# Determination of the time of lowering depression surface in transition zones with a smooth and instantaneous decrease in water level in reservoir

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**Abstract.** The Republic of Uzbekistan pays great attention to the development and implementation of a program for the development of hydropower based on ensuring the share of hydropower in the energy potential and the integrated development of hydropower potential. Over the last three years, hydropower plants have been built or reconstructed in more than a dozen small and medium-sized earth dams to accomplish this task. Typically, unstable filtration is observed in the body of earth dams because of deviations from the normal filling and emptying of water reservoirs. The main goal of the research is to determine the time to lower the depression surface in the Tupalang earth dam transition zones, which characterizes the intensity of unstable filtration during a smooth and sudden drop in reservoir water level. The calculations were made according to the theoretical dependences of V.P.Nedriga for two cases of smooth and sudden lowering of the water level in the reservoir, starting from the normal backed level (NBL). In the calculations, the values of the main parameters were taken to be the coefficient of water loss of the soil (0.3), the coefficient of filtration of the transition zones (9.5 m/day), and the coefficient of laying the slope of the transition zones (0.2). Calculations showed that the time of lowering the depression surface in the transition zones with a gradual decrease in the water level in the reservoir was 84.1 days, and with an instantaneous decrease in the water level during the operation of a dam with a height of 120 m 3.86 days, and during the operation of a dam with a height of 185 m 6.82 days.

## 1 Introduction

One of the most important issues in the world is the fight against unstable filtration in the body and foundation of earth dams that exploit as part of these reservoir hydroelectric facilities [1–4].

Field studies have been conducted in reservoirs, and a methodology for analyzing the formation of a depression curve has been developed, considering changes in the water level

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in the reservoir [5,6]. The operation of reservoir cascades is analyzed based on the known theory of control, considering the specific conditions of the economy and social and economic aspects of the region [7–10]. Water-retaining structures could hazard hydrological, hydraulic, structural, filtration, and channel systems [11–13].

One of the aspects related to filtration in reservoirs, correlations for convective diffusion and determination of salt dissolution coefficients, had been proposed. In this case, the convective diffusion equations were constructed, and the problem was solved under conditions where all the salts in the cracks were dissolved, and the diffusion coefficient did not depend on the filtration rate [14,15]. In addition, the water reservoirs, particularly the Akdarya reservoir, analyzed the state of turbidity. The method of determining reservoirs' useful capacity and turbidity volume has been developed. This method allows you to significantly reduce the volume of paperwork and reduce the cost of determining the amount of silting [16–18].

Demetris Koutsoyiannis proposed a scheme for layer-by-layer consideration of the volume of water in the reservoir [19]. In [20,21], a mass balance model was developed to calculate the concentration of a substance in water for several scenarios of filling and emptying a reservoir. The organic carbon construct is taken as a representative measure. This approach estimates the optimal time for filling and emptying reservoirs.

According to the conditions of water resources management, it is necessary to rationally manage the reservoirs, considering the calculation of the water flow regime and without excluding pre-established dispatch schedules[22]. In [23], the solution to the mathematical problem of non-stationary filtration of an earth dam of rectangular cross-section is given when it is wet from below and dry from above. Several books [24–29] systematize all aspects of the design of hydraulic structures, incl. issues of calculation of unsteady filtration in the body of earth dams.

In [30] Patent of the Russian Federation, a method is proposed for determining filtration coefficient and soil water loss in the field using the pumping method. [31,32] analyzed the issues of water storage upstream. It is noted that this increases the economic value of the water supply system. In works[33,34], studies were carried out for earth dams with a core and when there were horizontal drains in the upstream wedge, which contributed to an increase in water loss and reduced seepage pressure gradients when unsteady seepage appeared.

In [35], the questions of the influence of unsteady filtration on the slopes of mountains during a drop in water levels in the river were studied. Research works [36–38] are devoted to solving non-rocky geotechnical problems, including when there is a large filtration along the slopes of rivers and its influence on their stability. In dissertation work. [39] considered the issues of improving the reliability and safety of hydraulic structures on subsidence soils.

In [40,41], catastrophic floods in the middle part of the Yellow River (China) were subjected to analysis. The influence of these floods on the transport of river sediments was studied. Influence of the confluence of floods on the currents of the river, on the direction of floods in the main channel. The construction of Sanmenxia on the Yellow River greatly changed the natural regime of the river. The article [42] states that the construction of reservoir waterworks in the Sanchahe River (China) basin has led to a sharp change in the river flow. Since 2000, there has not been a single case of a major flood. In [43,44], the fundamentals of fluid hydraulics, methods for calculating stationary and non-stationary filtration, the theory of wells, and groundwater migration are presented.

The purpose of the research is to establish the influence of the presence of transition zones on the intensity of unsteady filtration in the soil dam of the Tupolong reservoir.

