GEOPHYSICAL EVALUATION OF THE STABILITY OF THE LANDSLIDE SLOPE

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Abstract: *Some peculiarities of radiometrical and electrometrical methods for landslide slope study are considered. Taking as a basis the theory of slope abyssal creepage, the mechanism of formation of emanation anomalies within the limits of an active landslide is suggested. It is noted that all the three preparation phases of the abyssal creepage process are characterized by the extreme values of radioactive emanation field. The revealed statistic intercomunication between ground geoelectrical and physical-mechanical properties makes it possible to carry out effective calculation of landslide slope stability reserve.*

Keywords: *landslide, geodynamics, radiometry, geoelectricity.*

1. Introduction

Among exogeneous geological processes (EGP) in Armenia landslides belong to the most developed and dangerous ones. According to data of modern research more than three thousand landslides are revealed on the territory of Armenia. Study of these landslides began in 1926 [1]. As it is known, well-founded assessment of landslide hazard requires solution of a number of problems concerning the slope structure, composition, state, properties, occurrence conditions, etc. Solution of these problems together with data about climatic, hydrogeological and seismic conditions of the region, materials concerning human activities and history of landslide development represent necessary basis for calculation of the landslide slope stability. Traditional methods of engineering-geological investigations are not always capable of answering the above-mentioned questions with the required fullness. In this respect application of geophysical methods discovers additional possibilities. They make it possible to investigate in detail great areas, which is inaccessible for other types of geological and geomechanical research. Specifically, measurable parameters of geophysical fields automatically take into account geological and hidrogeological peculiarities of landslide slopes, which at times can't be identified singly. Finally, possibilities of routine observations infinitely increase, as geophysical measurings can recur any number of times without disturbing natural conditions [2], [3], [5]. In the suggested work we'll try to present some characteristic peculiarities of landslide hazard assessment according to radiometrical and electrometrical data.

2. Radiometrical Research

At present numerous examples of application of radiomertical methods in the sphere of seismology and engineering geodynamics indicate their comparatively high informative character on one hand, and availability of a number of variable theoretical and methodical problems on the other hand [4], [7]. The most sensitive method among radiometrical ones, reacting to the change of fields of rock mass stress and deformations, is the emanation method. The results of investigation of landslides in Armenia prove existance of certain connection between the changes of landslide stressed-deformed state and variations of radioactive field. Let's consider in brief the mechanism of formation of emanation anomalies in the active landslide zone [3].

On the basis of the theory of slope abyssal creepage, developed by Ter-Stepanyan G.I. [8]. one may suggest that in the slope upper steady part, at some deapth, the tangential stresses concentration occurs. The creepage takes place in the closed zone in which the ground stressed state is evaluated by the coefficient of mobilized shearing strength tgθ the value of which is defined by the relation of tangential and reducted stresses. Note that $\mathrm{tg}\Theta_0$ is some threshold value of the mobilized shear strength with which longtime deformation do not occur yet and $\mathrm{tg}\varphi'$ is the mobilized shear strength value when there is ground shear.

In consequence of the ground mass slow movement, in the creepage zone landslide cracks are formed, thus surrounding this zone (Figure 1).

The zone itself is the deformed part of the continuous environment. Upward and downward of the creepage zone, respectively, the undeformed moving slope part and the undeformed non-moving slope part are located. As a rule, the abyssal creepage is considered as a preparatory stage for landslides proper which is superimposed on the general tendency of the geological landslide development. Such a distribution of stresses and creepage is called hearth. The creepage zone is located along the sliding surface DE (Figure1) along which the creepage ground displacement occurs. Owing to this the stressed state changes, that is the front part of the creepage zone is compressed and the back part is dilatated. So, in the creepage process potential sliding surface sections are involved.

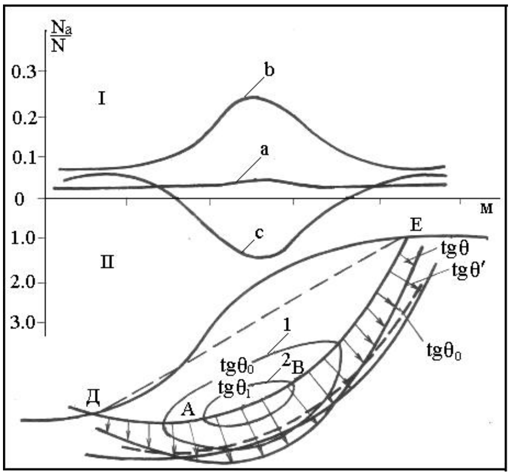

Figure 1: Emanation concentration (I) and value distribution of mobilized shear strength coefficient (II) along the potential slip surface.

