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GEOTECHNICAL PROBLEMATICS OF DIRECTED RESEARCH IN ROCK MASSES

Abstract:
During the construction of Civil Engineering structures in rock masses, different and specific problems may occur. Engineering Geological research has a significant role in their solving. With this kind of research relevant data can be obtained with purpose to get detailed insight in engineering - geological rock mass characteristics and its geological structure. Absence or insufficient scope and quality of the mentioned research may result in occurrence of the problems during design and performance of Civil Engineering structures, which in this work has been shown on the example of road construction in the cut in the rock mass.

Keywords: Engineering-geological research, rock mass, problems

ГЕОТЕХНИЧКА ПРОБЛЕМАТИКА УСМЈЕРЕНИХ ИСТРАЖИВАЊА У СТИЈЕНСКИМ МАСАМА

Сажетак:
Приликом изградње грађевинских објеката у стијенским масама појављују се разни специфични проблеми у чијем рјешавању значајну улогу имају инжењерско – геолошка истраживања. Овим истраживањима се добијају релевантни подаци који служе за детаљно сагледавање инжењерско – геолошких карактеристика стијенске масе. Одсуство или недовољан обим и квалитет поменутих истраживања за посљедицу има настанак проблема приликом пројектовања и извођења грађевинских објеката, што је у раду и приказано на примјеру изградње саобраћајнице у засјеку у стијенској маси.

Кључне ријечи: Инжењерско – геолошка истраживања, стијенска маса, проблеми

1. INTRODUCTION

One of the basic steps during structure design is thorough research work implementation. Different environment conditions, as well as types of constructions require different kind of research works in order to obtain the desired information which is necessary for quality design. Rock mass research represents specific field considering the fact that adoption and determination of parameters is a serious challenge. During research implementation it is necessary to pay attention equally to the intact rock research and discontinuity. The scope and research type should adapt to the type of the structure which is performed, as well as to the cutting size in the slopes. Depending on the structure type and size, a division of the basic research can be done, which is necessary for implementation during research process. Several common cases are considered:

- Cuts in the rocks – orientation and slopes of the primary and secondary cracks, phreatic surface; degree of the crack roughness.
- Foundation structures – deformation modules; ground homogeneity degree; strengths.
- Tunnels – uniaxial strength; RQD; discontinuity distance; discontinuity state; discontinuity stretch and slope; phreatic surface.
- Landslides in the rocks – sliding surfaces depth determination; physical – mechanical parameters of the soils susceptible to sliding.

2. GEOTECHNICAL PROBLEMATICS IN ROCK MASS RESEARCH IN THE CUTS

During design and realization of the routes of the new highways, contemporary practice implies application of the great notch and snaps. Depending on the environment conditions, it is often necessary to insure them by supporting structures which provide security and road persistence during exploitation period. Parameters gained by research works have major significance during design of support constructions (Figure 1) [3:55-56].

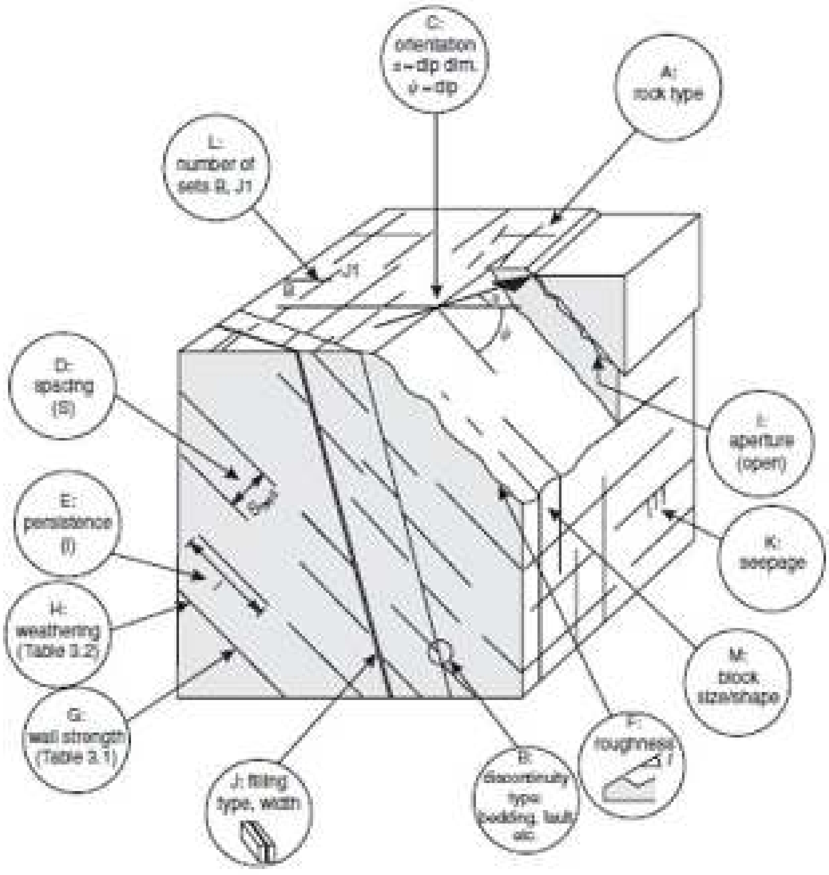

Figure 1 *Defined parameters by rock masses*

There is some key information when defining physical-mechanical parameters (Figure 2):

