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Methods of Assessing Technical Conditions of Earth Dams Based on Space Monitoring Data

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Methods of Assessing Technical Conditions of Earth Dams Based on Space Monitoring Data

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Abstract. This scientific study investigates the stress-strain state of the Tashkent earth dam and presents a methodology for determining the strength characteristics of the dam's material. The displacements of the earth dam were assessed by comparing them with results from satellite monitoring. The rigidity of the dam was gradually increased until the displacements aligned with the satellite data, and this value was accepted as accurate.

INTRODUCTION

To assess the strength and stability of dams, it is essential to have reliable data on their geometric and physical-mechanical characteristics. In many cases, only the original design data concerning these attributes is available. Additionally, since many dams are quite old, their characteristics may have changed significantly over time, and information regarding these changes is often lacking.

Since 2019, Uzbekistan has been continuously monitoring the condition of approximately 30 dams located in seismic areas using satellite technology. The results from this ongoing space monitoring indicate the displacement of specific points on the dam in two directions: vertically towards the base and horizontally along designated axes. These measurements of displacement are correlated with the water levels in the reservoirs. The data obtained reflect the actual static conditions caused by hydrostatic water pressure and the weight of the dam itself.

To further analyze the displacements, numerical methods were employed using the PLAXIS 2D software package. The displacement values recorded during the space monitoring were taken as accurate. By comparing these actual displacement values with those calculated numerically, and by adjusting the initial input data through a method of successive approximation, satisfactory agreement was achieved within specified accuracy limits. The initial data that aligned within a 5-10% accuracy range was considered to accurately represent the current technical conditions of the dam.

The stress-strain state of the dam was assessed using actual initial data. By considering the stress-strain conditions under various hydrostatic water pressures, Mohr-Coulomb circles were plotted. These circles help determine the strength characteristics of the soil, which are essential for calculating the stability of the slopes of an earth dam.

Using results from continuous monitoring, we can evaluate the technical condition of the dam and obtain values for the physical and mechanical characteristics of the soil. This information is critical for assessing the strength and stability of the dam, taking into account factors such as its weight, the moisture content of the soil, and the hydrostatic pressure exerted by the water in the reservoir.

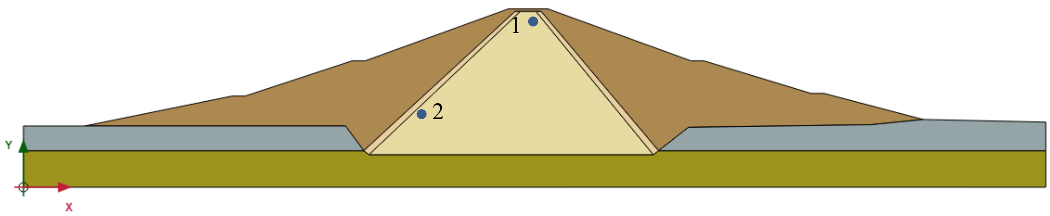
Earth dams are vital for society, providing drinking water, electricity, and irrigation for agricultural lands. Given the enormous size of these structures, calculating their strength and stability presents practical challenges. Therefore, such large structures are primarily studied theoretically, and numerical models are developed and implemented to aid in this process. Numerous studies have been conducted around the world to date [1-16]. Models of soils have been created in elastic and elastic-plastic statements. When calculating the stress-strain state and stability of earth dams, the physical and mechanical properties of the materials play a crucial role. It is important to note that the properties of earth dams at the time of their design often differ from those calculated years after construction. Consequently, it is necessary to reassess soil properties based on their current real state. This task requires specialized expertise and resources.

MATERIALS, METHODS, AND OBJECT OF STUDY

To analyze the stress-strain state of earth dams, several numerical methods were employed, including the finite difference method, the finite element method, and the boundary conditions method. In this study, the stress-strain state of the Tashkent earth dam was examined, taking into account both its weight and the water pressure acting on it. The Plaxis 2D software package, based on the finite element method, was utilized for this analysis.