The emanation concentration increase is conditioned by arising in the hearth zone slope of creepage where small tension, fractures form which promote the free emanation displacement to the soil layer (in this case in the creepage zone the coefficients of rock diffusion D and emanating an increase).

It is known from the emanation method theory that the emanation concentration in the ground air mainly depends on the quantity of radioactive elements being present in the ground. For infinite half-space this dependency is discribed by the following formula [6]

$$N_{Rn} = 3{,}7 \cdot 10^{13} N_{Ra} \cdot \rho \cdot \alpha \cdot \eta^{-1} \qquad (1)$$

where N_{Rn} - radon content in ground pores; N_{Ra} - radium content in ground; ρ ground density; α - emanating coefficient; η - porosity.

As it is evident from formula (1) that emanation concentration besides the quantity of radioelements depends also on petrophysical properties and rock emanating coefficient. Assuming that it is easy to note for the concrete rock types $N_{Ra} = \text{const}$; that N_{Rn} will depend on ρ, η, α only. These very parameters undergo the largest changes in different geodynamic zones (landslides, karst, tectonic disturbances etc.), thus influencing essentially the displacement process and the emanation concentration process in rocks. Without pretending to the unambiguity of such an interpretation of the rock emanating process in geodynamic zones, at the sections of sliding process development particularly, one notes that by the experimental investigation results all the three preparatory phases of the abyssal creepage process are characterized by the extreme values of the emanation concentration (Figure 1, Table).

Table
Emanation concentration of different phases of sliding slopes abyssal creepage

Creepage Phases	Coefficient of Mobilized Shear Strength	Emanation Concentration
1. Absence of longtime deformations (phase of stiffness)	$0 < tg\Theta < tg\Theta_0$	back ground
2. Long-time deformations (phase of creepage)	$tg\Theta_0 < tg\Theta < tg\varphi'$	max
3. Shear occurs (phase of plasticity)	$tg\Theta = tg\varphi'$	min

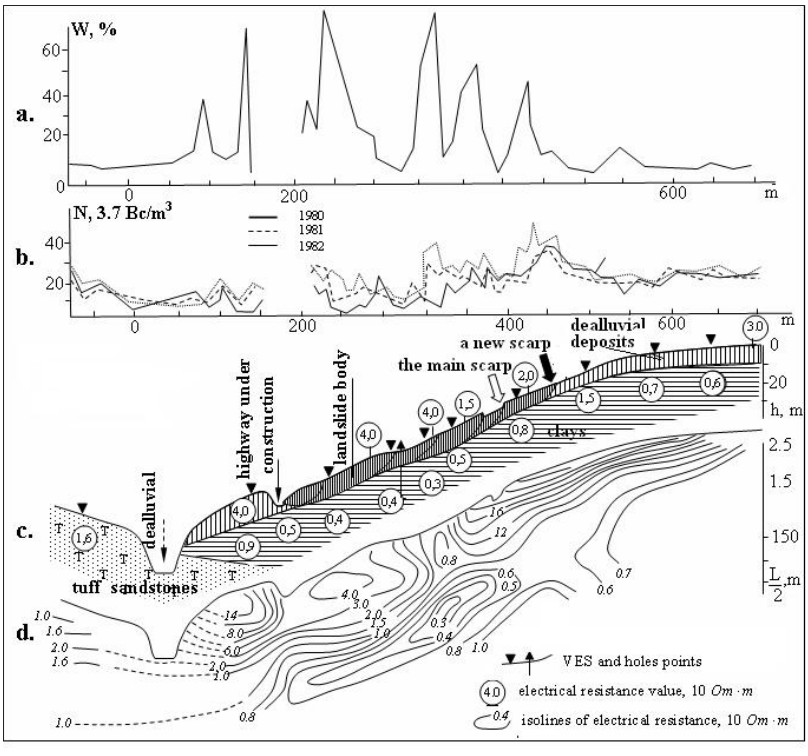

Figure 2. Results of the geophysical prospecting of the landslide slope (Armenia, Jajour pass). a – coefficient of radon variations; b – emanation survey profile; c – geological section; d – geoelectric section

Figure 2 presents the results of field experimental research of one of the active landslides in Northern Armenia.

