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Analysis of Methods of Landslide Processes Forecasting on Highways

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Abstract

This paper analyzes the methods of investigation of the stress-strain state of the landslide slope rock, as well as the research methods of geotechnical properties of rocks that form the sliding slope. The quantitative characteristics obtained during observations are necessary for grounding and selection of optimal anti-landslide measures, as well as to predict the occurrence of landslides. The geodesic observation techniques of landslide displacement which make it possible to predict with high accuracy a variety of simultaneous displacements within the general landslide zones and the manifestation of their features are considered.

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Keywords: stress-strain state; sliding slope; strength and deformation properties of the geological properties of rocks; prediction method.

1. Introduction

Currently, due to the intense economic development of large areas geotechnical studies of exogenous geological processes are becoming increasingly important, among which a special place is occupied by landslide processes. Landslide processes are the most common and at the same time the most difficult, time consuming and multifactorial that cause huge losses to the national economy.

According to the definition of P. Brayt (Брайт 1965), the landslide is a difficult and dangerous physical and geological process in the form of mass soil displacement downslope under the influence of gravity. Brayt and then G. Ter-Stepanyan (Тер-Степанян 1955) attempted to classify different types of landslides according to the character

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and causes of their natural displacement in relation to the system of implementation of geodetic methods for studying the landslide dynamics. However, it should be recognized that the nature of the dynamics of landslides is naturally different and can be systematized and classified only within the total landslide area with similar physical and geological properties. G. Ter-Stepanyan (Тер-Степанян 1971, Тер-Степанян 1979) generalized and deeply grounded the geodetic methods for studying the dynamics of landslides based on several studies of N. Kell (Келль, Белоликов 1954). However, they were not implemented in a timely manner sufficiently, and they are currently no longer relevant in connection with the development of modern methods and means of geodetic measurements, allowing simultaneous controlling a variety of displacements with high precision within the general landslide zones and the manifestation of their features.

The poorly known dynamics of sliding slopes prone to anthropogenic influences presents a particular complexity and interest. At the same time, as a rule, there is only data of non-regularly organized geodetic control of landslide displacement and there is a lack of not only quantitative but also descriptive characteristics of space-time parameters of the anthropogenic impact. Obviously, in such circumstances of incomplete initial information the task of uncovering the hidden patterns of the landslide process development is relevant.

Study of the landslide dynamics is inextricably linked with the study of the stress state of rocks of the landslide slope. The pattern of distribution of stresses in the rock mass must be taken into account when describing their strength and deformation properties. It is currently established that the relationship between stresses and displacement depends on the rheological properties of rocks (Budin 1982). Among the foreign studies the works of N. Khast (Sweden), A. Scheidegger (USA), A. Skeipton (England), L. Muller (Germany), P. Panyukov, R. Zolotariov, R. Ter-Stepanyan, V. Lomtadze (Russia) are of great interest.

The purpose of this investigation is analysis of existing methods of investigation of the stress-strain state of the landslide slope rock, as well as research methods of geotechnical properties of rocks that form the landslide slope. The quantitative characteristics obtained during observations are necessary for grounding and selecting optimal anti-landslide measures, as well as to predict the occurrence of landslides. These characteristics include data on the mechanism and dynamics of the landslide process; data on geotechnical properties of rocks that form the landslide slope, and the variation of these properties depending on the influence of various factors; data on changes in the state of stress within the landslide. Analysis of the above-listed including the study of landslide forming factors allows us to understand the essence of the landslide process, find out the main geological patterns of its development.

2. Methods of studying the stress-strain state of sliding slopes rocks

Processes that cause landslides progress can be identified and defined using various methods. Soil characteristics are possible to determine by terrain reconnaissance, survey of particular road sections or underground mining methods. Geomorphological changes are determined according to surveys of soils, geological maps, aerial photographs data decrypt or by remote sensing. Physical changes are determined using seismographs, pickoffs, temperature sensors, flow meters and piezometers (Золотарев 1990; Саломатин, Ерыш 1980).

At the initial stage of identification of landslide processes on highways in the mountainous area, the use the technique of area reconnaissance. Topographic maps contain details of ground loops. Significant changes of soil conditions can be established by examining topographic maps. Widespread Geological maps of different scales, allowing determining the geological features of soil foundations are used extensively. Climatological data and archival information obtained while observing a hazardous landslide region can provide the relevant data about the destruction during heavy precipitations.

Field survey is the final stage in the reconnaissance of the area. The main goal of field surveys is to update the previously obtained data, establishing criteria for subsequent underground observations and fixing dimensions or other manifestations of landslides.

