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ENGINEERING AND GEOLOGICAL SUPPORT FOR SLOPE STABILITY MONITORING AS A PART OF TRANSPORT INFRASTRUCTURE CONSTRUCTION PROJECTS

Exploitation of landslide-prone escarpments with low safety factor, or in a state of limiting equilibrium, can lead to a disaster when changing the seismic and hydro-geological situation. Therefore, recommendations must be developed for the deployment of a high density network of hydrogeomechanical monitoring information collection points for rapid notification when the critical water level is reached and for making management decisions to strengthen the slope.

Keywords: Landslide danger, slopes, slope processes, geological engineering surveys, hydrology, monitoring, sounding, mathematical modeling.

Engineering activities may result in the formation of complex natural and industrial systems which require interactive monitoring to ensure their sustainable development. A set of monitoring activities will make it possible to assess the rock mass space-time behavior and control its condition. This would ensure the industrial and environmental safety of construction projects delivered under complex engineering-geological, hydraulic geological and geomechanical conditions, and result in the development of new territories and mineral deposits.

Over the last decade the North Caucasus territory has experienced major new developments, mainly associated with the 2014 Winter Olympic Games. In particular, the combined (road and rail) Adler-Mountain Climatic Resort Alpika-Service highway was commissioned in Sochi to provide a reliable and regular transport link between the mountain cluster facilities and the main transport hubs. The road commissioned in November 2013 is approximately 50 km in length and has several junctions connecting to Federal Road M-27. In terms of the number of tunnels, this is a unique project for Russia. The entire construction site for this transport line features very complex engineering and geological conditions. The works were performed under young Alpine orogenesis conditions that give rise to the development of hazardous geological processes of both endogenous and exogenous nature. The northern section of the road is in a high seismic region (up 8–9 intensity), and this area also features minor surface slopes that results in the active development of slope processes (rock slides, landslides, mudflows, avalanches), as well as water erosion.

The slopes on the left bank of the Mzymta River and those on the section from Alpika-Service terminal to the nearest railway tunnel portal pose the highest soil slip hazard. The main conditions for the formation and development of hazardous slope processes are the specific nature and geological structure of the mountainous area, including the composition and mode of occurrence of geological material, structural and tectonic characteristics of rock mass, hydrodynamic mode of underground waters, neotectonic movements and other factors. The area's upper rock layer includes eluvial, diluvial and soil slip deposits comprising argillite, sandrock, porphyrite, and others bed rock land wastes. In this respect, these surface deposits include crushed stone, granitic subsoils with various joining materials (mild clay, sandy loam), as well as mild clay and clay [3].

To ensure safe operation of the road and on-time implementation of modern measures to minimize slope process hazards, in 2011–2013 the NUST MISiS Geology and Mine Surveying Department, together with Alkomp-Evropa LLC, developed a complex program for monitoring potential landslide slopes. The monitoring activities include collecting geodetic and geological information (directional survey, automated tacheometric survey, collection of piezometric data across the well network) with the aid of a set of interactive equipment. Most survey activities of potentially hazardous slide masses were performed in 2012–2013.

A reconnaissance survey of the territory of the Alpika-Service terminal construction site was performed at the initial phase. The main sections for field activities were determined based on the site route survey and geological structure data.

Based on reconnaissance survey data and available geological information, several clay slate block sample sites (interstratified argillite) with not more than 2.5 m loose deposit thickness were determined. Then, within each selected site, the points were positioned in accordance with modern approaches for network development and testing, with the aid of mathematic models and complying with the main engineering and geological survey techniques: equal reliability, survey completeness, step-by-step approximation of data collection, minimum time and financial expenditure. In every selected site the general variability functions were determined based on the sum of surveyed deposit characteristics. This made it possible to design an engineering and geologic sampling network. The used method helped to minimize the number of sampling sites without any loss of data integrity [3, 4].

Cores were drilled directly from the mass following the cleaning (cutting down) of the upper waste layer and taking grab samples from the lumps and uncoverings in perennial and dry water stream beds (Figure 1).

