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Determining global stability for a group of geotechnical objects in complex geological conditions

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Abstract

An old Arab proverb says that if a mountain is to fall, it will fall even if it is caused only by a grain of sand. In this sentence, the whole, humanly observed process of the influence of nature and time on global stability is described. Its determination is therefore not only a simple calculation, where all forces can be put in proportion. In complex geological conditions it is mainly about understanding the overall geological environment with the time development and effective design of geotechnical structures to ensure long-term stability. Effective design means a set of structures that complement each other so that their ultimate impact has the desired effect. Therefore, the calculation is also conditioned by a precisely given construction process and time dependence. This is the primary input that should be identified by the geotechnical engineer at the start of the design work. This procedure is constant and all further work must be based on it. On this basis, it can then be easily engaging individual contractors in the process of building and effectively manage the overall construction.

The paper deals with the construction of highway in difficult geological conditions of Carpathian flysch and numerical determination of global stability for primary state. Areas represent active landslides, through design of geotechnical structures for its stabilization in dependence on time and progress of construction in urban area to real construction of highway itself.

1 INTRODUCTION

Mechanism of slope movements is defined as the inherent natural procession of general development. The course of slope mass movement conditioned by the geological – tectonic structure of a slope, by slope site topography as well as by operating natural and human activity factors. On the basis of the specific deformation and kinetic mutual coupling of separate parts of a moving mass in entire zone of a slope movement. This integrating mechanism determines that in a given space and time there develops and proceeds a characteristic type of downward slope movements and also a resulting type of slope failure. Always with minimal energy consumption. The mass movement mechanism and the type of slope movement, as well as its velocity, can however change in space and time.

The most widespread slope mechanism is sliding. It is distinguished by the gravitational movement of soil or rock mass in solid (hard) to plastic state (from very stiff to soft consistence) on a slope without loss of contact with the bed ground.

Analysis of slide movement in respect to kinetics is based on Newton´s law of motion, valid for the acceleration of solid bodies in the gravity field. With respect to the variable geometry of landslide, its surficial topography and its sliding surfaces, it possible to solve the kinetics of slide movement just in simple cases or in particular parts with clearly de-fined sliding mass path.

2 GEOLIGICAL SITUATION IN SLOVAKIA

With gradually expanding populations are extensive and demanding technical works built in increasingly complex and less favorable geological conditions. The optimal foundation conditions are not limited only on the territory of the Slovak Republic but also in other countries, leading to an increase in the cost of engineering construction. The complicated geological structure and geomorphology of Slovakia makes the occurrence of several geological failures, the most widespread being the slope deformations.

In Czechoslovakia as the first state in the world, all dangerous landslides in economically significant areas were registered nationwide in 1962-1963. Approximately 62% of the country's surface area was ascertained. All areas that have been damaged or threatened by landslide or other forms of slope deformation have been documented and mapped to a scale of 1:25,000.

The last summary registration of slope deformations in the Slovak Republic was in 2008, where it was recorded 21 190 slopes deformations with a total area of 257 591, 2 ha, which represents approximately 5,25% of the total area of the country. Slope deformations are the cause of road damage, deterioration of agricultural land, woodland and so on. In May last year, high precipitation events were recorded in Slovakia resulting in hundreds of landslides being activated (a total of 551 new landslides were registered) (Figure 1).

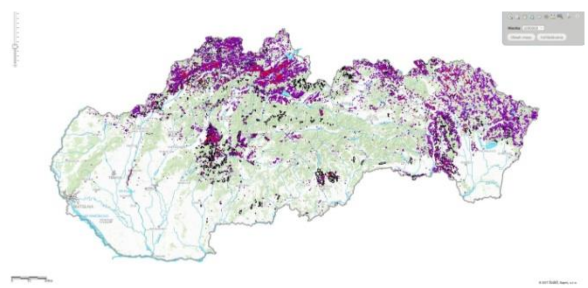

Figure 1. Recorded slope deformation in Slovakia

Slope deformations in Slovakia that represent one of the most common types of geological faults of the country and represent a significant geobarriers in urban planning. Evaluation of landslide risk is especially useful in areas where it is expected socio-economic and technological development of the region.

