Modeling determination of landslide pressure of Akhangaran reservoir ground masses

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Abstract. Analyzing the landslide situation is one of the urgent scientific and practical problems in determining the conditions for carrying out construction works and protecting human life and economic sectors from danger. Landslides can cause economic damage, disable large structures and roads, destroy large areas of crops, and destroy villages and cities. In this study, for Akhangaran reservoir lands, techniques for assessing slope stability, ground mass stability during landslides, and landslide pressure were established for the scenario when soils exhibit both frictional and viscous qualities. These approaches took into consideration the internal factors impacting landslides. The obtained results are based on the development of activities that suppress the factors affecting the movement of landslides.

1 Introduction

Landslides can happen as a result of mining, slope destabilization caused by natural and man-made processes, natural processes like earthquakes and hurricanes, and economic activities carried out without taking into account the local natural conditions [1]. In the spring, rainwater passes through the fractured rocks and reaches the clay layer, and the softening of the clay also leads to the movement of dangerous landslides [2]. The increase in the weight of the moving layer, the slope of the slope, and the washing of the banks by the river water cause the migration of landslides [1], [3].

The influence of climatic conditions is one of the most important factors in the movement of rocks along a sloping surface. Landslides are common in areas with slow and continuous rainfall. Rainwater seeps into the depths of rocks, reducing the bond between their particles and reducing frictional resistance, increasing their weight.[4] As the weight and strength of the rock on the sloping surfaces change, their equilibrium state is disturbed, and the movement process occurs. That is why the movement of landslides occurs mainly in March when the snow melts and precipitation increases. By May and June, mobility decreases significantly [2], [5].

Usually, 93 percent of the total number of landslides are one-time landslides, and 7 percent are landslides that occur with periodic recovery of movements. G.S. Zolotaryov and E.P. Emelyanova divided the size of dangerous landslides into "classes of landslides", describing the scale of the natural disaster[6]. Landslides with a 1-10 million m3 volume are usually frequent [3], [4]. One of the urgent issues is the development of methods for determining soil mass stability and landslide pressure [7], [8].

2 RESEARCH METHODS

During the investigation, "Methods of sequential construction of force polygons graphically" were used for analyses and calculations [9]. Mathematical analysis of the data obtained from the research was carried out using the methods of determining the stability of soil masses and landslide pressure from the book "Soil mechanics" by N.A. Tsytovich [10], [12].

3 RESEARCH RESULTS

To determine the stability of ground masses during landslides, we assume that the "Akhangaran" reservoir soils have frictional and viscous properties [13].

Based on the experimental data of the formation curves of landslide zones that occur on the slopes of the reservoir during the landslide migration, we suppose that the sliding surface is approximately rotating-cylindrical [14].

Assuming that the center of the rotating-cylindrical sliding surface is at point O (Figure 1), we draw an arc $\boldsymbol{ac}$ from the point O through the lower edge of the slope. We then consider the equilibrium equation for the sliding landslide ground $\boldsymbol{abc}$ into several parts through the vertical planes of the sliding landslide. Each individual part of the landslide is affected by the following forces [15]:

a) Q is the force placed on the center of gravity of each individual part, which is equal to the weight of that part;

b) we consider the reaction of the unstrained ground to the sliding ground surface as the sum of the following forces:

- friction force, which is directly proportional to the normal force and is equal to $Ntg\varphi$ (where N is the normal component of gravity Q, φ is the angle of internal friction of the soil).

- adhesive force C, which is the quantity formed along the arc length corresponding to the individual part under consideration.

c) Ground pressure of unknown magnitude on the sides of individual parts.

End forces are internal to the entire moving mass but external to selected parts. Because regardless of the direction and magnitude of the lateral pressures, the sum of all vertical forces must equal the total weight of the moving mass $\boldsymbol{abc}$ [16].