Research objectives:

1) setting the time for the depression curve to decrease with a gradual decrease in the water level in the reservoir.

2) establishing the time for the decrease in the depression curve with an instantaneous decrease in the water level in the reservoir.

## 2 Method

Currently, the most theoretically substantiated method for calculating unsteady seepage in earth dams is the dependencies proposed by Nedryga V.P [45]. The project provides for a 180.0 m high rock and earth dam. The core is central, vertical, symmetrical in section, and made of loam. The width of the core at the top is 4.0 m, and at the base - 75.6 m. The laying of the slopes is 0.2. The mark of the bottom of the core is 785.0 m.

The transition zones provide the interface between the core and the thrust prisms. Considering the height of the dam, the steep sides of the canyon, and, as a result, the risk of cracking in the core, the transition zones are two-layered, with the thickness of the first layer - 3.0 m and the subsequent one - 4 m.

Until 2006, a 120.0 m high dam with a crest elevation of 905.0 m was built, and a basin for 150.0 million m$^3$ was created. m, including a usable capacity – of 120.0 million m$^3$; the storage capacity of flood waters is 30.0 million m$^3$. At present, the dam has been built to the design mark.

During the construction and operation of the Tupalang dam, several features had and continue to have a significant impact on the stress-strain state of the dam, the course of the core soil consolidation process, and the filtration regime.

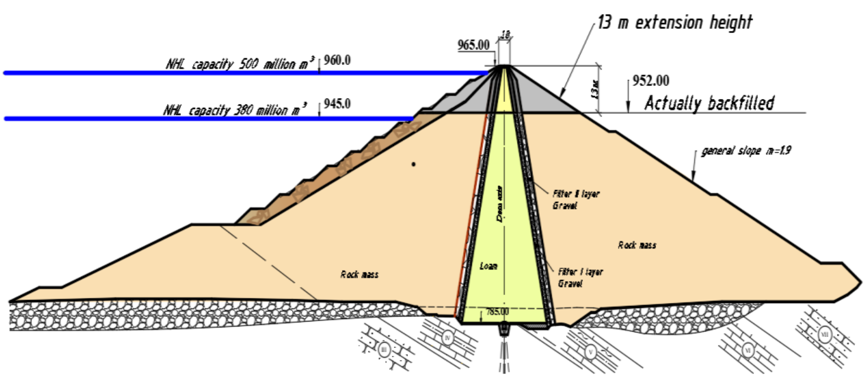


**Fig. 1.** Construction of the Tupalang dam.

The main ones are the following:

- backfilling of the lower prism was carried out along an incomplete profile, leaving in some zones descending slopes from the center to the lower face, the material on which was segregated.

- the dam was put under pressure during construction, having been erected less than half of the design height.

Therefore, the calculations were carried out for both cases when the dam height was 120m and 185m. In the calculations, the design characteristics of the soil of the transition zones were taken, the soil water loss coefficient was 0.3, and the filtration coefficient was 9.5m/day. Calculations were made with a gradual decrease and an instantaneous decrease in the water level in the reservoir. The calculation results were summarized in a table, and graphs for both schemes were built on them in Excel.

# 3 Results and Discussions

The calculation of the time for lowering the depression surface in the transition zones from a gradual decrease in the water level in the reservoir is carried out according to the method of V.P. Nedrig using the following formula:

$$t = \frac{\mu \cdot (h_1 - z)}{2 \cdot k_f \cdot \Delta h \cdot \sin \alpha} \cdot \left[ (h_1 + z) \cdot \sqrt{1 + m_1^2} + a \right] \quad (1)$$

$$\alpha = arctg(\frac{1}{m_1}) \quad (2)$$

where: $\mu$ is the coefficient of water loss of the soil; it is assumed to be 0.3; $k_f$ is the filtration coefficient of the transition zones; it is assumed to be 9.5 m/day; $\Delta h$ is the specified allowable water level difference under the cover and in the reservoir; $m_1$ is the coefficient of transition zones, is taken equal to 0.2; $Z$ is the current ordinate of the depression surface, accepted within ($h_1 \geq z \geq h_2$).

The calculation is summarized in table 1, and a graph was made (Fig 2).

