Application of Geophysical Methods in Stability Assessment of Slopes within Historical Natural-Technical Systems

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Abstract. The article is concerned with the use of geophysical methods in engineering geological surveys on landslide-prone slopes. The article discusses research methods that allow to obtain the necessary parameters for computer simulation and based on this performing slope stability assessment. As examples the slopes within the historical natural-technical systems (HNTS) are considered as the sustainability issues are of particular importance for them.

1. Introduction

According to various estimates, the state of 50 to 70% of the historical and cultural monuments on state protection in Russia [13,8] is characterized as unsatisfactory; for the most part they need urgent measures to save them from damage and destruction. Over the past 10 years, the Russian Federation has lost more than 2,500 monuments, including 2 thousand - under the influence of adverse natural and technogenic processes and landslides have one of the leading roles. Examples include landslides in the Nizhny Novgorod, Smolensk, Mozhaisk Kremlins, on the northern slope of the Resurrection New Jerusalem Monastery, the western slope of the Savvino-Storozhevsky Monastery, the southern slope of the Bogolyubsky Monastery, on the slopes of the Spaso-Evfilmiev Monastery in the Suzdal region, and in the processors, in the Suzdal region, and in the processors, in the Suzdal region, in the Hezdalievsky region, on the slopes of the Spaso-Evfilmiev Monastery, in the Suzdal region, and the Church of St. Nicholas on the right bank of Moscow river in Saburovo. On many of them the engineering protection measures are already performed, but still there is a need of monitoring. Some of them are protected by UNESCO.

In engineering geology there is a separate scientific direction of study the historical territories. It is impossible to consider historical buildings and structures separately from their ground base and the preservation and trouble-free operation of the monument depend on their interaction within the system. To describe this, EM Pashkin introduced the term Historical natural-technical system [13].

Among exogenous geodynamic processes landslides are widely developed. Due to their high prevalence they cause more damage than other similar processes. The key task in the study of landslides is the prediction of the place, time and nature of the landslide process.
2. Basic principles of slope stability assessment methodology

One of the main stages of slope stability quantitative assessment is schematization in the construction of a mathematical model. It can be generalized and special. Under the generalized schematization, in this context, we should understand the process of simplifying a real natural object with an infinite degree of complexity, to a conceptual model, which is limited by scientific knowledge on the one hand, and on the other hand by the degree of information security achieved in the performance of engineering and geological works [9]. Special schematization implies simplification of the conceptual model to a specialized (geomechanical) scheme, which within the framework of the task preserves the adequacy of the obtained scheme and the initial conceptual model and ultimately provides the required detail for a real natural object description.

The purpose of a special schematization can be expressed as the following thesis: maximum simplification with minimal adequacy loss [4,5].

Factors affecting the slope stability and the necessary participants of the schematization are the geometrical parameters of the slope, number of engineering geological items and their configuration, the density and humidity of the soil, soil strength properties and their distribution in the array, the groundwater level position, additional vibration and dynamic effects.

One of the difficult stages of special schematization is the assignment of a properties distribution model in a technogenic soils array, that cover the slope in several layers, often meters thick. [6].

The technique of properties field specification is to build the cohesion and the angle of internal friction distribution field using the known actually determined values of soil properties at their coordinates (determined during the sampling process) [8]. To construct the field different interpolation methods are used, for instance the Chugh method [12], the Delone method, the inverse distance method (Shepard, D., 1968), the thin method spline (Franke, Richard, 1985) [10, 11]. Next, using traditional methods of calculation based on limit equilibrium, the position of the sliding surface is determined and the slope stability coefficient is calculated.

When calculating the slopes stability within HNTS composed of man-made soils, the most interesting is the possibility of using models with the construction of soils strength properties distribution fields [7].

The basis for the schematization, as well as for the construction of the property distribution model, is the engineering-geological information obtained during the field and laboratory studies. Taken into account the direct methods of engineering-geological surveys complexity, it is advisable to assess the possibilities of indirect methods, in particular, geophysical methods for obtaining necessary values and their distribution in the array to input them in the model and calculate the safety factor.

3. Geophysical surveys on landslide slopes

Geophysical surveys on landslide slopes can be divided into works in engineering geological surveys and monitoring of the landslides development. According to the results of exploratory geophysics the data on the lithological composition of rocks and the conditions of their occurrence, the sliding surfaces position, hydrogeological conditions, the physical, mechanical and filtration properties of the rocks, and the stressed state of the soil strata are specified [1].

Using the methods of engineering geophysics the sliding surface position, separation cracks and landslide boundaries can be detected, the structure and state of the main deformable landslide layer (the degree of fracture and decompression zones) are studied, the boundaries of the watered areas in the soil massif and changes in rock properties near the displacement zone are determined [1].