To take the required amount of samples, 10 sample pits (up to 2 m in depth) were made; 65 samples were taken in total, including 42 cores with a diameter of 42 mm and minimum length of 85 mm; 17 sample pits for drilling samples with required geometrical shapes and sizes, as well as 6 samples of non-disturbed connected geological material (clays formed after slacking of waterlogged slate stone).

a

b

Fig. 1. Core drilling: *a* – directly from rock mass; *b* – from lumps.

The samples were also taken from stream flow sites (18 sampling points in total in two sampling sites): 134 cores (diameter of 42 mm, length from 88 to 181 mm), 23 grab samples for further drilling-out in laboratory conditions. The uncovered clay slate and black earth area near the exit from the rail road section was subject to 100% sampling with average sampling step from 1–1.5 m.

The following was determined during the laboratory test phase: density (ρ), rock strength under uniaxial compression (σ_c), rock strength under uniaxial tension (σ_t), elastic modulus (E_{el}), deformation modulus (E_d), Poisson ratio (ν), angle of shear resistance (φ), specific cohesion (Figure 2).

Shear testing of clay slate for lamination as well as testing of the land waste mild clay (with crushed stone inclusions) provides an almost identical angle of shear resistance and cohesion. This proves the presence of clay material between the slate stone layers. This leads to major weakening inside the mass and increases the soil slip hazard.

The obtained field and laboratory survey data made it possible to create a pattern and a model of slopes accounting for the physical and mechanical properties of build-up rocks and local hydrogeological conditions.

Stability factor (η) was calculated at monitoring sites 8 and 9 to assess potentially hazardous slopes; the calculations took into account the test profiles and various rock mass waterlogging levels. The work was performed using a software system developed at the Geologic Department of Moscow State Mining University.