In the Figure.2 are presented geological formations in the Slovak part of the Western Carpathians.

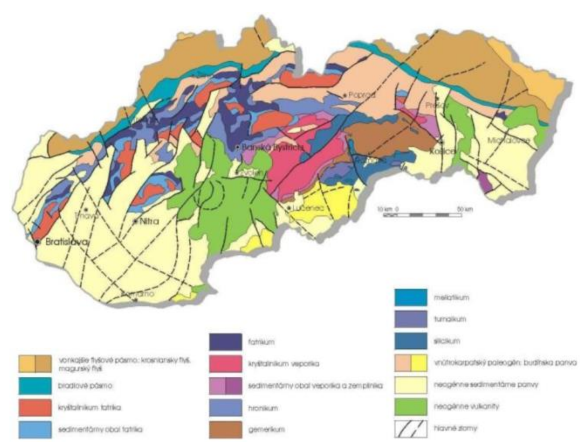

Figure 2. Tectonic faults of the Slovak Western Carpathians

The slope deformations are the most disturbed unit of the paleogene and the mesozoic of the limb zone 14.8% and the paleogene of the flysch zone 12.7%. Follow neogene volcanicity 9.3% and intra-Carpathian paleogene 7.2%. The least damaged are

Mesozoic rocks 2.4%, neogenic and quaternary sediments 1.5% and crystalline rocks 1.5% (percentages represent the shares of the total area of the formation).

Regarding the activity of slope deformations, active is 11.6%. These active forms represent just landslides (94.9%) and erosions (3.5%).

In one of these areas it is currently under construction of an important linear structure. This is the highway D3 Čadca, Bukov - Svrčinovec and the bypass of Čadca (Figure 3).

Such extensive construction can have a positive but also a negative impact as it represents a relatively large impact on the environment. First of all, there is a direct relationship of the technical work with the rock environment. One of the main geotechnical problems in the design and construction of technical works in the morphological terrain it is slope stability. Incorrectly stable assessment of the slope stability, where the technical intervention is to be carried out, can lead to disastrous consequences.

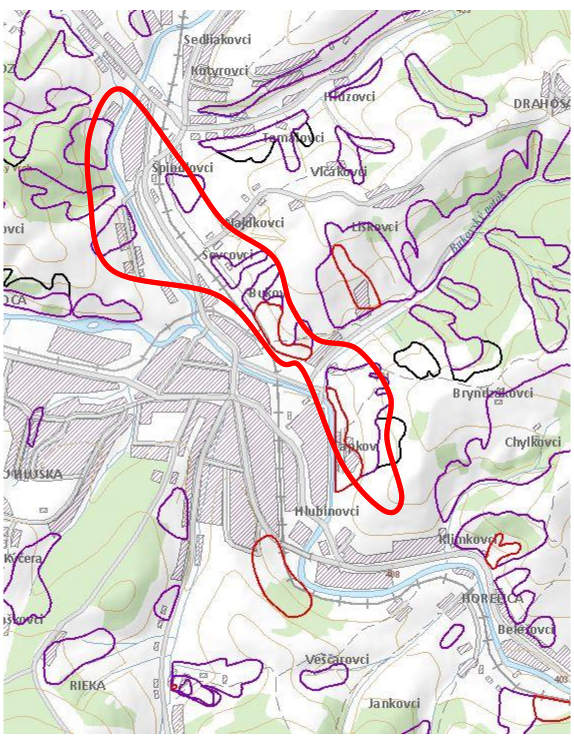

Figure 3. Recorded landslides at the site of the D3 highway (schematically marked)

3 LANDSLIDES AND THE LINE CONSTRUCTIONS

Slope deformations generally have a negative impact on construction areas. The greatest interest is focused on landslides endangering the new family houses. It being remembered that many times the owners, who decided to build on the slope without the help of geologist or geotechnical engineer, they can often themselves for this situation. Linear structures, however, represent strategic constructions that have a very wide use for the population and the state.