**Table 1.** Determination of the time of lowering the depression surface in the transition zones with a gradual decrease in the water level in the reservoir

| **μ** | $k_f$ | **sinα** | $h_1$ | $h_1$+z | $h_1$-z | $m_1$ | **Δh** | **z** | **a** |
|---|---|---|---|---|---|---|---|---|---|
| 0.3 | 9.5 | 0.98 | 160 | 310 | 10 | 0.2 | 0.5 | 150 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 300 | 20 | 0.2 | 0.5 | 140 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 290 | 30 | 0.2 | 0.5 | 130 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 280 | 40 | 0.2 | 0.5 | 120 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 270 | 50 | 0.2 | 0.5 | 110 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 260 | 60 | 0.2 | 0.5 | 100 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 250 | 70 | 0.2 | 0.5 | 90 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 240 | 80 | 0.2 | 0.5 | 80 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 230 | 90 | 0.2 | 0.5 | 70 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 220 | 100 | 0.2 | 0.5 | 60 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 210 | 110 | 0.2 | 0.5 | 50 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 200 | 120 | 0.2 | 0.5 | 40 | 7 |
| 0.3 | 9.5 | 0.98 | 160 | 190 | 130 | 0.2 | 0.5 | 30 | 7 |

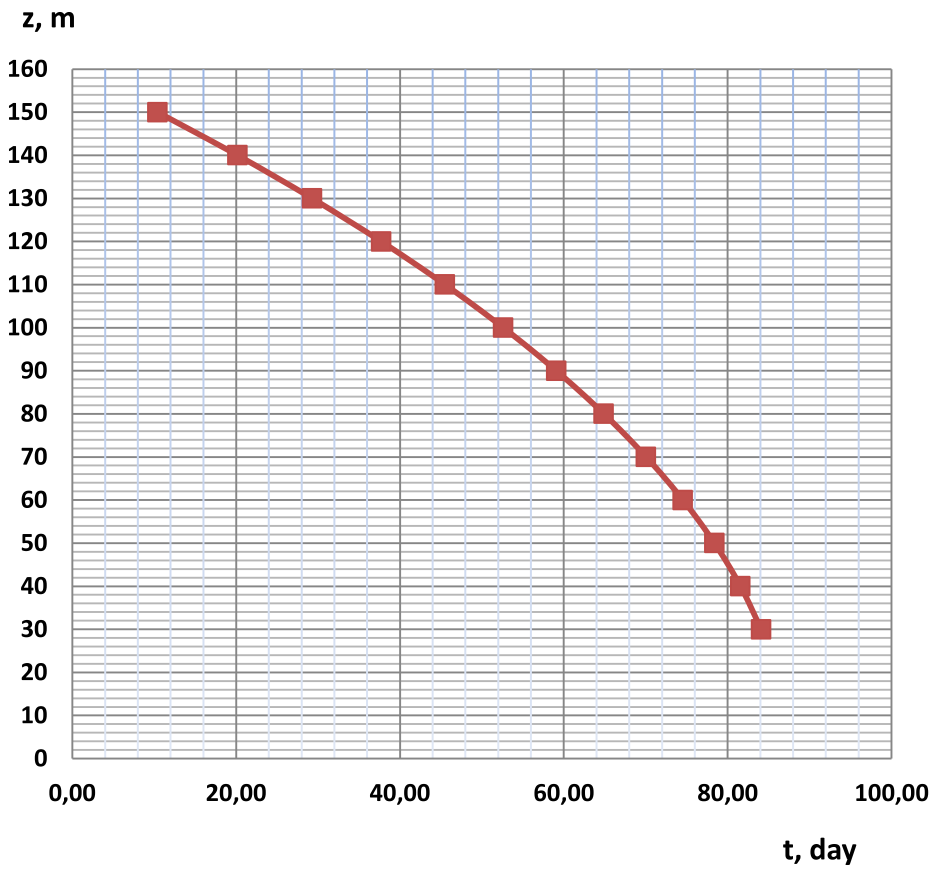


**Fig. 2.** Graph of the time of lowering the depression surface in the transition zones with a gradual decrease in the water level in the reservoir

Calculation of the time of lowering the depression surface in the transition zones from an instantaneous decrease in the water level in the reservoir is carried out according to the method of V.P. Nedriga using the following formula:

$$t = \frac{\mu \cdot (h_1 - z)}{2 \cdot k_f \cdot \Delta h \cdot \sin\alpha} \cdot \left[ (h_1 + z) \cdot \sqrt{1 + m_1^2} + (h_2 \cdot \sqrt{1 + m_1^2} + \frac{a}{2}) \cdot \ln \frac{h_1 - h_2}{z - h_2} \right] \quad (3)$$

$$\alpha = arctg(\frac{1}{m_1}) \quad (4)$$

where: $\mu$ is the coefficient of water loss of the soil; it is assumed to be 0.3; $k_f$ is the filtration coefficient of the transition zones; it is assumed to be 9.5 m/day; $h_1$ is water depth at the initial moment of time (*t=0*), taken at the NHL mark (operational and design case) $h_2$ is water depth in the reservoir after an instantaneous drop in the level to the dead volume level (DVL) mark; $m_1$ is the coefficient of transition zones, is taken equal to 0.2; *Z* is the current ordinate of the depression surface, accepted within ($h_1 \geq z \geq h_2$).