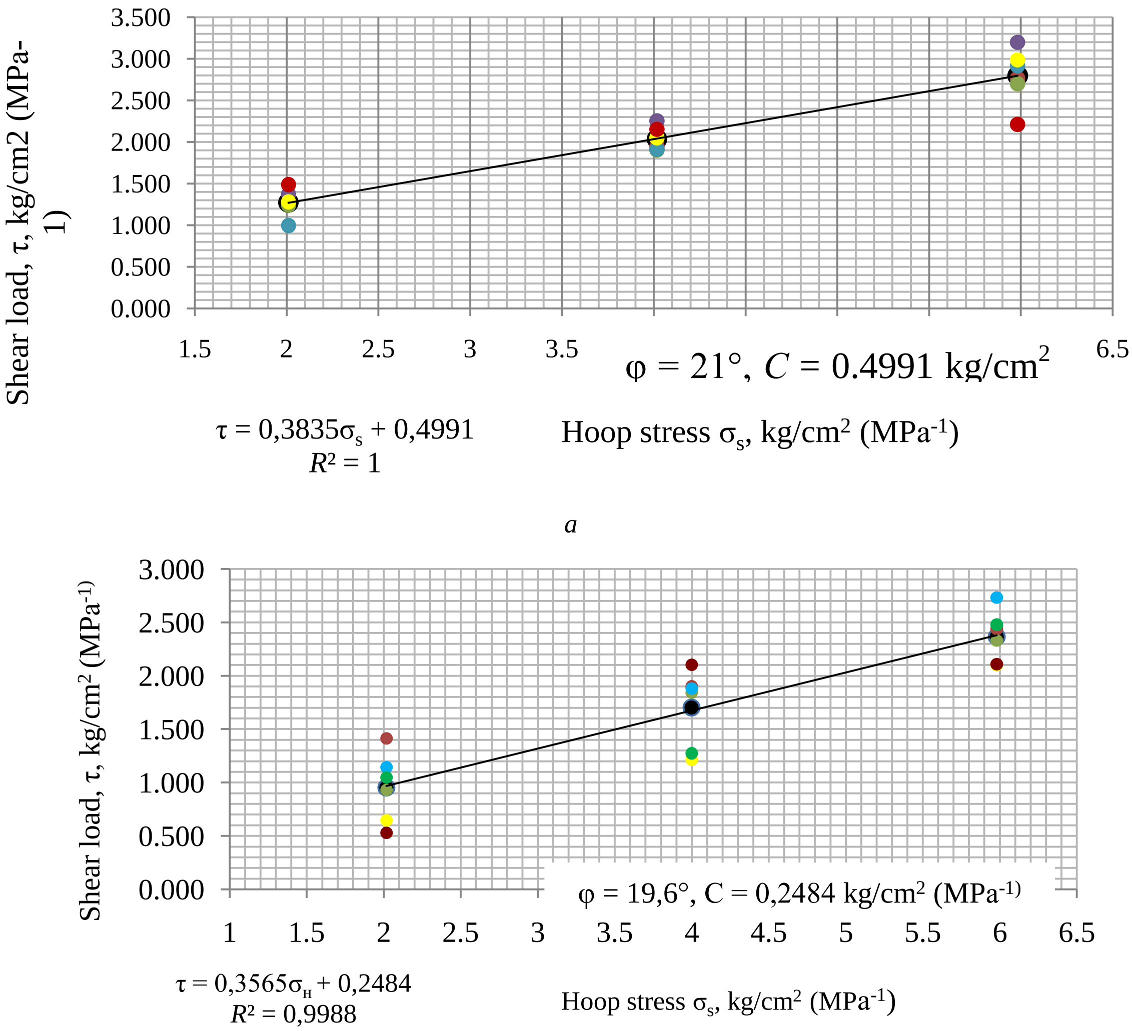

Fig. 2. Dependencies $\tau(\sigma_s)$ for clay slates (*a*); mild clay (*b*).

The calculations are based on methods approved by the Russian State Mining and Industrial Inspectorate (Gostekhnadzor); these methods are founded on the "loosen medium" limit equilibrium approach which also covers limit equilibrium of frictions connected medium (i.e. geological material under consideration, Figure 3) [1].

Slope stability under various seismic, hydro-geological and climatic conditions was assessed in 2013. This work helped to develop criteria (in terms of numbers) to assess soil slide hazards. For the project area under consideration, the obtained dependencies of the stability factor on water levels in hydro-geological wells, accounting for the amount of precipitation, were used in the automated rock mass condition data collection and processing system (Figure 4).

From the works completed in 2012–2013, it can be concluded that the slopes near Alpika-Service rail road terminal feature a low stability ratio; some potentially sliding bodies are in the limit equilibrium state, which could result in emergency situations if seismic and/or hydro-geological conditions change. Therefore, recommendations were developed on deploying a high density hydrogeomechanical monitoring network for rapid notification when the critical water level is reached and for making management decisions to strengthen the slope.