Determining the Strength Characteristics of Earth Dams. The strength characteristics of earth dams were determined using the Mohr-Coulomb criterion, which is defined as:

$$\tau = \sigma tg(\varphi) + c. \tag{1}$$



Point coordinates: 1 - (154,2; 50,6); 2 – (119,8; 25,1).
FIGURE 1. Selected points where plastic deformation occurs

The principal stresses are determined by the following formulas for each point (Fig. 1):

$$\begin{aligned} \sigma_1 &= \frac{1}{2}\left[\left(\sigma_x + \sigma_y\right) + \sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2}\right], \\ \sigma_2 &= \frac{1}{2}\left[\left(\sigma_x + \sigma_y\right) - \sqrt{\left(\sigma_x - \sigma_y\right)^2 + 4\tau_{xy}^2}\right]. \end{aligned} \tag{2}$$

The coordinates of the points of the circles and the radii of the circles for plotting the Mohr-Coulomb graph are determined by the following formulas:

$$x_1 = \frac{\sigma_1^I + \sigma_2^I}{2}, \quad x_2 = \frac{\sigma_1^{II} + \sigma_2^{II}}{2}, \tag{3}$$

$$R_1 = \left|\frac{\sigma_1^I - \sigma_2^I}{2}\right|, \quad R_2 = \left|\frac{\sigma_1^{II} - \sigma_2^{II}}{2}\right|, \tag{4}$$

where x_1, x_2 are the coordinates of the center of the first and second circles, R_1 and R_2 are the radii, σ_1^I and σ_2^I are the principal stresses at the first point, σ_1^{II} and σ_2^{II} are the principal stresses at the second point.

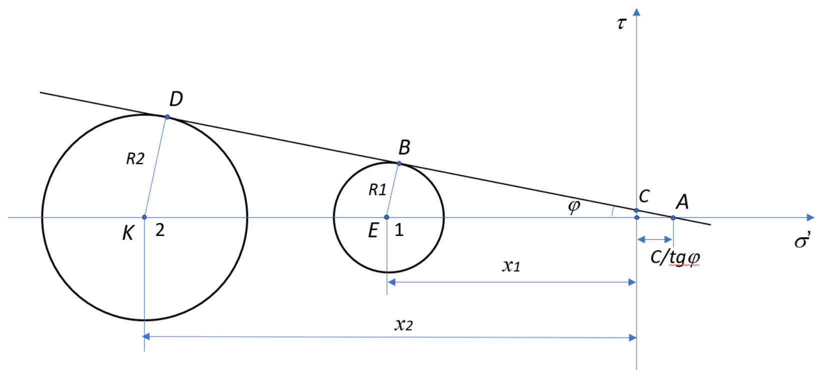


FIGURE 2. Plotting the Mohr-Coulomb circles by the values of the principal stresses at two points

From the right triangle ABE, we can write the following (Fig. 2):

$$\frac{R_1}{\frac{c}{tg(\varphi)}+x_1}=\sin(\varphi), \tag{5}$$

$$R_1=\left(\frac{c}{tg(\varphi)}+\frac{\sigma_1^I+\sigma_2^I}{2}\right)\sin(\varphi), \tag{6}$$

$$\frac{\sigma_2^I-\sigma_1^I}{2}=\left(\frac{c}{tg(\varphi)}+\frac{\sigma_1^I+\sigma_2^I}{2}\right)\sin(\varphi), \tag{7}$$

$$\sigma_2^I-\sigma_1^I=\left(\sigma_1^I+\sigma_2^I\right)\sin(\varphi)+2c\cos(\varphi). \tag{8}$$

The same can be written from the right triangle ADK for the second point (Fig. 2):

$$\sigma_2^{II}-\sigma_1^{II}=\left(\sigma_1^{II}+\sigma_2^{II}\right)\sin(\varphi)+2c\cos(\varphi). \tag{9}$$

Let us introduce the following notations:

$$\sigma_2^I-\sigma_1^I=a, \quad \sigma_1^I+\sigma_2^I=b, \tag{10}$$

$$\sigma_2^{II}-\sigma_1^{II}=d, \quad \sigma_1^{II}+\sigma_2^{II}=e, \tag{11}$$

then equations (8) and (9) take the following form:

$$\begin{aligned} a&=b\sin(\varphi)+2c\cos(\varphi), \\ d&=e\sin(\varphi)+2c\cos(\varphi). \end{aligned} \tag{12}$$