V. Lomtadze offers to divide the field methods for studying the stress state of rocks into structural and geological methods, geophysical methods, and methods of direct measurements (Ломтадзе 1977). According to structural tectonic conditions one can get an idea about the magnitude of the stress rise in the rocks. Geophysical methods based on the study of changes in various physical parameters depending on the stress state provide indirect indicators of stress orientation and its magnitude.

The method of re-fracture shooting is an indirect method of studying the stress-strain state of landslide slope rocks. The nature and type of landslide cracks signifies about the development of various kinds of stresses-compression, tension and shear. When studying the cracks repeatedly, it is possible to evaluate the distribution of stresses in the slope during the time at different stages of its development.

In recent year, geophysical methods for studying the stress-strain state of the rocks, which make up the landslide-prone slopes, are widely used in stationary regime studies. It should be noted that the geophysical methods applied in engineering geology and hydrogeology for studying landslides, the stress state of rocks, as well as the dynamics of the landslide process have been used for a relatively long time.

The geo-electric survey methods are based on the dependence of electrical properties of rocks as a result of change of the stress state of rock mass. The main factors affecting the electrical conductivity of the landslide of rocks are the composition, structural and textural features and humidity. Hydrological conditions should be stable over time, in order to identify the effect of strain on the electrical conductivity.

Use of anisotropy parameters allows to avoid the influence of hydrogeological factors and consider the magnitude and direction of the major axis of anisotropy ellipse with preferential orientation of cracking, i.e., with the development of the landslide process. There may be two versions of the study: 1) determination of the sliding process direction and delineation of zones of compression and tension, 2) monitoring observations of landslide process development.

They offer to register the results of monitoring observations in the form of the following relationships (Саломатин, Ерыш 1980):

$$\rho_{\hat{e}a} / \rho_{\hat{e}i} = f(t);\ K_a / K_i = f(t) \text{ or } \lg(K_a / K_i) = f(t), \tag{1}$$

where ρ_{ki} and K_i – initial values of measured parameters; ρ_{ka} and K_a – current values of parameters; t – calendar time in days.

The advantage of the considered ***electric resisting method*** lies in the ability to record the changes that occur in rocks on the stage of preparation for a shift, as well as to identify and delineate the most landslide-prone areas that cannot be done using traditional methods. Limitation of method application is due to the fact that the results are distorted under the conditions of rugged terrain, in case of inhomogeneous composition of rocks, crushed into folds, and due to technical interferences that excite electric currents both on the surface and at depth.

3. Methods of engineering and geological properties of rocks that form a landslide slope

In studies of landslides special attention is paid to the rocks composing the landslide slope, the properties of which are important factors in the formation of landslides (Gulakyan 1992). Research methods of geotechnical properties of rocks attach great importance on the part of both domestic and foreign scientists.

Recently, they have widely used field methods for testing rocks. In the mountain-folded regions (Crimea, Carpathians), a large number of coarse inclusions in landslide deposits in many cases excludes the use of conventional laboratory techniques for studying the strength and deformation properties of rocks. Standard laboratory instruments are used here to study sand-clay aggregate, and when testing large rocks they use large-sized equipment and special techniques.

The study of geological properties of rocks is of great interest for assessing the slope stability and landslide process forecasting. The stress-strain state of rocks involved in the landslide process varies under prolonged exposure to stress. The basic features of mechanical properties of rocks are the values of deformation and strength characteristics. The data of laboratory studies of rheological properties of rocks are extrapolated for periods much longer than the duration of the test.

4. Prediction of landslide occurrence

A detailed study of the geological structure of the landslide area is a very important and necessary step in studying the mechanism and the kinematics of the landslide process that causes the need for geological exploration, mainly drilling and geophysical works (Рудько, Осиюк 2007).

Hydrological factors can have a significant impact on the development of landslide processes. These factors can have a power impact (filtration pressure, increasing the mass of rocks when wet) as well as reduce the strength of the rocks due to the increase of natural moisture, diffusion leaching, and suffusion (Золотарев 1990).

Ground landslides may occur during a long rainy season when porous sedimentary rocks located on dense rocks is fully saturated with moisture, which increases their weight and reduces the shear stress at the interface of contact with the underlying sediments having a low coefficient of filtration or with the bedrock of magmatic origin, the surface slope of which to the horizon is large enough.

In order to predict the time of landslide occurrence it is necessary to have the geological record and the terrain topographic features in order to detect the location of the most dangerous areas with critical slope angles of the bedrock surface.

