Landslide processes as a risk factor for Russian cultural heritage objects

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Abstract This article is concerned with problems of stability assessment of slopes that are part of the interaction scope of historical natural-technical systems (HNTS). The need of using the new methods is caused by increasing development of landslide processes near the architecture monuments. 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-Evfimiyev and Vasiliyevsky Monasteries in the Suzdal region, Pechorsky Monastery in Nizhny Novgorod. The temples and monasteries of Russia are unique monuments of history and architecture, treasures of the cultural heritage of the state and a place of pilgrimage and reverence for many people. Many of them are protected by UNESCO.

Keywords pre-setting of engineering geological conditions, historical natural-technical systems, landslide, modelling of slope stability.

Introduction

The state of the Russian cultural heritage at the present time can be considered as critical. There is a steady decline in the cultural wealth of the country. According to various estimates, the state from 50 to 70% of the historical and cultural monuments that are under state protection is characterized as unsatisfactory, for most of them it is necessary to take urgent measures to save them from breakdown, damage or destruction. Over the past 10 years, more than 2.5 thousand monuments have been destroyed in the Russian Federation, including 2 thousand - under the influence of adverse natural and man-made processes and landslides have played one of the leading roles.

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.

Ancient architects built temples and monasteries in Russia using the principle “How the measure and beauty will say”. This often led to the selection of a construction site on elevated places near the slopes. Many slopes under the influence of changes in natural conditions in in time became landslide dangerous. Therefore at present engineering geologist are often faced with the need to study landslide processes developing within the boundaries of historical natural-technical systems. And this is very difficult. Each architectural monument is unique as the natural conditions of each of them. The evolutionary transformations of the historical territories relief began with the construction of the first buildings. This was expressed in the leveling of the territory and its adaptation to the requirements of economic needs. Over the centuries-long history of the HNTS functioning the surface topography as a rule has been changed very significantly. A change in the terrain entails a change in quantitative and qualitative indicators of engineering geological processes.

Professor of RGGRU E.M. Pashkin introduced the term “pre-set” that means a set of conditions that serve as a sign of processes realization which is determined by the conditions of previous events. With new construction there is an opportunity to avoid areas with landslide process active development. Dealing with HNTS there is no such possibility and the significance of the landslide danger forecast reliability increases. The disclosure of the “pre-set” concept for landslide processes within the historical areas can be given through the definition and evolution of landslide formation factors. These factors primarily include topography, geological structure, hydrogeological conditions and physical and mechanical soil properties. The relief and geological structure of HNTS slopes upper part are determined by the latest history of the territory development and are associated with human activity, which lead to the formation of various technogenic soil layers that overlap the original natural relief. Artificial changes in hydrogeological conditions and surface runoff can cause waterlogging of the contact zone between technogenic accumulations and natural soils. Thus, the pre-determined sliding surface of landslides developed within the HNTS is most often located on the border of natural and technogenic soils.

The distribution of properties in technogenic soils is very heterogeneous due to the peculiarities of their formation conditions, which are not always possible to establish. This makes the task of separating layers of different physical and mechanical properties within a series of technogenic soils extremely difficult. And the slopes that are included in the HNTS interaction sphere are often composed of multimeter strata of technogenic soils, so the quantitative assessment of such slopes stability is rather difficult. All mentioned above requires the development of a special approach to the study of such landslide slopes.

General statements of the methodology for HNTS slope stability calculation.

One of the main stages of work concerned with quantitative assessment of the slope stability is schematization in the mathematical model construction. This kind of schematization can be generalized and special. Under generalized schematization in this context we should understand the process of simplifying a real natural object, which has an infinite degree of complexity to a conceptual model. On the one hand it is limited by scientific knowledge and on the other hand – by the information security degree achieved in the engineering geological survey (Zerkal OV, Fomenko I.K., 2013). 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. Ultimately the special schematization provides the required detail of the real natural object description. The purpose of a special schematization can be expressed in the following thesis: maximum simplification with minimal loss of adequacy (Pendin VV, Fomenko IK, 2015).

One of the special schematization main stages is the assignment of soil properties distribution model in a landslide massif (Bufeev F.K., Fomenko I.K., Sirotkina O.N., 2016)

When calculating the stability of HNTS slopes composed of technogenic soils, the most interesting is the possibility of using models with the construction of soil strength properties distribution fields (Cho, 2007), (Allan, F.C. Yacoub, T.E. Curran, J.H., 2012).