- slopes of the primary and secondary systems;
- crack fill;
- shear resistance along cracks;
- water permeability;
- phreatic surface.

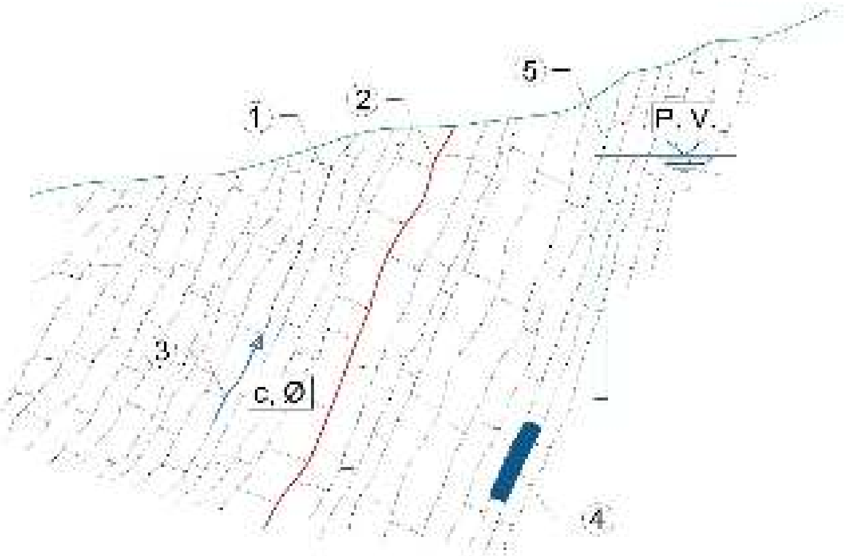

Figure 2 *Physical – mechanical parameters*

Data analysis of drilled core of the wells lead to the conclusion that is possible to state the string of factors which provide information about the state in the ground. If discontinuity is detected on the wells core, further analysis requirements, concerning orientation, thickness, fill, material characteristics which fill discontinuities are imposed. There is a sequence of applicable methods, nevertheless making inclined boreholes imposes as one of simpler and better methods (Figure 3).

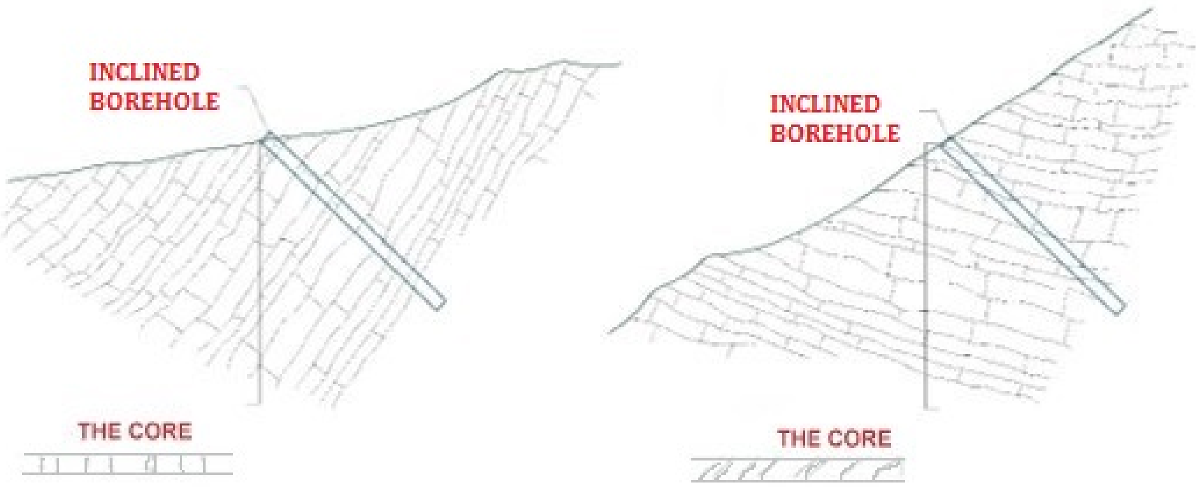

Figure 3 *Inclined borehole with core*

Information obtained by making inclined boreholes can be supplemented additionally by review and opened profile analysis if existing (Figure 4).