The biggest problem of Slovakia is the complicated geological structure complex in the interaction with the construction of highways and the related occurrence of slope deformations. The map of slope stability, in which the landslides and other slope deformations are registered, is updates. The responsible geotechnical engineer often encounters unexpected complications.

Project planning counts on what has been documented in the past, and therefore are realized remedial arrangement which results from a previous survey. As already mentioned, there are cases when the combination of adverse natural conditions and anthropogenic intervention of construction into the natural environment activate slope deformations. One of the most frequent building interventions in the rock environment during construction is the undercut. Nothing unusual, but from stability side, it is very dangerous. By undercut on the toe of the slope, amount of material is extracted and therefore the soil above the building pit influenced with higher weight. In combination with adverse natural conditions (geological conditions, extreme precipitation, etc.), when the rock environment acquires reduced shear parameters c (cohesion) and φ (internal friction angle), landslides develop. Although the safety factors are calculated, due to the stability constructions, the slope deformations are often unpredictable and thus inapt and mainly overcharge the actual construction.

4 STABILITY ASSESSMENT OF SLOPE DEFORMATIONS IN HIGHWAY CORRIDOR

As an example, paper describes the construction of a highway in complex geological conditions, where the alteration of stiff and with high plasticity occurs. This alteration results in several shear zones at different depths.

The most significant case for near the highway was landslide, which is a response to the geological and tectonic structure of the area and its hydrogeological conditions. Slope deformations, that are in multiple locations combined with a movement of rubble´s layers, cover the bulk of the area slopes engaged motorway route (or a range).

Landslides are flat and frontal. Sliding deluvium was verified by geophysical measurements. Slope movements were monitored by inclinometers in boreholes.

Rock environment damaged by slope movements - the landslide deluvium is made up of quaternary soils and locally the pre-quaternary rocks which are also damaged. The landslide deluvium has a variable lithological character depending on the type of underlying rocks as well as the cover quaternary soils. They are represented by clay soils, stony-clay debris, clay-stony and also fully weathered claystone with unique positions of weathered sandstones. The thickness of the landslide deluvium is variable.

The surface layer of the rock environment affected by the debris climbing is predominantly clayey-rocky debris. In the area they are discontinuous in rock zones. In the place of tectonically weakened rock environment erosive grooves originated.

Risk factors:

- local occurrence of low-bearing compressible clay soils with an admixture of organic substances,
- variable thickness of fluvial quaternary sediments,
- discontinuous occurrence of the landfills with a variable thickness,
- volatility of claystones due to exogenous factors,
- clay´s volume changes,
- rugged territory,
- occurrence of waterlogged areas and springs,
- raising groundwater levels in extreme rainfall.

4.1 Seismicity of the area

The opinion of the majority of complex, that there are practically no strong earthquakes in Slovakia, to cause a serious threat to human lives and material values is due in particular to the fact that there have been no strong earthquakes in our country in recent decades.

Earthquake data forming input database for seismic threat calculation. For this purpose, it is necessary to pay more attention to the allocation of individual focal areas in the Slovak Republic, as well as to determine the location of registered earthquakes.

Based on the seismological and geological observations were identified the focal areas. In all focal areas have experienced earthquakes with epicentral intensity greater than or equal to 7 ° EMS 98th.

In the probabilistic calculation of the seismic endangerment of the territory it is necessary to include data not only on earthquakes from the local zones in the territory but also from the zones in the neighboring states, as these may also influence the resulting values of seismic hazard characteristics for the territory. The extent to which these zones need to be included in the calculation depends on the magnitude of the strongest earthquakes in the individual zones, the shape of the attenuation curves for the respective seismic hazard characteristics, and the return period of interest. As a rule, it is necessary to include in the calculation all local zones whose closest distance to the site of interest is less than 150 km.

In Figure 4 is a seismic hazard map for the Czech Republic, Poland and Slovakia. The map shows the peak acceleration for a return period of 475 years, it is 10% probability of exceeding over 50 years (this period corresponds to the expected lifetime of normal buildings in the seismic load standards of building structures).

