Assessment of wind effect on reservoir

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Abstract. This article presents the research results on assessing the strength of the reservoir slope under the influence of different wind speeds. Calculating the parameters of the wave effect on the dam of the Rezaksoi reservoir was carried out. The average wave height was determined using existing calculation methods for the Rezaksoy Reservoir. Stones of different sizes are used to strengthen the slope of the dam and protect it from the effects of wind waves, and stones with an average diameter are selected for calculations. Based on the determined stone dimensionsK_{Δ}; K_{NP} values were determined. The diameter of the stone D_1 and D_2 for the conditions of Rezaksoi was determined.

1 Introduction

Reservoirs, also referred to as dams, are crucial infrastructures utilized for storing and managing water resources for various purposes, including water supply, hydropower generation, flood control, and irrigation [1-7]. Among the significant factors that impact the operation and safety of reservoirs, the effect of wind waves is of particular importance. Wind waves, resulting from energy transfer from wind to water, can have considerable consequences on water bodies, including erosion, accretion, structural damage, and sediment resuspension [4-8]. Therefore, understanding and mitigating the impacts of wind waves on water bodies are critical for ensuring their reliable and efficient operation, particularly in the context of changing wind patterns and wave characteristics due to climate change. This paper presents an overview of the effects of wind waves on water bodies, including the mechanisms of wave generation, propagation, and interaction with reservoir structures, as well as wave impact assessment and mitigation methods [5-10]. The findings and insights of this research can contribute to the design, operation, and management of reservoirs in a changing climate and provide valuable knowledge for academic and professional communities engaged in water resources management and engineering [11-14].

The safe operation and efficient utilization of water reservoirs, with consideration of reservoir reserve, are crucial in managing these facilities. In this context, it is imperative to account for the effects of wind impact on the reservoir dam, as it can affect the assessment of the reservoir's useful volume and the dam's structural integrity [1-4]. The evaluation of dam strength for water reservoirs remains a pressing issue, and numerous countries, including the Republic of Uzbekistan, are actively engaged in scientific research related to the design and reconstruction of reservoirs [1-4]. However, the significant variations in natural climatic conditions and hydraulic-hydrological regimes among different regions in Uzbekistan necessitate separate investigations for each reservoir.

The consideration of tidal effects on water bodies is of paramount importance for various reasons, particularly concerning safety and structural integrity. Wind-generated waves can impose significant forces on reservoir structures, including dams, culverts, and embankments, resulting in structural damage or failure [12-15, 17]. Therefore, comprehending the magnitude and characteristics of wave action is crucial to ensure reservoir structures' safety and integrity and prevent catastrophic events such as dam failure or overtopping. Furthermore, waves can impact the performance of water bodies by causing sediment resuspension, reducing sediment and water storage capacity. Additionally, waves can influence the operation of intakes, gates, and other hydraulic structures, which can have implications for water supply, hydropower generation, and flood control operations [14-16]. Accurate assessment and prediction of tidal effects are imperative to optimize reservoir operations and enhance their efficiency.

The impact of waves on water bodies, particularly regarding environmental consequences, is a significant consideration for the sustainable management of reservoir ecosystems. Waves can induce shoreline erosion, scour, and sediment and water quality changes, resulting in habitat loss and ecological imbalances. Understanding the environmental impact of tidal effects on water bodies is imperative for protecting aquatic ecosystems and the sustainable management of water resources [16-18]. Furthermore, the potential changes in tidal effects on water bodies due to climate change, arising from alterations in wind patterns and wave characteristics, demand thorough assessment and adaptation strategies. As climate change continues to disrupt weather patterns and hydrological regimes, it is crucial to evaluate and mitigate potential changes in tidal impacts on reservoirs to ensure their resilience and sustainability in the face of changing climate conditions. In designing and constructing new reservoirs, careful consideration of wave action is crucial [17-20]. Understanding the wave climate and assessing potential wave impacts is vital in selecting appropriate design parameters, construction methods, and safety measures to ensure the strength and reliability of reservoir structures. Proper integration of wave impact considerations in reservoir design and construction is essential to mitigate potential hazards and ensure reservoir structures' long-term performance and stability.