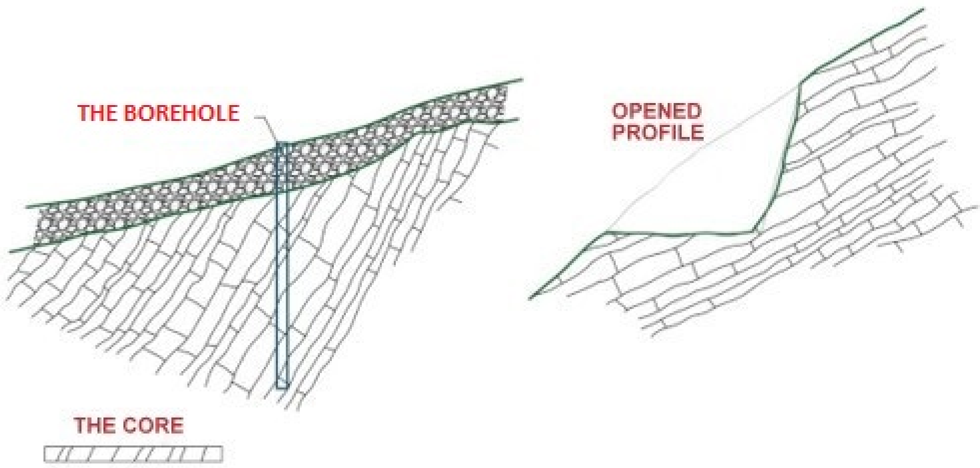

Figure 4 *The borehole and opened profile in the rock*

Discontinuities slopes, which decline is directed toward the excavation zone or snap, will enable unhindered falling of the blocks or moving of the greater rock mass, depending on the number of other factors (Figure 5).

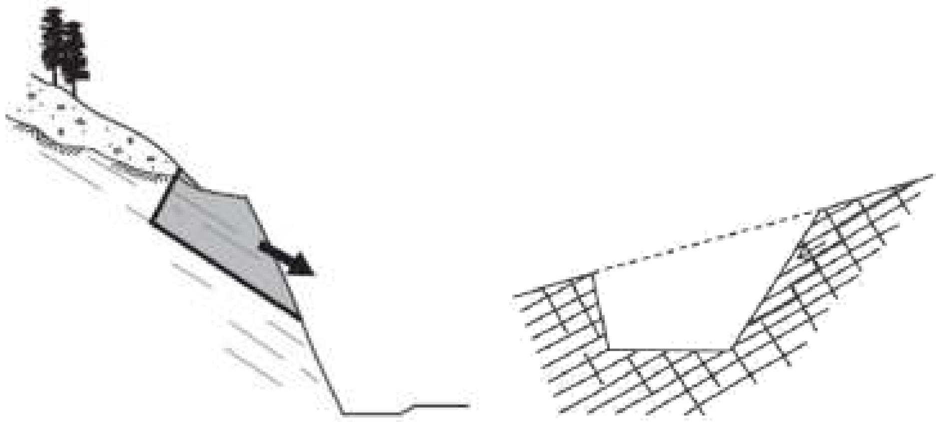

Figure 5 *Unfavorable discontinuity slope*

That is precisely the reason why notches with such discontinuity orientation should be avoided. Shear strength parameters will have major influence on stability of the blocks, and they are directly conditioned by shape and roughness of the discontinuity surface, rock waste state on the discontinuity surface, and fills. In case of the discontinuity, namely the blocks whose contact zone will enable matching, rocks stability will be less questionable. Considering that anomalies on the natural rock masses can be called discontinuities, thus the quality waste and disruption of the rocks are the most easily realized on these places. A number of factors can lead to an increase in rock solidity, primarily the environment influence, the rock massif characteristics, as well as the intact rock characteristics. Climate and chemical impacts are imposed as the most significant influences which encourage the rock waste [3:22-27].

When making the inclined boreholes the arrangement of the cracks must be taken into account. Depending on the drilling angle selection, it is possible that crack orientation will give completely wrong view about the natural state on the field. In case that the drilling axis occupies the upright position at the angle of discontinuity inclination, a clear view of their arrangement would not be obtained by drilling, there is even a possibility of they could be even neglected. Figure 6 shows the effects of the drilled core analysis. Likewise, they show, to a large extent, how high mistake level can occur if minor research scope is conducted during research works.

