factors the depth of inspection manholes was set to be \( d_c = 6.16 \) m.

Comparison of the state of phreatic surface obtained from model experiments and field factors showed satisfactory matching.

Drainage discharge value obtained from the model and recalculated for field, as well as the value observed during the operation of Sultansandjar dam in the area under study was equal to 2.2 l/sek.

5. Conclusions

We have created a filtration model for Sultansandjar dam with a scale of 1:75 with the use of natural sand having filtration coefficient \( K_f = 1.5 - 2.5 \) m/day.

The new drainage model is made with the account of geometrical scale using six pieces of 16 mm diameter perforated plastic pipes, installed inside of the existing drainage and covered into protective filtration material and with inspection manholes.

In setting the location of the drainage it was proposed to take into account not only the freezing depth of soil but also the height of capillary rise and including a reserve factor accounting for dam significance level, drainage system reliability, whose value was set to be \( d_c = 4.4 \) m; \( d_c = 6.16 \) m, and the
location of the drainage was determined to be at the distance of 118.05 m from the upstream slope of the dam.

Comparison of the state of phreatic surface and filtration discharge with the field data showed satisfactory compliance and acceptability of the obtained results. The maximum obtained filtration discharge values for model and for field are 0.000042 l/sec and 0.0313 l/sec, respectively.

The proposed drainage design is implemented in the area between pickets PK57+80 and PK58+20 of Sultansandjar dam and it has been operating successfully.

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