The technique of field specification of properties is as follows: the field of cohesion and the internal friction angle distribution (Bufeev, 2016) is constructed using known actually determined values of soil properties at points with determined coordinates (during the sampling process). Interpolation methods are used to construct the field, such as: the Chaga method (Chugh, AK, 1981), the Delaunay method (Delone BN, 1934), the inverse distance method (IAD) (Shepard, D., 1968), the thin spline method (Franke, Richard, 1985). Next, using traditional methods of calculation based on limiting equilibrium, the position of the sliding surface is determined and the slope stability coefficient is calculated.

Landslide danger assessment on the cultural heritage objects

The Holy Bogolyubsky monastery

The largest of the monasteries of Vladimir and its environs, the Holy Bogolyubsky monastery (Fig. 1) is a witness of more than 8 centuries of Russian history, in whose events he repeatedly played an important role. It is known that on May 20, 1851 during the procession a bridge collapsed as a result of a landslide. Then about 160 people died. In the beginning of the 2010s, the suffusion process intensity increased on the territory of the monastery. The main indicator was the volume of silty-clay material removal the water from a spring at the base of the slope. Two dips with a diameter of up to 1.5 m and a depth of up to 3 m were formed on the slope. Slope movements also began (Fig. 2). The UNESCO World Heritage Site of the Virgin Mary, the Ladder Tower and the passages of Andrei Bogolyubsky's chambers are under the impact of the landslide process.

Fig.1 General view of The Holy Bogolyubsky monastery. You can see landslide signs on the modelling slope.

Fig.2 The landslide shape of a slope.

To estimate the landslide hazard various models of interpolation methods were used to build models of soil strength properties distribution of the near-slope array (an example of the model is shown in Figure 3 and 4) and a series of calculations were performed (Figure 5) using the Morgenstern-Price method. This method was chosen because it satisfies the equilibrium conditions of moments and forces.

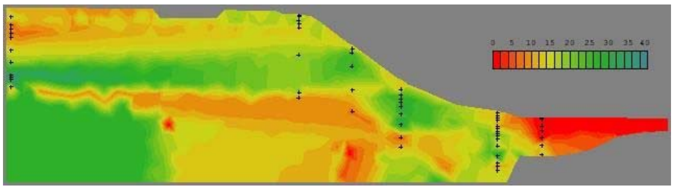

Figure 4 The distribution of internal friction angle in soil massif

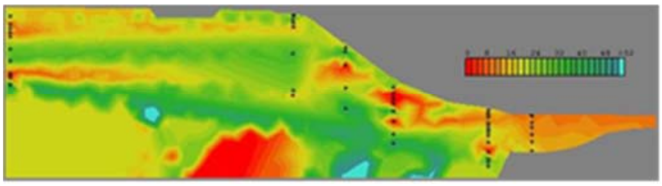

Figure 3 The distribution of cohesion in soil massif

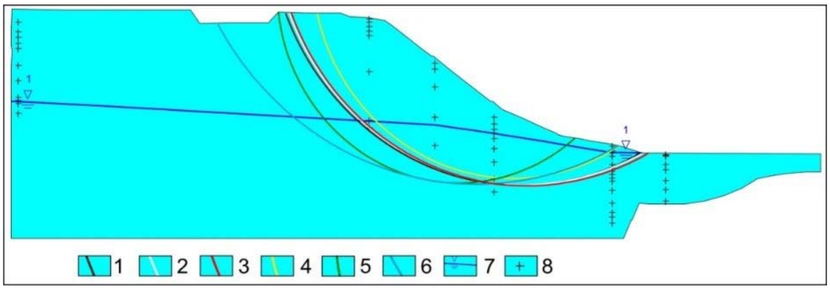

Fig.5 Geomechanical model of calculation by the limiting equilibrium methods. The results of the slip surface calculations: 1-according to the designed characteristics, 2-according to the standard characteristics, 3-using the interpolation method of inverse weighted distances, 4-using the Delaunay method, 5-using the Chag method; 6- using the method of thin spline; 7-level groundwater; 8- ground sampling sites.