If we subtract the second equation from the first, we obtain:

$$a-d=(b-e)\sin(\varphi), \tag{13}$$

$$\varphi=\arcsin\left(\frac{a-d}{b-e}\right), \tag{14}$$

$$c=\frac{a-b\sin(\varphi)}{2\cos(\varphi)}. \tag{15}$$

In Plaxis 2D, the total stress is expressed as follows (Terzaghi's principle):

$$\sigma_{total} = \sigma' + u, \tag{16}$$

Here σ_{total} - is the total stress, σ' is the effective stress, u-is the pore pressure (the pressure of water in the pores of the soil).

To create an algorithm for determining (c) and (φ), formulas (1) through (15) were utilized. If the effective stress components at any two points in the dam's cross-section are known, the principal stresses can be calculated using formulas (2) and (3). By sequentially applying equations (4) to (15), it is possible to determine the values of cohesion and the friction angle.

STATEMENT OF THE PROBLEM

An analysis was conducted on the stress-strain state of the dam at the Tashkent Reservoir, which is situated in the Tuyabogiz mound of the Urta-Chirchik district in the Tashkent region. The reservoir receives its water from the Akhangaron River and was filled in 1963. Along the northern shore of the reservoir, there is an urban-type settlement called Tuyabuguz. The Tashkent-Bekabad highway runs along the crest of the dam.

A static analysis was conducted to assess the stress-strain state of earth dams under the effects of their own weight and water pressure. The analysis considered a scenario where the water level reached 51.2 meters. The modulus of elasticity for the prism and the dam foundation was taken as Eprism = 500 MPa, Ebase = 700 MPa. The strength of the earth dam was evaluated. The problem was analyzed using a two-dimensional coordinate system in a plane-strain formulation. The calculation scheme is illustrated in Fig. 3. The Mohr-Coulomb model was employed as the soil model, and the physical and mechanical parameters of the dam are summarized in Table 1.

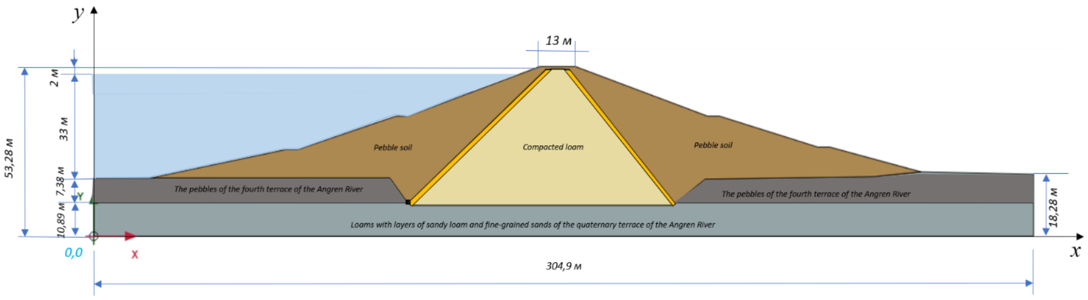


FIGURE 3. Calculation scheme of the Tashkent earth dam

TABLE 1. Physical and mechanical parameters of the Tashkent dam

Name of the dam and its elements		γ_{unsat} **[kN/m³]**	γ_{sat} **[kN/m³]**	k_x **[m/day]**	k_y **[m/day]**	E_{ref} **[kN/m²]**	c_{ref} **[kN/m²]**	φ **[°]**	v
	Core	15,9	18,1	0,1	0,1	30000	5,6	22,0	0,3
	Prism	17,5	20,4	10,0	10,0	50000	10	39,0	0,35
Tashkent	Foundation	20	22	0,01	0,01	60000	15	17	0,3
	Foundation (Pebble)	22	24	100	100	70000	24	39,7	0,3
	Filter	17	19	49	49	40000	7	25,0	0,3

RESULTS

The reservoir covers an area of 20 km², with a total volume of 250 million m³. Under the influence of water pressure, the upper slope of the dam has experienced a horizontal displacement of 7 mm to the right. This value corresponds to the horizontal displacement recorded in the space monitoring system (Fig. 4). Additionally, the vertical displacement of the dam crest is measured at 32 mm (Fig. 5), which aligns with the findings from the space monitoring system.