Uzbekistan is home to more than 55 reservoirs, collectively comprising a total volume of 19.2 km^3. Among these, 20 reservoirs are classified as large, with a combined volume of 17.8 km^3 and a useful volume of 14.1 km^3. In the determination of reservoir dam height, accurate estimation of the height of waves induced by wind is essential, including the evaluation of wave rise following the dam slope. Notably, investigations conducted in this field [11-14] emphasize the significance of assessing dam slope and structural stability parameters under the influence of wind waves. These findings underscore the importance of considering wind wave effects on dam slopes and structural parameters in reservoir design and operation.

2 Materials and Methods

2.1 Study area

Research on protecting the Rezaksoi reservoir dam from the impact of wind waves was conducted at the Rezaksoi reservoir, which is situated 5 km from the city of Chust in the Namangan region of Uzbekistan. The Rezaksoi reservoir, formed by damming the Rezaksoy River originating from the Kurama mountain ranges, serves as a water source for agricultural irrigation. It is a run-of-river reservoir that regulates the seasonal water flow of the Rezaksoy River. The dam of the Rezaksoi reservoir is a stone-earth dam with two structures capable of supplying 40 m^3/s of water to the Syrdarya and Northern Fergana canals and facilitating water discharge. The maximum length of the dam's surface is 3200 m, with a maximum design storage (MDS) of 80 m and a full capacity of 200 million m3. The wind wavelength in the western direction is 2200 m, with an average wind speed (W) of 10 m/s [5].

Fig. 1. Rezaksoi reservoir

2.2 Methods

In the design process, the dam's height is determined as a vertical distance "d" above the maximum water level, as shown in Figure 2. The objective is to ensure that water does not overflow the dam. The calculation of "d-" was carried out according to the method outlined in the reference [13].

$$d = h_v + h_n + a \quad (1)$$

Here h_v is the height of the water wave created by the wind; h_n is the height of the wave on the slope (slope) of the dam; a is reservoir height. 0.5m and 0.1 as maximum values $h_{1\%}$.

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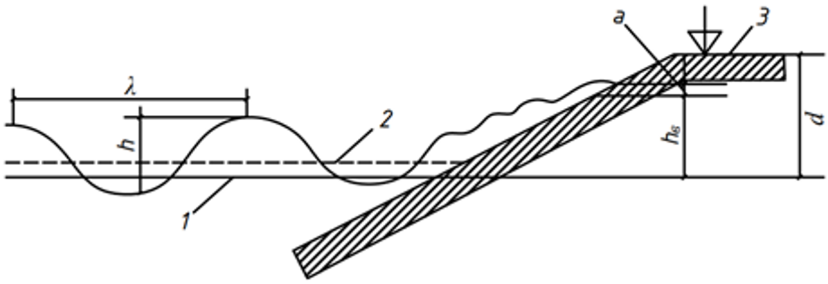

Fig. 2. Dam parameters in the reservoir: 1) calculated static level, 2) average wave line, h_v is wave height, λ is wavelength, d is the distance from the calculated static level to the upper part of the dam.

The average wave height for the Rezaksoy reservoir is determined using established calculation methods. These methods involve employing the following formula: [Insert formula for calculating average wave height for Rezaksoy reservoir based on available calculation methods [11-13]:

$$h_v = K_v \cdot \frac{W^2 L}{g \cdot H} \cdot \cos \alpha_v \quad (2)$$

Here, L is the propagation length of the wind wave, taken depending on the geographical location of the Rezaksoy reservoir (L=2200 m) [5]; g = acceleration of free fall m /s^2; H is water in the warehouse wave influence conditional calculated water depth, $H = 20\,m$ is accepted for Rezaksoi; α_v the angle between the longitudinal axis of the reservoir and the prevailing wind direction ($\alpha_v = 0$); $K_v = 2.1 \cdot 10^{-6}$ coefficient depending on wind speed;
The probability of the height of the wave rising along the dam slope under the influence of wind, for a given margin (1%), is determined as follows:

$$h_{H_j} = K_\Delta \cdot K_{NP} \cdot K_C \cdot K_\beta \cdot K_{NG} \cdot K_{H_j} \cdot h_{1\%} \quad (3)$$

Here, K_Δ and K_{NP} are determined depending on the type of dam slope design and relative roughness;

We use the dimensionless parameters below to determine the wave height.

$$\frac{gt}{W}, \frac{gL}{W^2}, \frac{gh}{W^2}, \frac{g\lambda}{W^2} \quad (4)$$

According to the recommendations, we accept the wind exposure time as 6 hours.