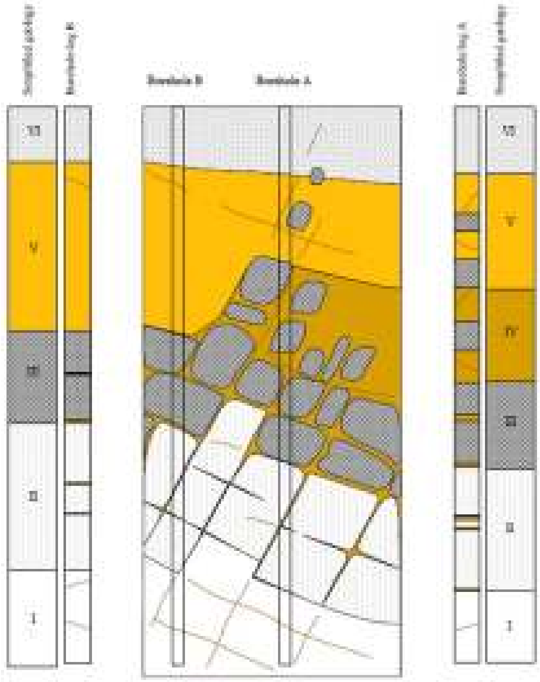

Figure 6 *Researching wells with coreing*

The water flow is an additional aggravating circumstance in case of the notch performing in the grounds with unfavorable oriented crack system. Beside flushing effects and crack fill weakening, water causes the hydrostatic pressure occurrence (Figure 7).

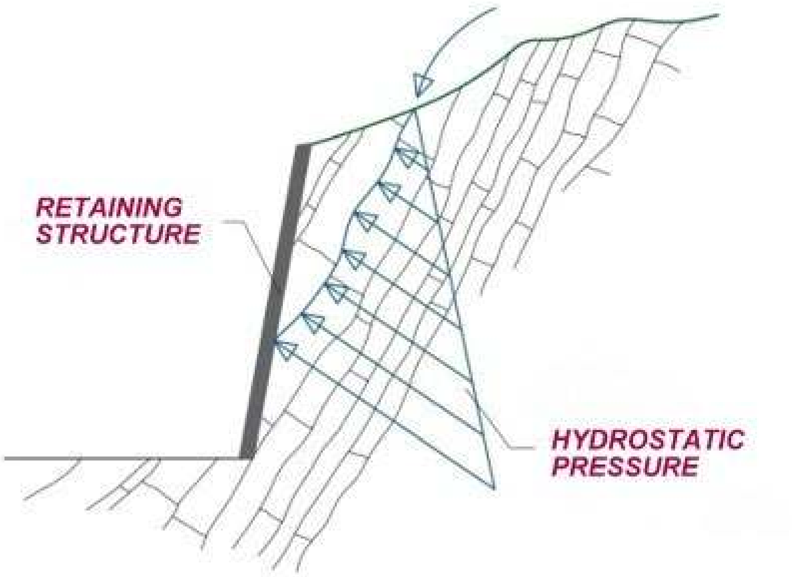

Figure 7 *Profile with unfavorable orientation of the crack systems*

It is necessary to take care of the numbers of this pressure, considering the fact that, in case of the high hydrostatic pressure presence, in fact it can be the reason of cancellation and initiation of a particular part of the rock massif. These negative impacts can be prevented by applying solutions shown on the figure 8.

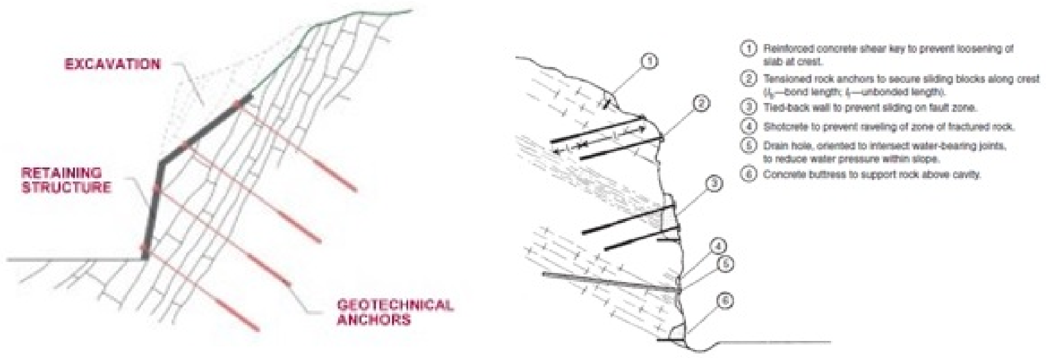

Figure 8 *Construction with geotechnical anchors*

During designing solutions, it is not uncommon to use large excavations. During excavation, natural stability is disrupted due to unloading. The material, which was previously on the excavation position was a natural counterweight that impeded the slipping and falling of blocks, therefore leading to occurrence of deep slippages and the global stability of the slope (Figure 9) [2:13-14].