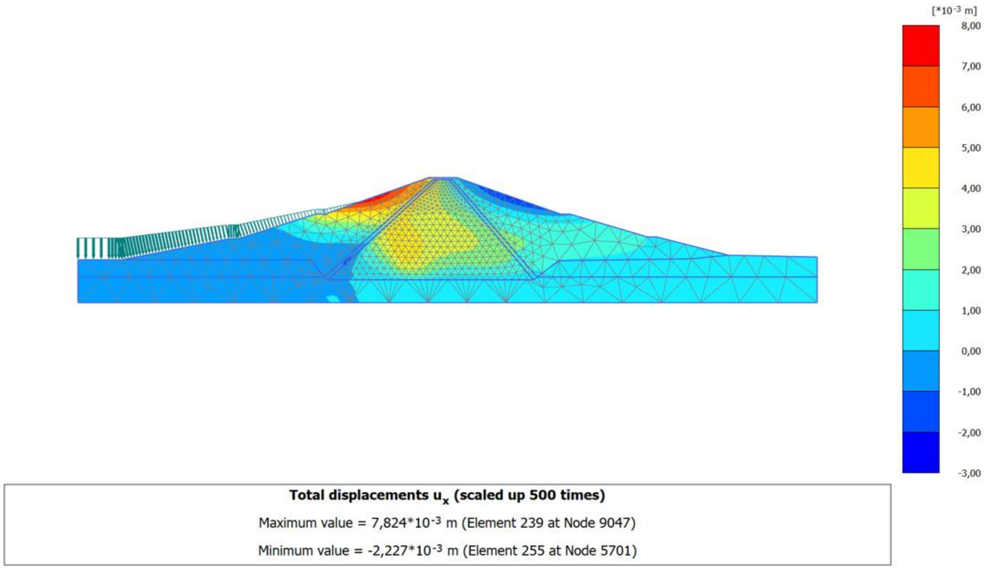


FIGURE 4. Isolines of horizontal displacement of the earth dam

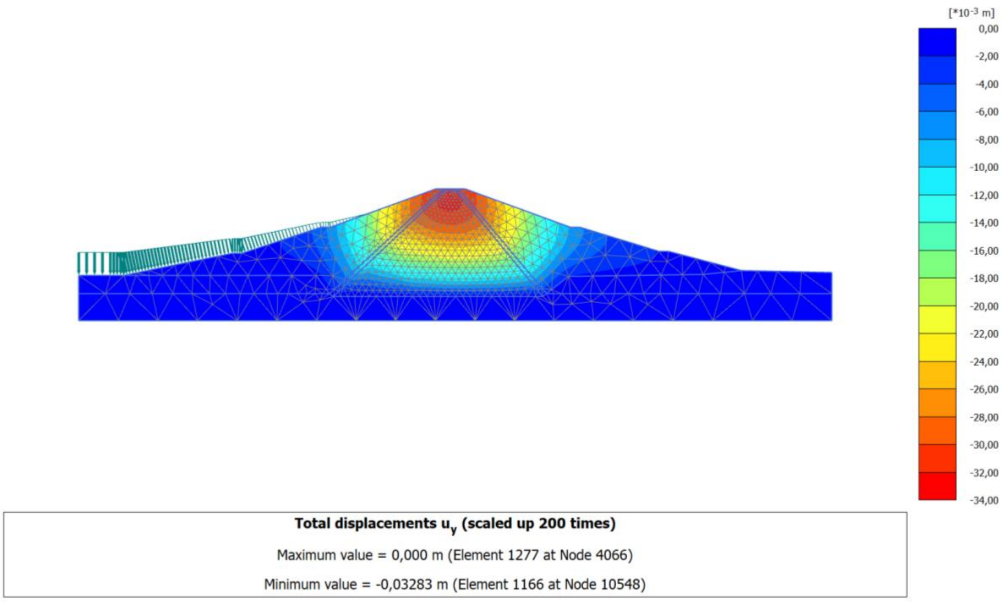


FIGURE 5. Isolines of vertical displacement of the earth dam

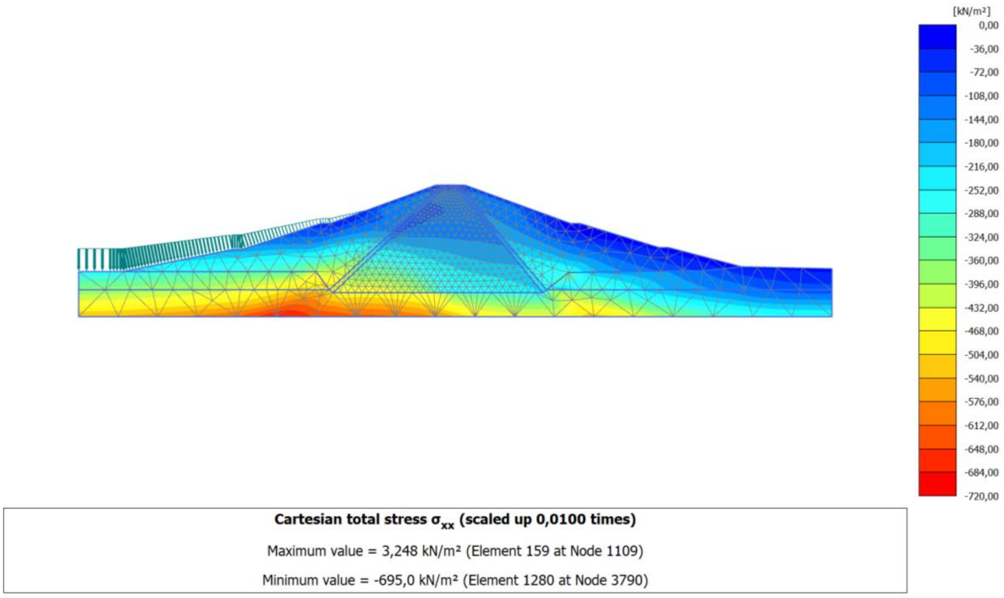


FIGURE 6. Isolines of horizontal stresses of the earth dam

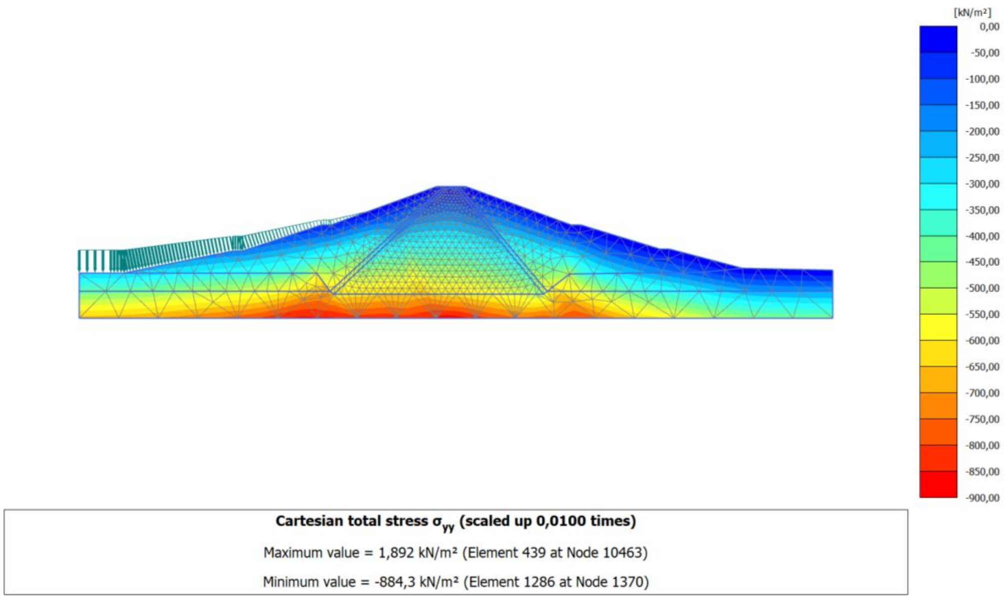


FIGURE 7. Isolines of vertical stresses of the earth dam

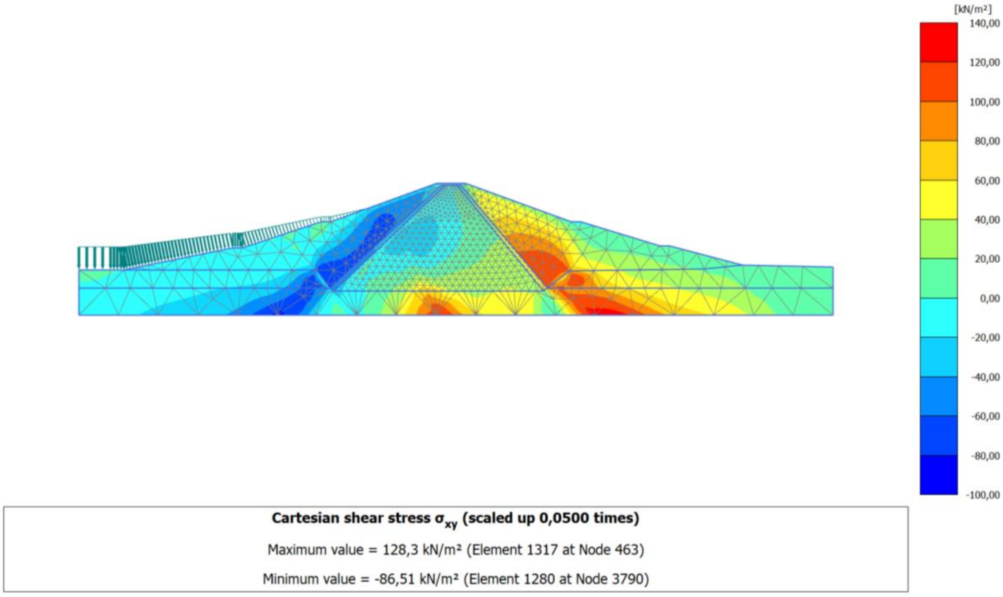


FIGURE 8. Isolines of shear stresses of the earth dam

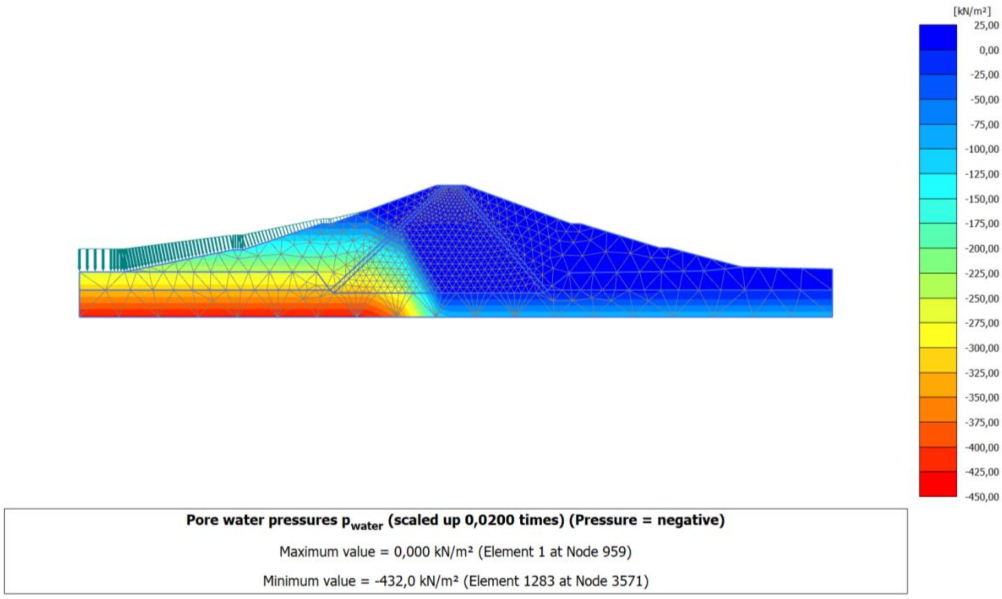


FIGURE 9. Isolines of water pressure of the earth dam