Table. 1 The results of slope stability calculation

Parameter/Calculation scheme	Designed soil values	Standard soil values	Interpolation by IWD method	Interpolation by the Delaunay method	Interpolation by the Chag method	Interpolation by the thin spline method of
Safety Factor (Ky)	1,03	1,17	1,20	1,06	0,80	0,92
Landslide body volume	335	327	330	270	354	447

Analyzing the results we can draw the following conclusions. The most comparable with the traditional approach (based on standard values) results were obtained using the interpolation method of inverse weighted distances. This follows from the fact that the values of equivalent volumes differ from the normative soil properties calculations by less than 2%. That is the position of the potential critical sliding surface coincided almost perfectly. The safety factor value differs from calculated by standard values by less than 5%.

Novo-Nikolsky Cathedral of Mozhaisk Kremlin.

The complex of Mozhaisk Kremlin is located in the Moscow region, in the city of Mozhaisk. The Kremlin was founded in the XIII century. The cathedral was built in the 17th century, and since then it has been repeatedly rebuilt. The cathedral acquired this view at the beginning of the XIX century. In April 2013 a landslide (Fig. 6) descended a few meters from the south-western corner of the Novo-Nikolsky Cathedral. It was formed in technogenic soils. Their thickness on this slope reached 12 m. (Bufeev, 2016).

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Fig.6 The landslide near the south-western corner of the Novo-Nikolsky Cathedral.

Table. 2 The results of slope stability calculation – Ky (landslide body volume)

Soil properties distribution models / Calculation method	Designed soil values Model 1	Standard soil values Model 2	Soil strength properties distribution with different types of interpolation			
			Delaunay Model 3	Chag Model 4	The thin spline Model 5	IWD Model 6
Bishop	1,23 (99)	1,16 (185)	1,11 (94)	1,08 (101)	1,14 (103)	1,13 (98)
Yanbu	1,18 (104)	1,14 (202)	1,09 (97)	1,05 (98)	1,10 (109)	1,10 (99)
Morgerstern-Price	1,27 (90)	1,19 (199)	1,13 (89)	1,10 (99)	1,17 (92)	1,16 (94)

From the calculation results analysis it follows that when quantifying the slope stability using the designed characteristics, the values of the safety factor (Ky) not always will be lower than when using standard values. Thus, taking into account the actual unstable state of the slope (see Fig. 6) the values of Ky obtained from the first model should be considered overestimated.

Comparison of the simulation results also shows that the maximum value of the equivalent volume was obtained using the second model, which is explained by the displacement of the sliding surface from the boundary of indigenous and technogenic soils to the underlying sediments with lower strength properties. That is, the position of the sliding surface and the value of the safety factor are influenced not only by the strength properties absolute values, but also by the ratio of the lower strata technogenic soils strength properties.

According to the actual engineering geological survey results, it was established that a landslide that had come down was formed at the boundary of primary and technogenic soils. In the field description of bore holes the line between technogenic and indigenous soils was clearly distinguished. The contact zone was represented by soils with high humidity; within the landslide circus, bedrock rocks outcropped, and technogenic accumulations were deposited in the bottom of the descended landslide.

Thus, the calculation according to the second model with the moving of the sliding surface into the bedrock, does not correspond to the actual data of the engineering-geological survey.

The minimum Ky of the studied slope were obtained using the third model (when the field of strength properties distribution was set). At the same time it is worth noting that the potential equivalent volume of a landslide body is almost the same as that obtained in the calculation using the first model.

Thus, we can conclude that the method of inversely weighted distances allows us to obtain the best results using the interpolation of the technogenic soils properties.

Conclusion

Historical territories as a rule are characterized by an increased thickness of technogenic accumulations. Their presence requires a special approach to the study of engineering geological conditions. The current state of Russian architecture monuments depends on unfavourable engineering geological processes developing within them. The main danger for the historical natural-technical systems located near the slopes is the landslide process. Slip-landslides often occur on such slopes, when technogenic accumulations slide along the bedrock. It happens due to relief changes in the process of human activity, which entails a change in the gradients of surface runoff and to the stress field's reformation in the soil massifs. As a result the hydrogeological conditions of the territory and the physical and mechanical properties of upper part of the section soils change.

Distribution of properties in technogenic soils is unpredictable due to their heterogeneity, and also it is not always possible to establish the conditions for their formation. So the selection of various physical and mechanical properties of the layers and the assignment within them the averaged values represents a certain complexity. Therefore, it is proposed to calculate such slopes based on the fact that the variability of technogenic soils should be taken into account by interpolating the strength properties values between the points in which it is known. When using this technique, it is necessary to substantiate the method of interpolation.

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