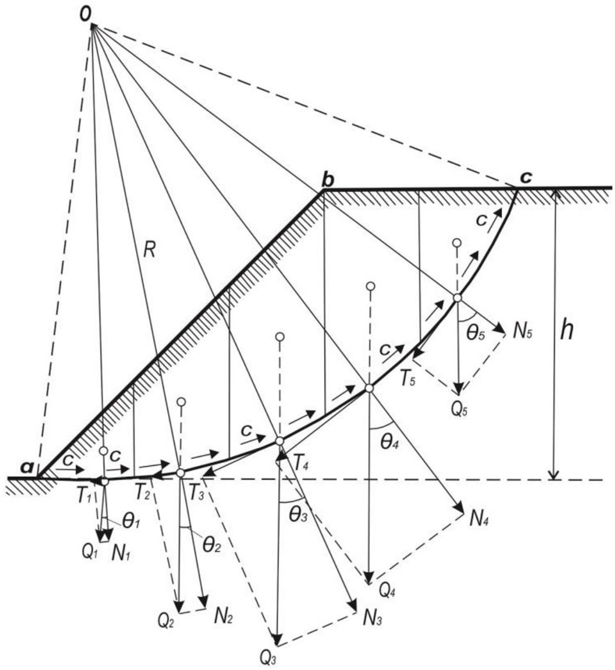

Figure 1. Scheme of effect of forces in calculation of stability of soil masses during landslides [17], [18].

Also, when determining the equilibrium state for the entire sliding mass, it is not necessary to consider the side pressure forces acting on the vertical surfaces of individual ground parts [19].

To write the balance equation of the forces acting on the sliding $\boldsymbol{abc}$ ground, we take the sum of the moments of all forces relative to the center of rotation and set it equal to zero (see Figure 1) [20]:

$$\int TRdx - \int Ntg\varphi dx - cLR = 0 \tag{1}$$

where the integral symbol must cover all parts;
L is length of sliding $\boldsymbol{ac}$ arc;
R is radius of sliding arc;
T is Q is the product of force;
φ is the angle of internal friction of soil;
c is the viscosity of the soil.
By reducing to R, we get the following expression[20]:

$$\int Tdx - \int Ntg\varphi Rdx - cL = 0 \tag{2}$$

The resulting equation corresponds to a limit equilibrium, where a slight increase in the thrust force T causes a displacement of the mass $\boldsymbol{abc}$. The value of the viscosity corresponding to the limit equilibrium is determined as follows:

$$c = \frac{\int Tdx - \int Ntg\varphi Rdx}{L} \tag{3}$$

The coefficient of stability of the moving groundmass, which is the ratio of the moment of the forces holding the mass to the moment of the driving forces, is as follows:

$$\eta = \frac{M_{holding}}{M_{driving}}$$

or, taking into account the symbols in Figure 1, we get [20], [21]:

$$\eta = \frac{\int_1^n N_i\, tg\varphi Rdx + cLR}{\int_1^n T_i\, Rdx} \tag{4}$$

where the values of N and T are determined by plotting or calculating from the measured angle θ [22]:

$$N_i = Q_i cos\theta, \text{ва } T_i = Q_i sin\theta$$

If we reduce the right-hand side of the expression (4) to R, the following equality comes out [20]:

$$\eta = \frac{\int_1^n N_i\, tg\varphi dx + cL}{\int_1^n T_i\, dx} \tag{5}$$

Here $f = tg\varphi$ is the coefficient of internal friction of the soil.

The coefficient of stability of the sliding surface is equal to the ratio of the sum of the holding forces to the sum of the driving forces for both the cylindrical and the flat case [23].

The stability coefficient of the groundmass during landslide is determined by expression (5), and the stability is ensured under the following conditions [24]:

$$\eta > 1 \tag{6}$$

Usually, in calculations, the stability coefficient is taken in the range of 1.1 to 1.5. If the center of the landslide is known, the stability of the soil mass is simplified to determine the stability coefficient η using the expression (5) [25]. The task's complexity is determining the contour of the most dangerous sliding surface.

4 Determination of slope stability and landslide pressure

Sliding surfaces can sometimes be known in advance. For example, it can be observed on steep slopes, when earthworks are laid on the surface of existing ground structures, and also for a series of landslides, when loose rock (e.g., deluvial deposits) moves along the surface of dense, immobile rock (e.g., rocks) [20], [27].

In such cases, as Professor G.M. Shakhunyants shows, the coefficient of stability of the sliding mass is determined by the expression (5). Also, the landslide pressure from the boundary parts for individual parts can be determined simply [6], [28].

For example, let's say that the moving masses are moving along the $\boldsymbol{abcde}$ surface of the rock (see Figure 2) [29]. To determine the coefficient of stability and the amount of pressure from the landslide, we divide the whole moving mass into several parts, as in the previous case. In this case, the surface of each sliding part must be flat. After that, we determine the weight Q of each part and divide it into normal and tangential components relative to the thrust plane of each part. The coefficient of stability for all $\boldsymbol{abcdea}$ thrust mass is determined by the previous expression (5). At the same time, it is also valid for determining their stability coefficient, considering the pressure of each individual part [30], [31].