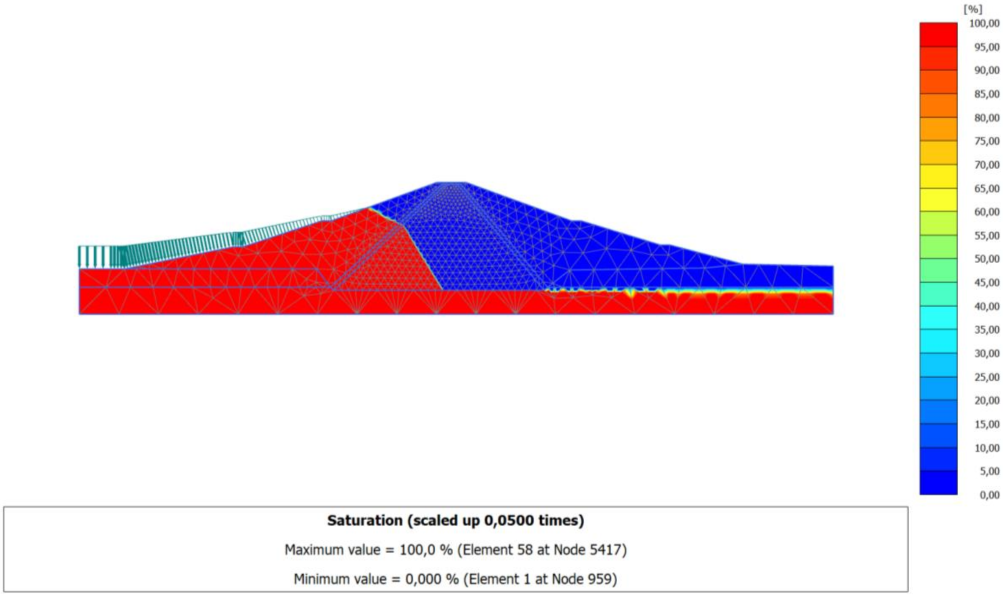


FIGURE 10. Isolines of moisture content of the earth dam

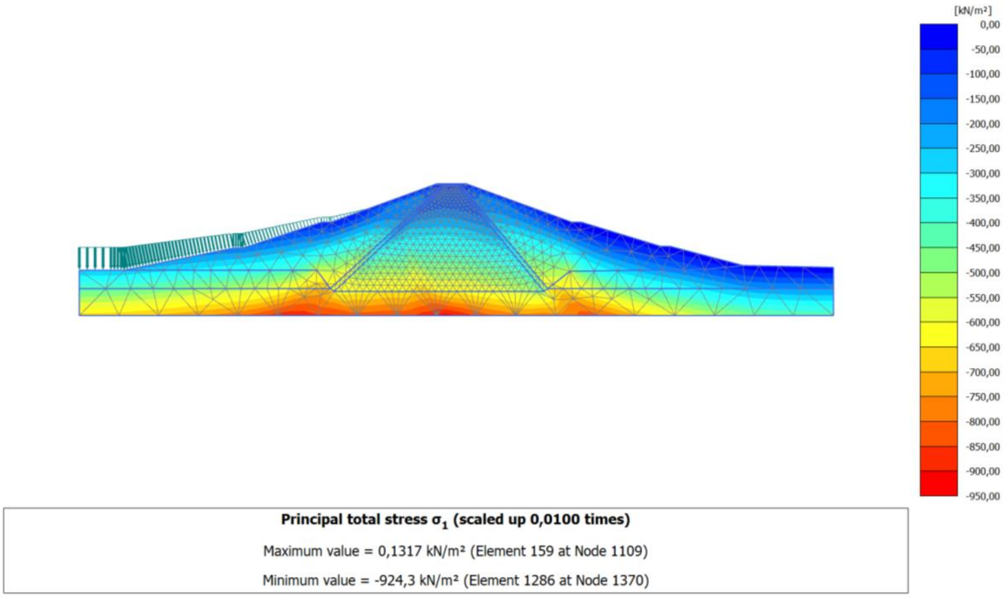


FIGURE 11. Isolines of principal stresses of the earth dam

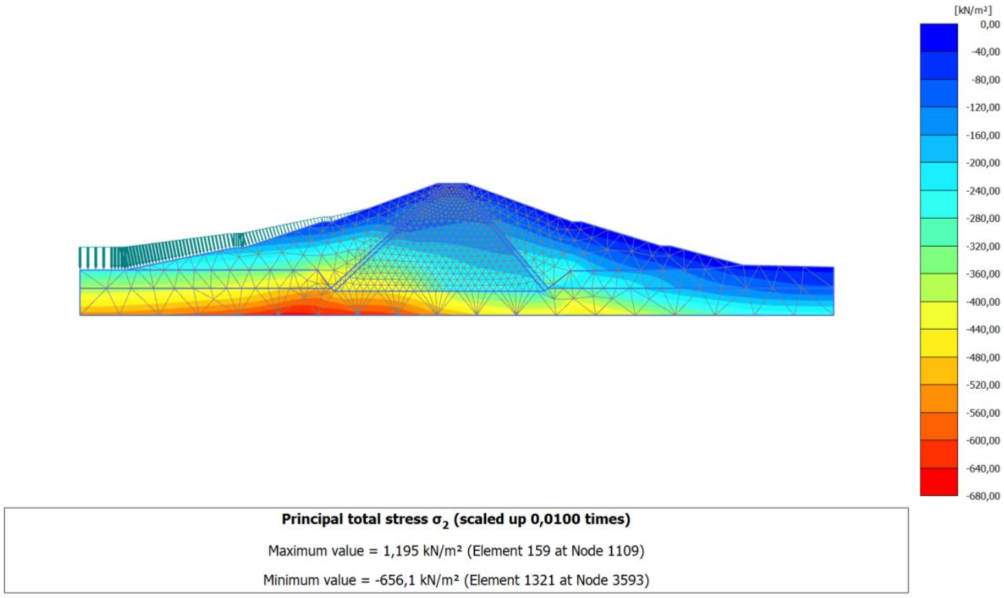


FIGURE 12. Isolines of principal stresses of the earth dam

The isolines of horizontal and vertical stresses are presented in Figs. 6 and 7. These results indicate that the stresses take on specific values in areas where water is exerting pressure on the upper slope. Figure 9 illustrates the isolines of water pressure, while Fig. 10 displays the moisture content of the earth dam's cross-section. Figures 11 and 12 present the isolines of the principal stresses.