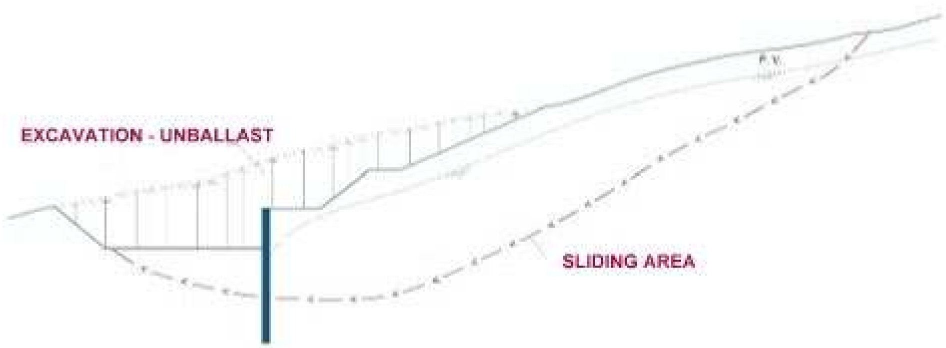

Figure 9 *Damaged slope stability*

When it comes to the span discontinuity, the significance of the research work in rock masses has been mentioned before. There are other methods that can be used to estimate the discontinuity parameters. The most favorable case is direct width discontinuity measuring when there are conditions for it. However, there is a number of other methods which can determine the widths. Discontinuity prevalence within the rock massif will have a major impact on its stability. Dense arrangement of discontinuity can cause the cohesion weakness of the rock mass, while scarce arrangement can cause clamping of the blocks. If there is a very small discontinuity disposition, it may cause the occurrence of the circular sliding plates, which in general are not characteristic of the rock massif. The discontinuity orientation significantly contributes to the stability if they are positive oriented discontinuities, while at the same time they may have completely negative influence if it is negative orientation. Positive and negative orientation of discontinuities may not be considered until the route or structure positioning is performed in relation to rock massif. Therefore, the character of excavation is defined. The basic parameters which define the orientation are stretching, inclination and inclination discontinuity direction. All three parameters are interdependent, which leads to complete definition of orientation necessary for their determination, without excluding any of them. The discontinuity roughness is one of the factors which also has direct influence on the slope stability during the rock cutting. The discontinuity width has impact on various factors, and it can be defined as distance of the discontinuity walls without considering the fill presence or fill absence. Natural processes that have occurred during both, their rock origin and existence period, have direct influence on the discontinuity occurrence. The effect of the natural influences is mostly visible on the surface zones, where the discontinuity presence is a very common occurrence. The discontinuity width directly conditions fill presence as well as the influence of the roughness between disheveled members of the rock massif. The wasting processes cause discontinuity width increase, which contributes to the stability disruption [3:52-59].

Discontinuity fill by its nature almost always has different kind in comparison to the basic rock, considering the fact that the filling material is practically secondary raw material (Figure No.10). Roughness and compressive strength are considered to be the basic deformation and strength parameters of discontinuities case without fill, while physical and mineral filling characteristics are imposed as basic parameters in case of discontinuity which has been filled. Humidity, permeability, state of consistency, shear strength and other factors are necessary during definition of the fill character. It is not uncommon to perform macroscopic observation and field testing of the mineral structure from the fill materials during research and testing. The strength can also be determined by field observation, geologist evaluation in the field, using a pocket knife, geological hammer or some other instrument. The recommendation is to use the pocket penetrometer or Schmidt's hammer [6:47-48].