To determine the pressure from the landslide, we take the sum of the projections of the external forces in the direction of movement of each part and consider the equilibrium conditions of each part of the landslide. For convenience, we start from the top part, part 1, then move to the adjacent part 2, and so on.

The direction and value of the reaction force E_1 is determined by taking the sum of the projections of all forces on the $a-b$ thrust plane for part 1, including the unknown pressure from the side of the adjacent part 2, and setting it to zero. For part 1 to be in equilibrium, part 2 must be applied to part 1 in the direction $a-b$. E_1 is the landslide pressure [7], [32].

$$E_1 + fN_1 + cl_1 - T_1 = 0 \tag{7}$$

or

$$E_1 + fQ_1 cos\theta_1 + cl_1 - Q_1 sin\theta_1 = 0 \tag{8}$$

we get from here:

$$E_1 = Q_1 sin\theta_1 - fQ_1 cos\theta_1 - cl_1 \tag{9}$$

When considering the balance of the second part, the movement of the force E_1 should be taken into account with the opposite sign. The same way is continued in the next parts. In general, the following expression is used to determine the landslide pressure in any avalanche section [20]:

$$E_i = Q_i sin\theta_i - fQ_i cos\theta_i - cl_i + E_{i-1}. \tag{10}$$

where E_{i-1} is the projection of the landslide pressure in the previous section in the direction of thrust of the considered section.

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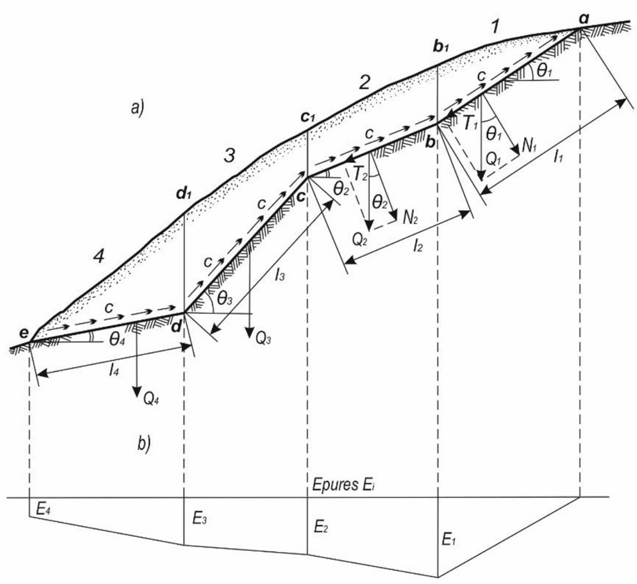

Figure 2. Diagram of forces acting on landslide soil on slope

The value of E_i can be easily determined graphically by constructing a series of force polygons.

By determining the landslide pressure for individual parts of the avalanche, we build a landslide pressure contour based on the obtained data (see Fig. 2, b)). The contour of the landslide pressure serves to choose the place of construction of the structure, which has the minimum value of E_i along the length of the landslide and is the most suitable for the design. By multiplying the determined landslide pressure by the required reserve factor η, we determine the calculated pressure for the structure [32].

The sliding surface of the whole $abcde$ landslide is, in special cases, the determination of the calculated landslide pressure is simplified and generally defined for any part as follows [8]:

$$E_i + fN_1 + cl_1E_i = \eta sin\theta \int_0^i Q_i - cos\theta \int_0^i f_iQ_i - \int_0^i c_il_i - T_1 = 0 \quad (11)$$

where θ is the angle of inclination of the thrust plane relative to the horizon;
η is the given value of the stability coefficient.
The formula (10) for the entire sliding prism for a homogeneous ground becomes simpler, that is [33]:

$$E = \eta Qsin\theta - fQcos\theta - cL \quad (12)$$

where Q is the weight of the whole sliding prism;
L is length of sliding plane trace.

5 CONCLUSION

1. A method for determining the stability of ground masses during landslides was given, assuming that the soil of the Akhangaran reservoir has friction and viscosity properties.
2. The surface of landslides in the landslide zones occurring on the slopes of the reservoir during the landslide movement was assumed to be circular-cylindrical.

3. Determining the pressure due to the landslide in two parts: taking the sum of the projections of the external forces in the direction of movement of the sliding ground part, the conditions of equilibrium of each part of the landslide were given.
4. By determining the avalanche pressure for individual parts of the avalanche, based on the obtained data, an avalanche pressure curve was built. The contour of the landslide pressure serves to choose the place of construction of the structure, which has the minimum value of E_i along the length of the landslide and is the most suitable for the design [34], [36].

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