Thus, the problem of landslide determination is reduced to solving the moisture transfer equation with appropriate boundary conditions on the soil surface and at the contact interface of the studied sedimentary rocks width with underlying rock, which can be either indigenous or of dense sedimentary origin with a low coefficient of filtration. If the thickness of rocks of the intended landslide consists of several layers of different types, the following conditions apply at contact boundaries:

- equality of moisture fluxes;
- conjugation conditions of rock humidity.

Obviously, in actual conditions the free surface of the studied for landslide rock mass is generally not parallel to the surface of contact with the bedrock. We will apply the principle of maximum disfavors and consider the most simple averaged version of the problem, when the surface of the soil and the underlying rocks are parallel (Figure 1).

In Fig. 1 by a dotted line there is plotted the average position of the free surface of the soil. The origin is located at the soil surface. The Y-axis is directed downward. The moisture transfer equation for different weather conditions is given in (Volkovich *at al.* 1995).

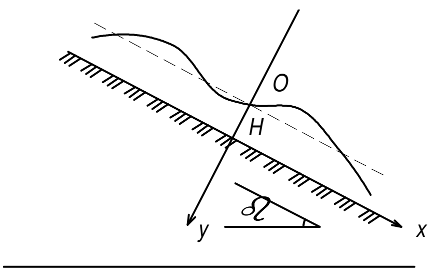

Fig. 1. Scheme of design.

If there is no rain flow on the soil surface the moisture transfer process in the soil is described by the equation

$$\frac{\partial\theta}{\partial t}=\left\langle \cos\beta\left\{D(\theta)\frac{\partial\theta}{\partial y}-\frac{K(\theta)}{\theta_{\max}-\theta_{gl}}\left(\frac{\theta-\theta_{gl}}{\theta_{\max}-\theta_{gl}}\right)^{n-1}\times\left[\left(\theta-\theta_{gl}\right)+ny\frac{\partial\theta}{\partial y}\right]\right\}\right\rangle-s(y,t), \tag{2}$$

where θ – volumetric soil moisture; β – the angle of the soil surface slope to the horizon; θ_{gl} – characteristic soil moisture at depth after the full gravity drip; $D(\theta)$ and $K(\theta)$ – respectively the diffusion coefficient of moisture in the soil and the coefficient of hydraulic conductivity; $s(y, t)$ – change in the volume of moisture in the soil per unit of time due to water absorption by plant roots.

Equation (1) satisfies the following boundary conditions:

a) the equality of moisture fluxes through the soil surface at $y = 0$:

$$\cos\beta\left\{-D(\theta)\frac{\partial\theta}{\partial y}+K(\theta)\left(\frac{\theta-\theta_{gl}}{\theta_{\max}-\theta_{gl}}\right)^{P}\right\}_{y=0}=q\ , \tag{3}$$

b) humidity conjugation condition of rocks at $y = H$:

$$\theta(H,t)=\frac{\theta_{\max}}{\theta_{\max}^{P}}\theta_{p}(H,t); \tag{4}$$

c) the condition of equality of moisture fluxes at $y = H$:

$$\left\{-D(\theta)\frac{\partial\theta}{\partial y}+\left(\frac{K(\theta)}{\theta_{\max}-\theta_{gl}}\right)^{n-1}\times\left[\left(\theta-\theta_{gl}\right)+nH\frac{\partial\theta}{\partial y}\right]\right\}_{y=H}=\left\{-D(\theta)\frac{\partial\theta}{\partial y}+\frac{K_{p}(\theta)}{\theta_{\max}^{P}-\theta_{gl}^{p}}\left(\frac{\theta_{p}-\theta_{gl}^{p}}{\theta_{\max}^{p}-\theta_{gl}^{p}}\right)^{n-1}\times\right.$$

$$\left.\times\left[\left(\theta_{p}-\theta_{gl}^{p}\right)+nH\frac{\partial\theta_{p}}{\partial y}\right]\right\}_{y=H}; \tag{5}$$

d)

$$\theta_{p}(\infty,t)=\theta_{gl}^{p}\ , \tag{6}$$

with the initial conditions

$$\theta(y,0)=\theta_{0}(y),\ \theta_{p}(y,0)=\theta_{gl}^{p}\ , \tag{7}$$

that are determined empirically.

Here q – the intensity of rainfall. The P index in the above boundary and initial conditions is related to the underlying earth formation. All other variables have the same meaning.