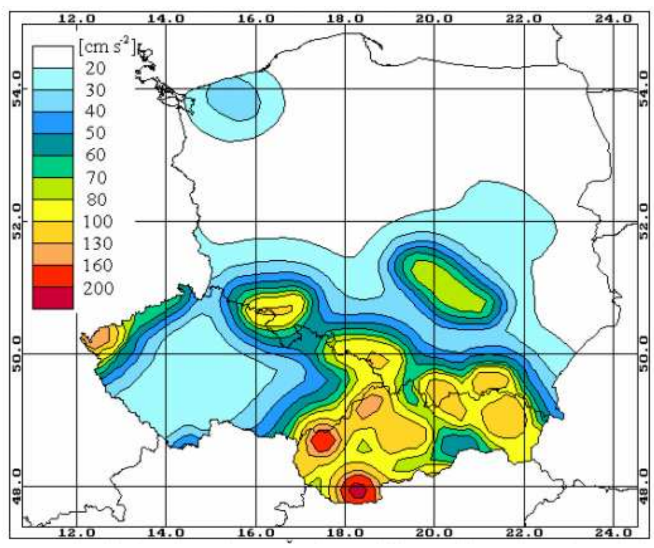

Figure 4. Seismic hazard map for Czech Republic, Poland and Slovakia

Earthquake represented increasing the effects of the active earth pressure on the structure and reducing the effect of passive resistance. There are several computational ways to simulate this increase. The most used are Mononobe-Okabe and Arrango theories.

In this time, there are many geotechnical programs that have the algorithm of these theories built in, and the only task of geotechnical engineer is to simply "feed" calculation with the input values. The problem occurs when the input parameters are poorly rated or badly selected. Then there happen only two variants. The construction is undersized or oversized (What is from the point of view still the better side.)

The basis for the whole calculation is the correct determination of the seismic coefficient of vertical (k_h) and horizontal (k_v) acceleration. These coefficients are a direct expression of the velocity of seismic waves we discussed in the first part of the article. The coefficient k_h is taken always positive and therefore it is considered that the effect is always negative and the coefficient k_v can be positive or negative.

After determining the acceleration coefficients, is estimated seismic angle of inertia ψ (deflection of inertial forces results.)

Increase in active pressure due to seismic effects, if is not part of the computational algorithm, is added as extra static load, which is computed from the bottom of the structure.

5 CONSTRUTION OF NUMERICAL MODEL AND CALCULATION

The whole landslide area and the individual calculation phase in this case were modeled using the GEO5 2020 FEM module.

Material models can be divided into two groups. Linear and nonlinear. For calculations of larger structures (in this case the construction and landslide territory) are nonlinear models only way to minimize the uncertainty of the outcome, because linear models of earth, precisely in the calculations sheeting structures provide totally unrealistic results.

The choice of the material constitutional relationship and subsequent input of soil parameters into the calculation are one of the most important and at the same time the most problematic tasks in the modeling of the structure by the finite element method. The main task of the material model is to describe the behavior of the soil (rocks) as reliably as possible.

As computational model was chosen modified Mohr-Coulomb. It is a tried and tested constitutional relationship and it was also the most satisfactory within the task assignment, mainly because of its ability to describe the mechanical violations already present in the site. Also, a big advantage of this model are geotechnical parameters, which do not require special laboratory tests.

The input parameters for this model are the modulus of elasticity of soils E and Poisson number, further the angle of internal friction and cohesion of soils, which determines the limit of plasticity. Modified Mohr-Coulomb models steady state after pore pressure redistribution and uses effective parameters (in this case for residual deluvial landslides).

The modified MC model adjusts singularity of classic MC model. The projection of the plasticity surface passes into the deviator plane through all vertices of the Mohr-Coulomb hexagon and the plasticity condition depends on the mean effective stress and the Lode´s angle. With this model we can expect a stiffer response of the material than with the use of the classic Mohr-Coulomb.

Figure 5 shows one from more calculated cross-section, based on a geological survey, an exposed model with individual material layers.