Figure 10. *Fill in discontinuites*

All previously listed factors have indisputable influence on the strength and therefore on the slope stability during rocks cutting. Discontinuities characteristic will also have a major impact on water permeability, that is, conditions of the water moving in the rock. If the rock massif has very small degree of rupture, conditions of the water movement will be rather difficult, almost disabled. However, if the rocks have increased, degree of rupture, and connected crack network, the water will flow through cracks. The movement and water presence in the cracks will contribute significantly to the process of development of wasting rock, that is, to the physical and chemical changes which the intact rock to weak. The presence of the water will contribute to the decrease of physical-mechanical fill parameters in discontinuities and will contribute to the transport of eroded materials. Water often has crucial significance in the aspect of destabilization of slopes by fine-grained materials, considering it causes stress state change and attenuation of internal friction angle and cohesion of natural material. Determination of the physical-mechanical characteristics parameters of the rock massif implies a number of field and laboratory experiments, which must have a high level of connection between each other in order to describe their natural state more adequately. Capital value of the investment, exploitation period and various other effects will directly influence on the scope of research works. For an adequate introduction of the state in the field, it is necessary to define optimal number of the wells, in order to be able to present with certainly geological view of macro and micro location which is a subject of the design. During works realization, it is not uncommon to perform research wells just in the flange of the future snap. The problem occurs when they are the only wells performed for the snap design, which is the case with an example from the practice which will be processed further in the text. Insufficient knowledge of the geological conditions right on the slope in the later stages of the project realization may complicate the solution multiple and increase the costs. The studies testify that value of research works in comparison with the total investment value about 0,1 – 4 % of the total quantity of funds necessary for project realization [1: 3-4]. For many years, it is endeavoring to somehow define the quantity of the research works for different structure types. The quality of the drilled core, percent of the obtained core, quantity of the cracks caused by drilling and a number of other factors will influence on the final result, and that is categorization of the rock massif. Contemporary practice knows and uses a number of different accesses, in the terms of ground, as well as in terms of laboratory classification. Each classification depends on quality and scope of performed works. One of the key factors in research works is definition of the research stages. Every design stage requires certain degree of research works in terms of the ambit thus the recommendation is to perform research works in several stages. In case of road design, less than 5 research works on one hectare is considered to be low research degree [1: 12-13]. Geotechnical experts work on the development of the research phases, for a long period of time, which depend on various factors, such as structure size, structure kind, ground conditions, capital value of the project and a number of other factors. The depth of the research wells is in direct relation with research quality. In particularly depends on the kind and size of the structure, and is directly proportional to the quality of the designed solution. Likewise, quantity and size of the research sample have a great influence on ground state knowledge. The size of the ground particles directly influences on the needed quantity of the research sample, which is necessary for quality implementation of the laboratory research. The percentage of conducted laboratory, reflects on quality of the conducted works. Less than 10 % of tested samples observed in comparison to total quantity of delivered samples in laboratory is considered as a low degree of the conducted research [1: 12-13]. Correct discontinuity definition will determine the designer on reliable calculation model of the rock massif in stability capacity for the given conditions.

3. PROJECT SOLUTIONS AND RESULTING PROBLEMS THROUGH PROJECT REALIZATION

The subject of the work analysis is designed road in the notch during which performance the landslide startup occurred. Contractor approached to the work performing with second, new project solution. The cause of the problem during conducting is inadequate performance of research works in the initial design stages. During the initial research stage in period 2009-2010, first research works were done for the purpose of the main project. The main characteristic of this research works is that they have been conducted entirely on the slope base which should be cut. There were 7 wells, carried out on the field, depth 6-8 m, and they could not give an adequate data with which design could be commenced. Additional research works conducted during 2015 were necessary, considering that during initial work stages on the excavation and slope arranging, extremely large deviation was noted in comparison to adopted parameters values, necessary for making the main project. The additional research works implied performing of 9 research wells with depth of 10 – 25 m, which included research works on the slope above planned route zone, in order to gain insight into ground characteristics. Based on works from 2015, several stages of the implementation project were conducted. In addition, several project variants of slope rehabilitation above the route were conducted as well. Rehabilitation projects were necessary and inevitable, considering that during the project realization, cutting and removing of the sliding flange were conducted, which caused movement of the ground layers in the upper slope zones.

Project for implementation, and later for the slope rehabilitation implied several modifications. At first, the road was conducted according to the first project, which caused the landslide to start, after which the second project was prepared. With this project, the slope rehabilitation was treated, as well as the rest of the slope where the vertical notch in the ground and making the supporting wall with micro piles and geotechnical anchors were provided. During the execution of the works, major changes in the quality of the rock mass were observed at the total length of the cut. Geological conditions in the area of the supporting structure were significantly worse than anticipated and presented to the previous geotechnical studies, which lead to the second project. Due to the above-mentioned issues, development of the third version of the project was launched, on the basis of which the supporting structure was derived (Figure 11).

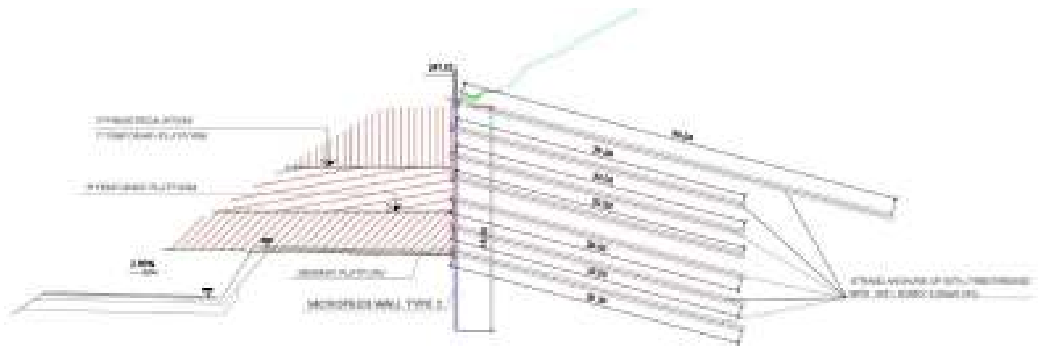

Figure 11. *Performed supporting structure*

After finishing work on the supporting structure, the control works on the field were done behind the performed structure, and it was identified that geological soils deteriorated drastically in quality, which caused doubt in terms of the structure's durability and stability. The control stability and capacity calculations were done, and it was established that ground in the hinterland of the support structure was in the conditional equilibrium, and that it was necessary to apply additional measures in order to increase the sliding stability factor, and thus increase structure durability and stability, as well as the ground behind it (Figure 12).