Wave parameters under the influence of wind are determined by the following formula.

$$h = \frac{0.045 W^2}{g} \quad (5)$$

The wave period in water under the influence of the wind is determined by the following formula.

$$t = \frac{1.94 W}{g} \quad (6)$$

The wavelength in water under the influence of wind is determined by the following formula.

$$\lambda = \frac{gt^2}{2\pi} \quad (7)$$

Based on the above information, we get the 1% guarantee of the wave height as follows:

$$h_{1\%} = K_i \cdot h \quad (8)$$

K_i is the coefficient $\frac{gL}{W^2}$ determined based on the connection [11-14].
Various methods have been proposed for determining the size of stones used to reinforce the slope of the dam and protect it from wind wave effects. In the calculations, stones with average diameter are typically selected. Based on the determined stone dimensions, values of K_{Δ} and K_{NP} are determined. Several studies [6-10] have provided different views on determining the size of stones for slope reinforcement. Some researchers recommend determining the mass of rock (M) according to the following relationship when ensuring the stability of the dam slope in the form of rock cover. A formula was found to be inserted for determining the mass of rock (M) based on the recommended relationship from the cited studies.

$$M = \frac{0.025\rho_k h_v^2 \lambda}{\left(\frac{\rho_K}{\rho_B}-1\right)^3 \sqrt{1+m^2}} \quad (9)$$

Here, ρ_K, ρ_B are the density of rock and water, respectively, kg/m^3; m is slope coefficient; For Rezaksoy, t= 2.5;
D_1, m for the conditions of Rezaksoy

$$D_1 = \sqrt[3]{\frac{M}{0.524\rho_k}} \quad (10)$$

spherical ball D_2, To determine m, formula (6) is presented [11]:

$$D_2 = 1.5ch_v\left(\frac{\sqrt[3]{m}}{m} + 0.5\right)\frac{m+1.8}{1.8m-1} \cdot \frac{\rho_v}{\rho_k-\rho_v} \quad (11)$$

Hereρ_v is the specific weight of the aeration water flowing from the cover at the end of the wave is assumed to be 10 kN/m^3; ρ_k is specific gravity of stone ρ_k= 2600 n/m^3; ρ_v is specific gravity of water $\rho = 1000$ n/m^3; s is the coefficient of hydraulic resistance is assumed to be equal to 0.2, the diameter is greater than 0.15, and the height is greater than 0.50 m.

3 Results and Discussion

K_C is determined depending on the slope coefficient and wind speed, $K_C = 1.45$ accepted for Rezaksoy; K_β is determined depending on the direction of the wave, the angle of the wave direction $\alpha = 0$is assumed to be equal $K_\beta = 1$; K_{NG} is determined that the coefficient depends $K_{NG} = 1{,}3$on the wave slope $\frac{\lambda}{h_{1\%}}$; K_{H_j} is represents the probability that the wave will rise on its slope [11-14].

Based on the parameters obtained for the Rezaksoi reservoir, the values determined by the above formulas were wave height $h = 0.17$, wave period $t = 1.68,$ and wavelength

$\lambda = 1.73$. This (9) the mass of the stone calculated based on the formula was equal to M=21.5;

Based on this method (10), the average stone diameter was calculated as follows: $D_1 = 0.12\ m$. In that case, based on recommendationsK_Δ value is as follows$K_\Delta = 0.75$. In this method (11), the average stone diameter was calculated as follows: D_2 =0.29 m. Based on the formula (1), d_1-0.64 and d_2-0.64 were calculated as follows, ensuring that water does not flow over the dam.

4 Conclusions

Using data from the Rezaksoi reservoir, the wave parameters were determined: $h = 0.17$, $t = 1.68$, $\lambda = 1.73$ K_Δ and K_{NG} coefficients were determined based on these parameters. Based on the determined coefficients, the probability of the height of the wave rising along the dam slope under the influence of wind was determined for the given margin (1%).

To calculate the parameters of the slope of the stone dam under the influence of waves, based on the limit equilibrium theory, the suitable stone diameters for the Rezaksoi reservoir were determined: D_1 =0.12, D_2 =0.29 m. Using the formulas to determine the parameters of the dam, the height of the dam d_1 -0.64 and d_2 -0.64 was determined, taking into account the physical and mechanical properties of the materials for the main forces created under the influence of the wave flow in the Rezaksoi reservoir.

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