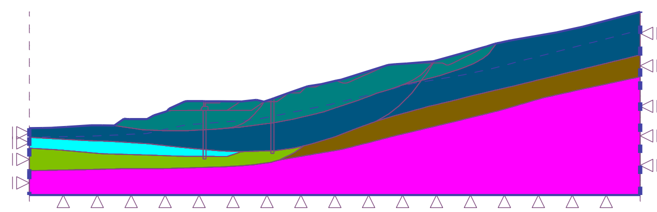

Figure 5. Model of movement zone

As previously written, the calculation of the first phase and its correct evaluation is one of the most important steps of the whole modeling. This phase should best describe and describe the behavior of the environment before construction begins. The first phase, after the dispersion of the pore pressures, from which all the main deformations will be derived thereafter. To say that the model and the total zero phase is almost accurate, the model as such would have to include a historical link (ie to take into account possible overconsolidation it is necessary to take into account the historical development of the territory and its glacial period). Due to the necessary optimization, such a detailed examination is omitted and the main focus is on the correct identification of both active and potential slip surfaces.

Figure 6 shows the locations where shear strength is exhausted.

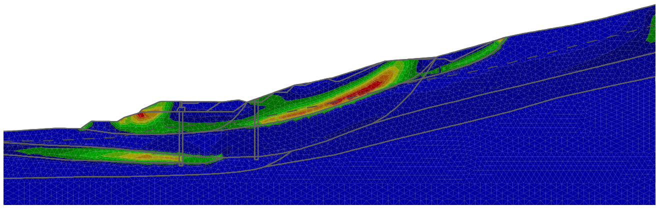

Figure 6. Equivalent of relative strain for calculated cross-section

Equivalent relative deformations point to two active and one potential landslides. These points can still be verified by evaluating the volumetric ratios that more precisely delimit the overall cubic movement (Fig 7).

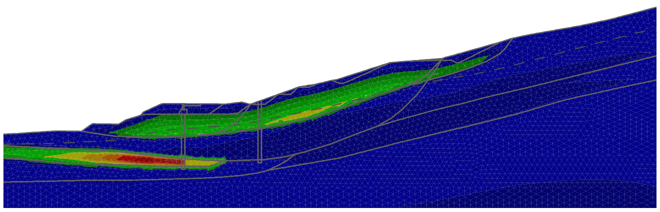

Figure 7. Equivalent of relative strain for calculated cross-section

Another calculated cross-section with determining the primary condition is in figure 8.

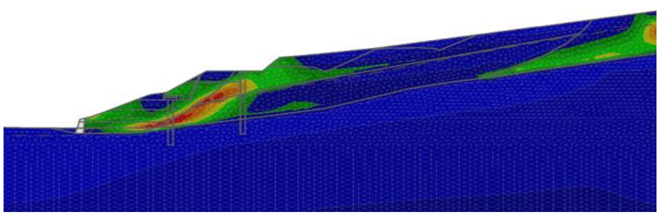

Figure 8. Shape of the shear surfaces for the first construction step

These sites represent a potential risk during the construction of the D3 motorway must be adapted and stabilized by geotechnical structures. This stabilization is modeled in the next steps and also takes into account the expected construction progress.

Next modeling phases represented the process of construction of the whole building from drilling large-sized piles to completing the embankment for the highway body itself. At each stage of the construction, the stability calculation was performed and the relative deformations and internal forces were evaluated as on the piles and anchors that were part of the assessment (Fig. 9, 10, 11).