In solving the above stated moisture transfer problems (1)–(6) one can determine the time span during which the investigated rock strata for appearance of sliding will reach full saturation by moisture under different precipitation intensity.

5. Geodetic monitoring methods of landslide shift

One of the ways to a deeper understanding of landslide processes is quantification of their dynamics, changes in the stress-strain state of rocks, landslides, phases and stages of their development, strains and the nature of the earth masses shift, etc. Therefore, the issues of quantitative study of the dynamics of landslide processes are attracting increasing attention. This includes monitoring the landslide shift, landslide cracks and deformations of buildings and engineering structures located on them.

There are many methods of instrumental observations of landslide displacement; most of these methods are based on the use of geodetic techniques.

The advantage of geodetic techniques lie in the ability to obtain absolute values of landslide displacement (Брайт 1965).

Geodetic observations are usually provided for a limited number of offset points selected on the surface of a landslide; wherein a portion of points are located on the adjacent fixed portions. The points, at which observations are made, are fixed in the form of permanent signs. They are usually wooden, metal or concrete pillars sunk into the ground having heads with centers, which are in fact signs for observations. In some cases, metal rods or painted survey targets embedded in the walls of buildings and structures called marks are used as signs.

Survey markers, depending on the installation site are divided into fixed and movable bench marks, or landslide points; the first ones are beforehand installed on movable portions, and the latter on the surface of the landslide. Part of the fixed bench marks is used for instruments to be fixed on them; such bench marks will be further called settlement bench marks. Other fixed bench marks are used to obtain the initial directions; they will be called the reference points. The landslide points should be located in areas most important to analyze the mechanism of the landslide. Therefore, when deciding where to install the support landslide points, one should consult with geologists.

Geodetic observation landslide displacement techniques are divided into the following groups (Тер-Степанян 1979):

1. Axial (one-dimensional) methods for determining the displacement of the point with respect to a given line or axis.
2. Scheduled (two-dimensional) methods to determine the offset of the projection point on the horizontal plane.
3. Altitude methods for determination of only vertical displacements of points.
4. The spatial (three-dimensional) techniques to determine the total displacement of the point in space.

Let us consider them consistently.

Axial methods are applied in cases where the direction of the point shift can be determined quickly or less accurately. Taking periodic measurements with respect to this direction, one can obtain the horizontal value of the point displacement. If the actual direction of the point motion is unknown, the axial methods yield lines indicating the motion.

Axial methods include:

1. A method of distances, which consists in measuring distances in a straight line between the wands mounted along the movement of the landslide.
2. The method of cross-sections consisting in measuring deviations (lateral displacements) of landslide points relative the alignment appointed perpendicular to the direction of the landslide movement.
3. The method of rays, which consists in determining the sight line from a fixed reference point on the landslide sign.

Routine methods are more versatile, as they give a complete picture of landslide points displacement in space. This is the most important group of methods.

Planning methods include:

1. A method of linear serifs.
2. The method of direct geodetic serifs.
3. The method of inverse geodetic serifs.
4. Combined method of measuring angles and distances.
5. Polygonometric method.

High-rise methods allow determination of vertical displacement of landslide points; these include:

1. The method of geometric leveling comprises paving leveling courses and determining the elevation of landslide points in relation to the reference vectors.
2. The method of trigonometric leveling.

6. Conclusions

1. Investigation of the mechanism and kinematics of landslides is mainly carried out using traditional survey methods. Improving the measurement accuracy is achieved by using more advanced geodetic equipment, as well as the right choice of measuring instruments. We need to develop a large-scale aerial survey and apply photogrammetric survey, which is particularly effective under the landslide-prone process that develops rapidly. To study the deformation at depth, they use a new design of frames.

2. Study of the stress-strain state of rocks by geophysical methods is a new trend in the monitoring study of landslides. The considered in the review methods and examples of their use show great possibilities of these methods and the appropriateness of their application for a variety of tasks. The main development of this area of research has to go through the modernization of equipment, development of new or improvement of existing working procedures.
3. In the study of geotechnical properties of rocks that make up the landslide-prone areas, there is a clear tendency to complex detailed analysis of the basic laws of these properties change over time and the impact of mineral composition on them, structural and textural characteristics and the degree of weathering. Field research methods of physical and mechanical properties of rocks gain ground.
4. This mathematical model describing the possibility of landslide occurrence does not cover all possible options, but it is only its first approximation. When calculating the moisture transfer in such soils they use the averaged moisture diffusion coefficients $D_{av}(\theta)$ and the coefficients of hydraulic conductivity $K_{a}v(\theta)$.

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