A prerequisite for the successful use of any geophysical method is sufficient differentiation of the studied objects by physical properties. Such components of the landslide slope as the sliding surface and landslide bodies differ from the undisturbed massif mainly in their electrical and seismic properties. In addition the landslide body is distinguished by the substantial anisotropy of all geophysical properties. Therefore the methods of electrical prospecting and seismic prospecting are highly efficient in landslide slopes studying [2].
Engineering seismic survey allows mapping seismic geological boundaries of different nature, i.e. the level of groundwater, the roof of aquifers, lithological boundaries and in favourable conditions - sliding surfaces, current and predictable. A prerequisite for using seismic methods is the difference in seismic properties (wave velocities and their relationships, absorption decrements, elastic moduli) of soils composing a landslide part and a stable part of the slope. The transition from the unchanged part of the slope to the disturbed landslide process of the array is accompanied by a decrease in the velocities of longitudinal and transverse waves and an increase in the decrement. Besides this an evident anisotropy of seismic properties is observed within the landslide slope, which is determined by the oriented fracture and characteristic stress distribution.

The sliding surface may not coincide with the boundary of technogenic soils and can be confined to homogeneous soils or crosses layers of different lithological composition soils. Under such conditions there are no difference between wave velocities in landslide body and the slope. However in recent years the topographic seismic method has been actively developed, which makes it possible to distinguish blocks of soils with increased anisotropy of elastic properties.

4. Object of study
As an example the results of engineering and geological survey at the landslide slope on the right bank of the Moscow River near the church of St. Nicolas (figure 1) are concerned. The church was built in 1595 and after then was rebuilt many times. The bank of the Moscow River is composed of technogenic and alluvial dispersed soils. In spring they are over saturated with water because of the snow melting, which is brought from the streets also and the landslide danger increases.

Figure 1. Church of St. Nicolas in Saburovo, Moscow.

The slopes of the river are complicated by the landslide process; it is clearly visible on aerial photographs (figure 2). According to the results of visual observations, cracks were recorded in the northern chapel of the St. Nicholas Church, which may be a sign of the development of landslide processes on the river bank beside the church.

Geodesic monitoring of landslide deformations is performed at this site, as a result of which the majority of the slope is in a relatively stable state (figure 3) [14]. The exception is the north-western part of the site, where over the entire observation period, the speed of planned displacements increases dramatically and reaches an average of 45 mm / year. Such anomalous values dare noted both in the multi-year observation period and in the last year. Within engineering geological surveys on the site geophysical methods were also used, the results were used to determine the position of potential sliding surfaces (figure 4). Soil blocks at the top of the landslide slope are in a stressed state; therefore the wave velocities and the anisotropy coefficient in them increase (figure 4). The sliding surface,
which may not stand out in the lithologically uniform layers over the seismic wave velocities, is reliably traced by an increase in the longitudinal wave absorption decrement or in a decrease in the reciprocal – quality factor (figure 5).

Figure 2. Old landslide body on the bank of the Moscow river.

Figure 3. Landslide cirque on the bank of the Moscow river.

Figure 4. The distribution of the anisotropy coefficient in the landslide slope, obtained according to the kinematic (time) seismic tomography.
Seismic methods were used to determine the depth of the groundwater level and local water level, based on the difference in the velocity of longitudinal waves in non-saturated and fully water-saturated soils. For dispersed soils the transition from incomplete water saturation to full is accompanied by an increase in the speed of longitudinal waves 3–7 times, that’s why the total water saturation limit (FSB) is a strong refracting boundary. For determination of physical and mechanical soil properties in the array seismic methods were used. This is possible due to the close links between the seismic properties and physical and mechanical properties of soils [1].

The transition from the undisturbed part of the slope to the landslide array is accompanied by a change in the electrical resistivity, polarizability, potentials of the natural field and anisotropy parameters. As usual the specific electrical resistance of the surface is anomalously low (resistivity) in places of groundwater discharge and infiltration, so anomalies of the natural electric field are observed. In addition there is a steady inverse relationship between resistivity and the weight humidity of soils. The anisotropy coefficient of the electrical properties in a landslide body increases. Consequently the external boundaries of a landslide, the position and properties of its blocks, can be determined using electrical prospecting. The most effective for this purpose is the application of electrical profiling various modifications, in particular electrotomography (ET) [3].

The results of physical and mechanical soil properties laboratory tests agree well with the geophysical methods results. The computer simulation of slope stability shows that the slope is in the limit equilibrium state and this accords well with the present state of the slope [14].

5. Conclusions
1. The problem of slope stability is a “hot point” when dealing with historical natural-technical systems.
2. Landslides on the slopes within the HNTS have their own features which must be taken into account in slope stability assessment.
3. The results of slope stability assessment also depend on soil properties distribution in the landslide massif.
4. There is a possibility to use geophysical methods on landslides slope to obtain necessary parameters. It is much easier and cheaper than drilling on the slope.
5. Competently interpreted data of geophysical researches allow you to determine the number of important boundaries position in the landslide body and beyond, which helps to assess the slope stability, predict and monitor the landslide processes development.
colour figures will degrade or suffer loss of information when converted to black and white and this should be taken into account when preparing them.

6. References

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