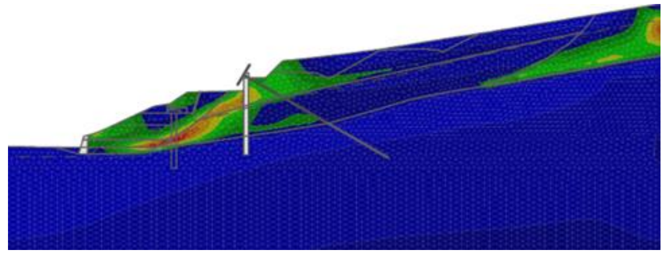

Figure 9. The redistribution of the shear displacements after completion of the first object, which now allowed the start of release the landslide

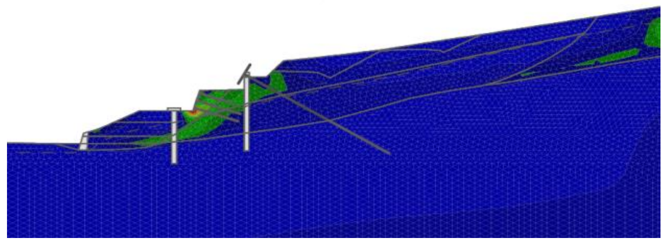

Figure 10. Construction of another pilot wall, the task of which will be primarily to secure the left-hand highway

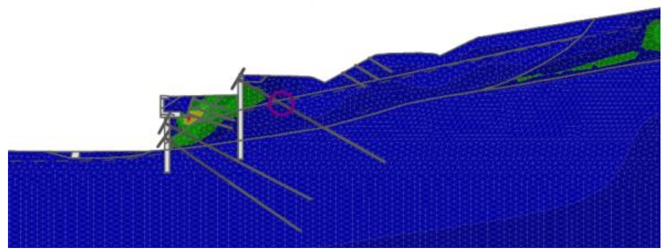

Figure 11. The final stability system of highway

6 CONSTRUTION PROCESS AND GLOBAL STABILITY

The main task of the geotechnical engineer is to pro-pose a set of measures that will, by their nature, pre-vent landslides. A set of constructions means that individual parts fulfil their partial role until the builds up the next part (gravitational walls, piles, MSE wall) and jointly take over the stability role as a whole.

The individual steps of geotechnical construction must be assumed and, on the basis of the primary stress state in the mass, it must be ensured so as to avoid landslides.

Each step must be supported by stability recalculation and only on the basis of it can be chosen the next procedure or take an auxiliary measure.

Geotechnical engineer is in constant contact with the geologist who is present on the site. Each change from the assumption is immediately analyzed and inserted into the design model to verify the calculations. In case of non-compliance, they are immediately proposed measures. This does not mean an unnecessary increase in the cost of the work and the time of construction is not extended.

The following Table 1 summarizes the results of the stability calculation for the individual phases.

The calculation of the stability factor for FEM is based on the method of reducing soil strength parameters and classic´s methods according to the theory of limit states (Fig. 12).

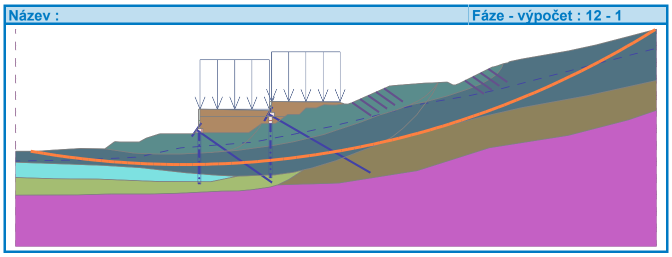

Figure 12. Determination of critical shear surface using classical theory

Table 1. Results of stability calculation

Calculation phase	FEM	Bishop	Spencer	Morgenster-Price
Primary stress state	93,0%	96,9%	97,1%	96,9%
Full operation	75,4%	71,4%	66,3%	67,2%
Seismic load	79,3%	74,6%	70,5%	72,0%

From the calculated it is clear that the first calculation phase, which characterizes the area of interest in its current state, it represents a potential risk in terms of stability, which has slowly lost any reserve and without further engineering-geotechnical intervention, could grow into a massive landslide.

In any case, all proposed measures related to the construction of the D3 motorway in this unfavorable environment lead to an increase in global stability of almost 25%.