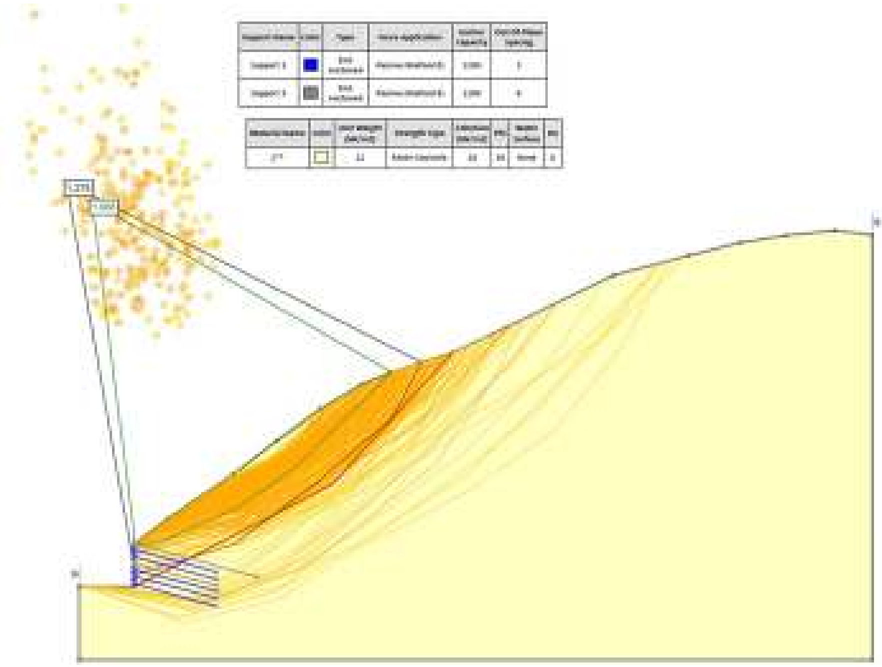

Figure 12. *Slope stability calculation*

A project for slope stabilization behind performed structure commenced, which caused unloading and slope arranging above the structure and the road, in order to decrease an influence on geotechnical anchors, and thus contribute to the slope stability and its structure which ensured the route. During design process, a number of stability analyses were done, particular and a whole as well, berm individually, and several berms in combination as well (Figure 13).

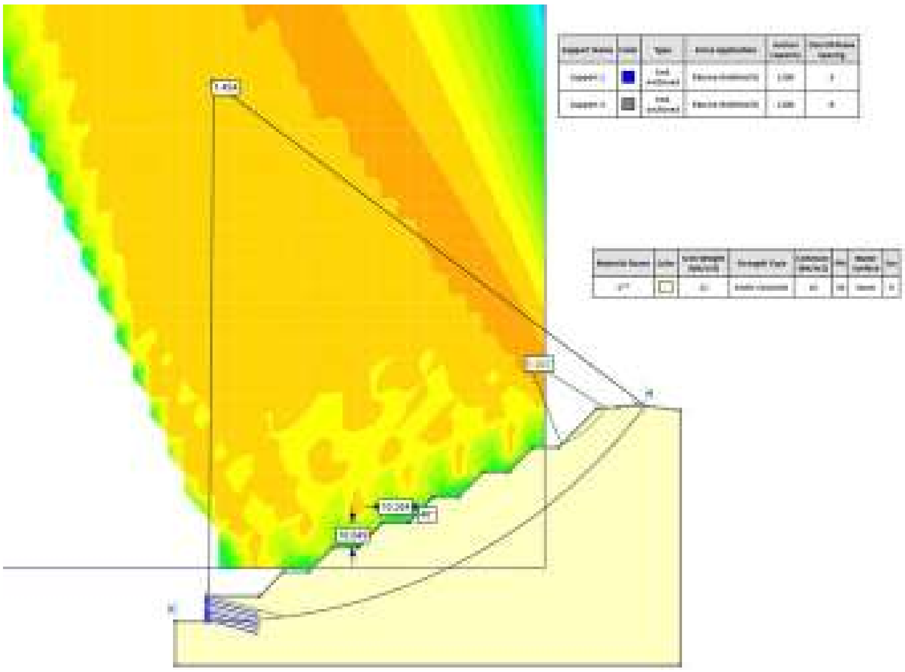

Figure 13. *Slope stability analysis after unloading*

Predicted slope arranging in the listed design phase implied making of 6 sections with slope incline 1:1,2 in combination with SN anchors (Ø 25 mm, long 9 m, 12 m and 15 m) and composite load-bearing network (Figure 14) [4].