ANALYSIS OF RESULTS

When solving equations (4)-(15) using the values of the effective stress components at any two points, the friction angle of the soil and cohesion were determined. Remarkably, these values matched the original measurements. This indicates that if the stress-strain state of the dam is accurately known, we can use the provided formulas to calculate both the friction angle and cohesion of the soil. These formulas are applicable for theoretical calculations, and a precise specification of the stress-strain state allows for the determination of these parameters. This finding aligns with the results obtained experimentally.

Based on the findings from the study of the dam's stress-strain state, we developed an algorithm and a software program to calculate cohesion C and the friction angle φ. By utilizing this program and inputting the stress components from the stress-strain state of the dam, it is possible to derive the values of C and φ, allowing for an assessment of the dam's stability.

CONCLUSION

- The stress-strain state of the Tashkent earth dam was evaluated by considering both the water pressure and the dam's own weight.
- Isolines representing the displacement, stresses, and strain components of the earth dam were generated, taking water pressure into account.
- The displacement results obtained using PLAXIS 2D were compared with those from space monitoring. After analyzing these results, it was concluded that the displacement values closely align with those measured through space monitoring.
- An algorithm and program were developed to determine the angle of internal friction and cohesion of the soil based on the stress-strain state data of the earth dam. These values are crucial for assessing the dam's stability.

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