7 RISK ANALYSIS AND LIKELIHOOD OF OCCURRENCE OF AN UNDESIRABLE EVENT

In geotechnical engineering, it is necessary to assume that the contractor make a fault during construction processes. It is in this area of construction that the manufacturer's mistakes are of a great nature and have dangerous consequences for the proposed work. It is necessary to take them into account during the design and thus to prevent, respectively at least reduce the negative impact of improper work. This analysis will increase the safety of the building and increase the safety of workers.

Generally, the risk can be understood as a probability of occurrence of an undesirable and unintended event and a negative consequence of this event. So, if we talk about risk, we are talking about the probability that a threat may occur. The risk is accompanied by uncertainty It is the event with which the risk is associated may or may not occur. On the other hand, it is a loss, which is the result of unexpected consequences.

The first stage in risk analysis is its identification, a save identification of risk, and the identification of the risks that may affect the building structure. Creating a list of potential risks is based on the fact that everything can occur during the static calculation solution and what events it does. At present, there are many techniques and methods for identifying risks. For example. If we want Reduction of geotechnical risk, we need Technical and economical optimalization. We achieve it with two method. With Reduce the apparlement of an unsirable phenomenon or with Redicing the consequences of the undesirable.

The next step is the risk analysis itself. It serves to sort the risks according to their impact on project goals. Quantitative risk analysis serves to determine the likelihood of risks and to link these risks to the objectives of the project. Various risk analysis methods can also be used for building and designing building structures. However, the mathematical method, the method of scenario analysis and the method of using experience are the most optimal.

The main advantage of the matrix method is the ability to capture a great deal of interrelationships between the rock environment and the building structure. The Scenario Analysis method has the ability to use simulation patterns of construction behavior. In practice, it is being used less and less. The method of exploiting experience is in turn based on similarities with other similar constructions, which have been proposed under similar geological conditions. However, as geological conditions are predominantly different in each site, this method of analysis is rarely applicable.

8 GEOTECHNICS IS NOT SCIENCE

Geotechnics is not science. This argument we often encounter in practice is very erroneous. Geotechnical constructions account for about 5-10 % of all costs on the financial side of the construction site. For civil engineering, it is 30 %, and for water constructions the share of geotechnics is up to 50 % of the total cost of the construction work. The largest share of these buildings is of course underground, where the share of geotechnics represents up to 95 % of all costs. Based on these statistics, it is clear that the impact of geotechnics is significant for all types of construction and cannot be neglected under normal conditions.

9 CONCLUSION

About slope movements man does not encounter every day. It should be noted that this happens, and it happens more often. These movements are influenced only by two factors, namely nature and humans themselves.

In complex geological conditions it is mainly about understanding the overall geological environment with the development and effective design of geotechnical structures designed to ensure long-term stability.

At the beginning of any geotechnical calculation, it is necessary to ask the basic questions that modeling is associated with and what the next step is to follow: what will be modeled and what results from the calculation are expected. The problems associated with the construction and subsequent calculation of the numerical model could thus be divided into two levels.

The first is associated with a separate model. It is not advisable to build a complex model at the outset without back controlling convergence. The error is then searched for why the calculation ended with an error message. But it rarely happens and starts from the beginning. This is associated with unnecessarily wasted time.

The second problem, which is associated with mathematical analysis. It is necessary to know exactly what the calculation should bring. One thing is to determine the degree of stability, another to evaluate the deformations caused by anthropogenic intervention and again something else, to determine the internal forces on the designed structures (piles, anchors, nails, etc.).

Any such analysis has its specifics which must be respected. To calculate a small structure, it is possible to use a linear model, or its modified version with the possibility of simulation of simple reinforcement. For stability analysis it is necessary to choose a more complex, non-linear model. It is possible to decide on the effectiveness of the constitutional relationship in the calculation only on the basis of information about the modeled area.

Only on the basis of a correctly selected constitutional model and the first calculations, it is possible to make an efficient design of geotechnical structures to increase global stability.

The term effective design is meant a set of geotechnical construction, which complement each other. Their final effect has the desired influence. The calculation is conditional on precisely the construction process and the time dependence. This procedure is unalterable and all other work has to come from it. Based on this, it is then possible to simply involve individual suppliers in the building process and effectively manage the overall process.

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