**Table 2.** Determination of the time of lowering the depression surface in the transition zones with an instantaneous decrease in the water level in the reservoir for the operational case

| μ | $k_f$ | α | $h_1$ | $h_2$ | $m_1$ | z | a | t |
|---|---|---|---|---|---|---|---|---|
| 0.3 | 9.5 | 79 | 91 | 24 | 0.2 | 81 | 7 | 0.46 |
| 0.3 | 9.5 | 79 | 91 | 24 | 0.2 | 71 | 7 | 0.94 |
| 0.3 | 9.5 | 79 | 91 | 24 | 0.2 | 61 | 7 | 1.46 |
| 0.3 | 9.5 | 79 | 91 | 24 | 0.2 | 51 | 7 | 2.05 |
| 0.3 | 9.5 | 79 | 91 | 24 | 0.2 | 41 | 7 | 2.77 |
| 0.3 | 9.5 | 79 | 91 | 24 | 0.2 | 31 | 7 | 3.86 |

**Table 3.** Determination of the time of lowering the depression surface in the transition zones with an instantaneous decrease in the water level in the reservoir for the design case

| μ | $k_f$ | α | $h_1$ | $h_2$ | $m_1$ | z | a | t |
|---|---|---|---|---|---|---|---|---|
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 150 | 7 | 0.38 |
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 130 | 7 | 1.16 |
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 110 | 7 | 1.98 |
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 90 | 7 | 2.84 |
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 70 | 7 | 3.79 |
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 50 | 7 | 4.91 |
| 0.3 | 9.5 | 79 | 160 | 24 | 0.2 | 30 | 7 | 6.82 |

Based on tables 2 and 3, a graph was made.

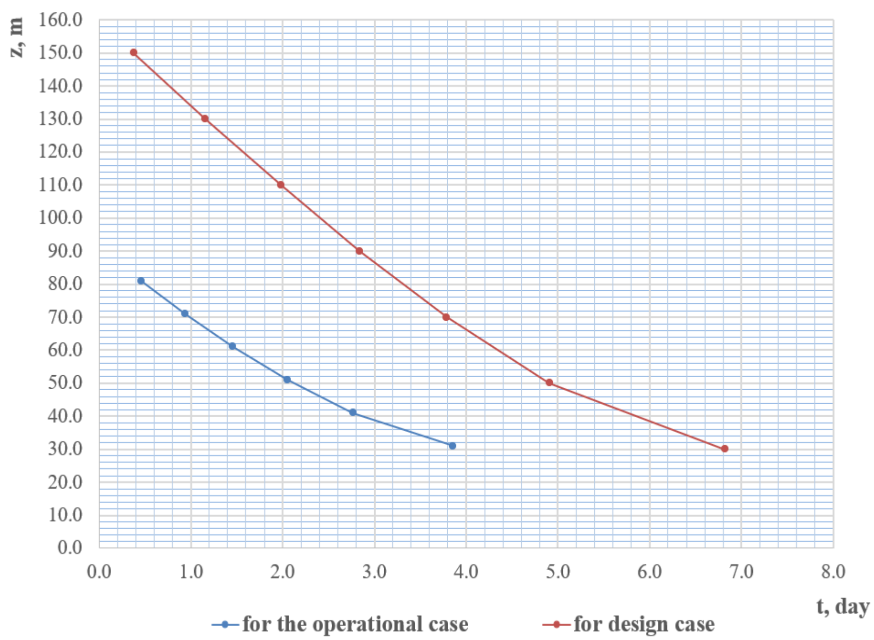


**Fig. 3.** Graph of the time of lowering the depression surface in the transition zones with an instantaneous decrease in the water level in the reservoir

At a maximum standard speed of 1 m/day in the reservoir with a useful volume height of z=130 m. The water level in the reservoir will drop to dead in 130 days; based on the maximum flow rate of the culverts of the hydroelectric complex, the maximum drawdown rate is from 11.8 to 16.1 m /day [30, 32], and the decrease time is 11.0 and 8.0 days.

If we assume that the rate of decline in the lateral rockfill is the same as in the reservoir, then the sagging of the depression curve will also occur within the transition zones [46]. This, in turn, can affect the lowering of the drawdown curve in the core, the stability of the upper slope, and, in general, the reliability and safety of the earth dam [1, 47].

## 4 Conclusions

The time for lowering the depression surface in the transition zones with a gradual decrease in the water level in the Tupalang reservoir with a maximum emptying rate of 1.0 m/day is 84.1 days.

The maximum emptying rates, calculated based on the maximum flow rates of the outlet structures, were set from 11.8 to 16 m/day, while the depression surface lowering time is 11.0 and 8 days.

Sagging of the depression surface was also established within the transition zone, which generally increases the overall reliability and safety of the upper slope.

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