The analysis of these data testify the fact that the middle level of coefficient of radon variation in the steady part of slope is higher than in the area of active landslide manifestation (Figure 2a). The fact is explained by the change of the strain condition of massive of the rocks on the plateau is taken place weaker. The interleaving intervals of extreme values of radon over all the slope are causedl by the various degree of jointing of landslide blocks and activity of the process. The zone of increase in variation coefficient in the steady part of the slope (interval between points 460-480) coincides with the region of genetic joints. The fresh joints of fishweir were formed further on the very zone by which the new blocks of landslide massive were torn away. The foregoing statement is obviously connected with the formationi of creepage focal zone of the landslide slope stable part, where abrupt change of values of ground diffusion and emanating coefficients has taken place subsequently, in the main ledge zone fresh fissures have been formed, which are the direct sign of the given landslide advancing character.

In the presence of emanation survey data and some compressional ground properties one may preliminarily evaluate the stressed-deformed state of a sliding slope using the following formula [2]:

$$\sigma = \{A - D[\ln(1 - \varepsilon Q^{-1}\lambda^{-1})]^2 x^{-2}\lambda^{-1}\} \cdot a^{-1} \quad (2)$$

$$E_0 = a^{-1}\beta\{D\lambda^{-1}x^{-2}[\ln(1 - \lambda\varepsilon Q^{-1})]^2 + 1\} \quad (3)$$

where ε-emanation concentration per volume unit of pore space; Q-emanation apportionment velocity into pores per volume unit of environment; λ- the decay constant emanation; D - diffusion coefficient; x - depth of air sumple collection; a - coefficient of ground compressibility; β - factor, for sandy-claycey rocks it changes from 0,76 to 0,43; A - value characterizing ground compressional properties; σ - stress conditioned by rock pressure; E_0 - modulus of total deformation. Values Q, λ and D for concrete ground types are quasiconstant. Compressional properties (A and a) are determined experimentally.

3. Electrometrical Research

The slope stability coefficient (K_s) is the main and, as a matter of fact, the only qualitative indicator, determining the peculiarities of landslide process development. Numerous practical examples of application of the K_s calculation methods, based on consideration of a landslide slope idealized model, give only approximate notion of the stability coefficient value. It is explained by the fact that calculation parameters of the stability coefficient, such as angle of inner friction, cohesion power, density, etc., are determined by relatively small number of examples, which are not representative for description of the whole landslide. Besides, between the existing rock resistance in the landslide, shear force and the results of sample laboratory tests essential difference is observed owing to the display of wide-spreading effects, etc.

The universal character of electrometrical methods in determining the calculation parameters (geometrical and physical-mechanical) of slope stability is their indisputable merit. We have studied the stastistic connections between the electric resistance (ρ_s) and specific cohesion, the angle of inner friction and the landslide ground density.

$$C = -1{,}19 \lg \rho_s + 22 \quad (4)$$

$$\lg \varphi = -1{,}48\rho_s + 2{,}95 \quad (5)$$

$$\gamma = 2{,}03 - 0{,}015\rho_s \quad (6)$$

where C - specific cohesion; φ - angle of inner friction; γ - density; ρ_s - seeming specific electric resistance of ground.

For sandy-clayey ground (if dampness is constant) statistic connection (4, 5, 6) between the above-mentioned parameters are quite satisfactorily motivated by physical prerequisites. Undoubtedly, for each concrete case (if necessary) correction of digital coefficients, included in these formulas, is required.

Conclusions

Summarizing the foregoing statement, the following principal conclusions can be drawn.

1. The main geometrical and geophysical parameters of landslide slopes are determined and their calculation models are constructed.
2. Geodynamic zones of landslide slopes (compression and strain zones) are characterized by the extreme values of radioactive emanation field.
3. The increase of subsoil emanation concentration in the landslide front part is caused by formation of the creepage zone, where free emanation is squeezed out to the surface.
4. The proposed analytical formulas and statistic intercommunication make it possible to assess the stressed -deformed state and the stability coefficient of landslide slopes.

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