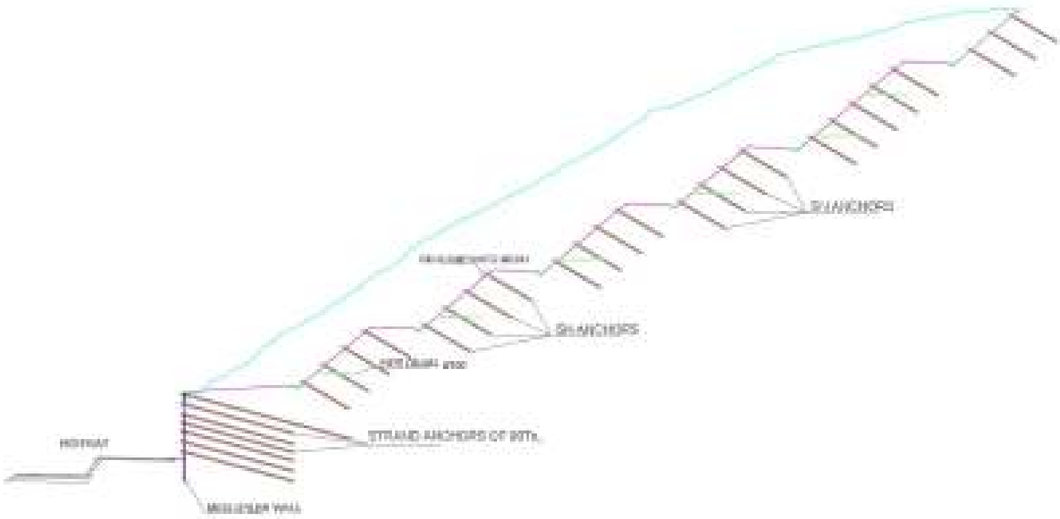

Figure 14. *Slope unloading on sections*

During 2019, works commenced according to the project, and during initial relief phases, a large number of slip-prone zones were indicated. Also, it turned out that designed slopes could not be kept on the project predicted slope long enough to bring about stabilization activities, which lead to project changes.

The realization of the design stabilization solution provided an insight into the condition of the rock mass, pointed to major changes in the composition of the rock mass, changes in the material of the cracks filling, and a very high degree of degradation of the green shale, which is largely widespread in the subject location. All above mentioned, initiated development of additional investigative works that were carried out during October and November 2019, and on that occasion, 6 exploratory 30-50 m deep wells were constructed and two inclinometers were installed to monitor the occurrence of any additional slope movement [6:3-4]. What is particularly significant is that the realization of these exploratory works was carried out on the derived berms of the slope in question and thus contributed to a better knowledge of geological conditions of the site. In terms of geological engineering characteristics, two groups of materials were identified:

- a group of solid rock formations comprising of lower crystallinity shales comprising green shales;
- a group of bound or weakly bound rocks, which include diluvial formations and colluvial masses [6:12-13].

4. CONCLUSION

Based on all previously listed data, it is concluded that the collection of existing data and conducting of research works represent one of the basic steps in the design process. Quality of research works is of major importance, because they directly condition the quality of the data of ground parameters. A lack of research works and inadequate determined physical – mechanical ground parameters will inevitably lead to the occurrences which have been described in the work.

All above mentioned is the result and consequence of inadequate risk analysis from hazardous phenomena. That is the case with landslides and slips on the roads. The design approach should reduce these occurrences to the minimum risk level, at the time of construction and during the operation on the road as well. Thus, it can be concluded with great certainty, that the influences leading to a hazardous phenomenon will always be less than the resistance of the occurrence of that hazard, during the life of the structure. Such approach would require a reassessment of the reliability of all parameters underlying calculation models and the reliability of the traffic in question. The reliability of the road defined in this way should be the basis for obtain the same. Design solutions would be based on such analyses, in order to meet the defined reliability based on the analysis of the risk analysis of hazardous events during the existence of the road.

LITERATURE

[1] Burt Look, Handbook of geotechnical investigation and design tables, pp. 1-15.

[2] Derek H. Cornforth, Landslides in Practice, Investigation, Analysis and Remedial/Preventive Options in Soil, pp. 14-15.

[3] Duncan C. Wyllie and Christopher W. Mah, Rock slope engineering, civil and minning 4th edition, 2005, pp. 22-59.

[4] Project documentation

[5] Sanja Dugonjić Jovančević, Inženjerska mehanika stijena - skripta, Građevinski fakultet sveučilišta u Rijeci, pp. 47-48.

[6] Study – Aditional geotechnical field investigation works and laboratory tests, Landslide at Cut No. 4, km 878+775 – 879+100, Predejane, 2019. pp. 3-13