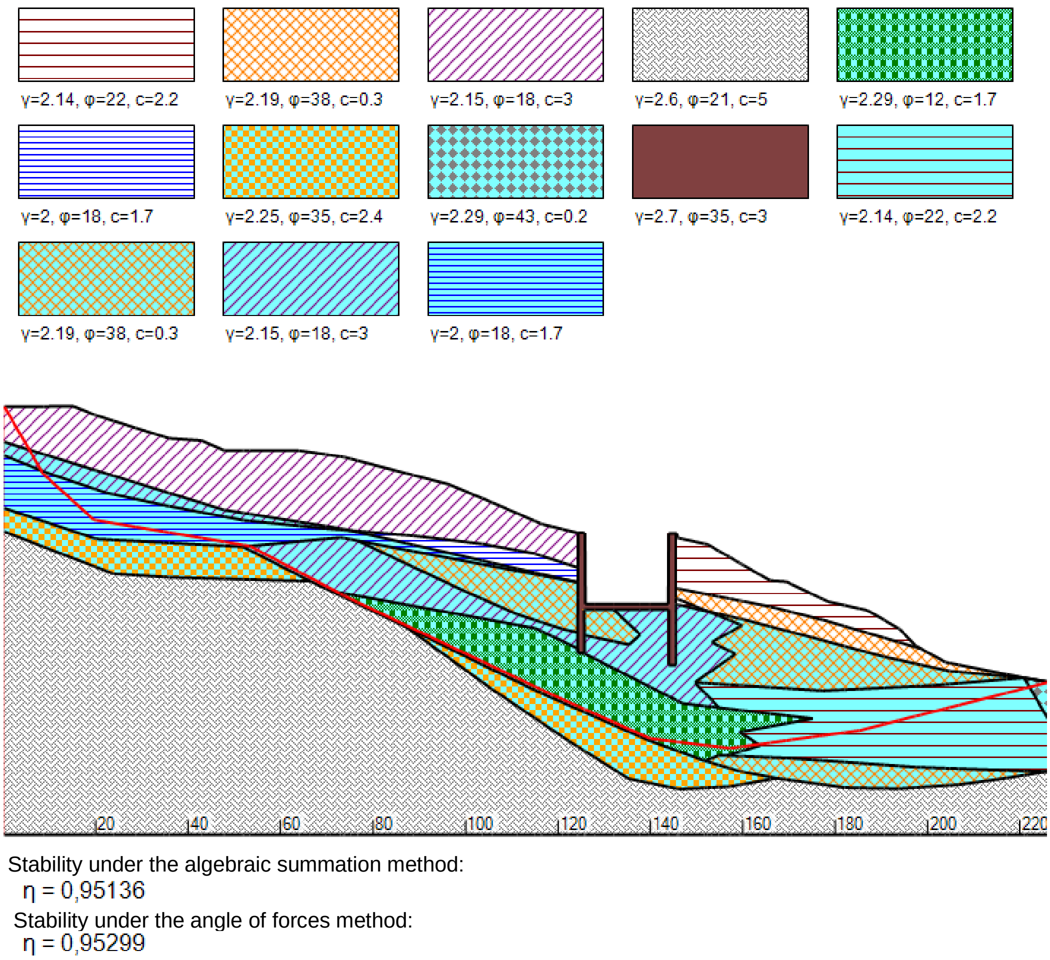

Fig. 3. Calculation of stability factor in Geodamp with preset water level in hydro-geological wells.

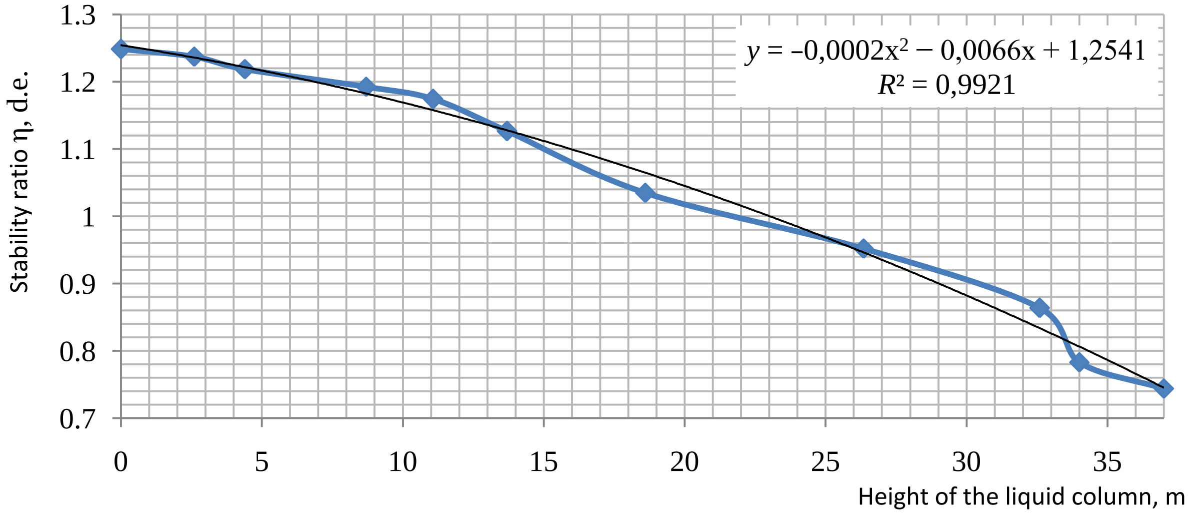

Fig. 4. Stability ratio dependence on the height of the liquid column in a hydro-geological well

A unique complex engineering and geological remote monitoring automated system was developed. The experience of deploying the system can be used by mining companies or building contractors when implementing construction projects on soil sliding areas. The developed system is capable of recording geological material condition changes in time and space; the sample collection networks are designed based on statistics methods and cluster analysis; this improves the reliability of geological material behavior assessment. The complex approach is achieved by calculating limit values using sets of parameters as the function of dependence of the system stability on the rock mass state vector.

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