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ZAŠTITA GRAĐEVNE JAME ZAGATNOM STIJENKOM I SIDRIMA

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Sažetak:

U radu je definirana zaštita građevne jame kako bi se ostvarili uvjeti za planirano izvođenje konstrukcije objekta i spriječilo slijeganje okolnog tla na kojemu je temeljen objekt. Osnovni nosivi element građevne jame u tlu je podgradna konstrukcija, koja u velikoj mjere ovisi i o geološkim značajkama tla. S obzirom na planiranu nadogradnju objekta i utjecaj postojećeg objekta uvijek je važno provest i zaštitu građevne jame. Potporna konstrukcija zaštite građevne jame je izračunata ručnim postupkom prema standardima Eurocode-a 7 i programskim paketom GEO 5, koji omogućava provjera stabilnosti zagatne stijenke, te daje moment i sile koje djeluju na stijenku.

Ključne riječi:

građevna jama, zagatna stijenka, sidra, Eurocode 7, Geo 5

PROTECTION OF CONSTRUCTION PIT BY RETAINING WALL AND ANCHORS

Summary:

This written work defines protection of the construction in order to create conditions for planned execution of construction of the building and prevent subsidence of the surrounding soil on which object is based. The basic load-bearing element of the construction pit in the ground is a substructure, which largely depends on the geological features of the soil. Considering to upgrade of object and influence of the existing object, it is necessary to do protection of the construction pit. The supporting structure is calculated using the manual procedure according to Eurocode standards 7 and software GEO5, which allows testing of retaining wall stability and gives moments and forces acting on the wall.

Key words:

construction pit, retaining wall, anchor, Eurocode 7, Geo 5

1. INTRODUCTION

A space in which foundation work is carried out is called a construction pit. This space must be safe for work and accessible to people and machines. Selection of the best solution for execution of a construction pit depends on the structure, characteristics of the terrain, presence of water in the soil or groundwater and on other circumstances.

Construction pits can be performed in a way that part of the excavation is made with a slope, and part is supported by some kind of support. Terzaghi and Peck (1967) defined the threshold between shallow and deep excavations as a depth of 6.0 meters. Excavations deeper than 6.0 m require support work for safety of people and material resources.

Protection of a pit excavation must prevent any kind of intrusion of water into the free space of the excavation and ensure stability of excavation sides. When carrying out excavation for any purpose, the bottom level can be kept above the groundwater level, but it can also be lowered below the groundwater level. If the excavated space should remain free of water and the bottom of the excavation extends below the groundwater level, then the protection structure must be watertight and in this case hydrostatic pressure acts on it. In terms of watertightness, it can be concluded that there can be different ways and forms of complexity of construction pit protection work as well as different possible forms of bearing structures to ensure stability of excavation surfaces.

Construction pit execution method depends on a number of imposed construction conditions:

- Characteristics of the soil material in which construction takes place
- Position of foundation surface in relation to the highest groundwater level
- Depth of foundation under the ground surface
- Working conditions (available space)
- Distances from adjacent structures

Two problems need to be solved during dimensioning and execution:

- to make stable sides of construction pit
- to solve the problem of groundwater if the foundation level is below the groundwater level

Selecting protection of a construction pit working area is regularly the result of a compromise in assessing technical advantages and disadvantages of possible solutions, but also the price. There are a number of methods to protect a construction pit. The following types of protection are usually used in practice:

- shotcrete lining secured by rock bolts
- driven steel sections of Larssen sheet piles
- protection made of drilled steel profiles with concrete fill, locally known as the "Berlin wall"
- drilled piles with or without spacing
- segmented walls - closed walls - diaphragms

Construction pit is a space that must be dry and since it is almost always a case of a hole in the ground, water cannot gravitationally flow out of it. For this reason, it is necessary to ensure drainage of construction pit by certain works. In the protection against external and own rainwater, it is necessary to adjust the level of safety depending on a number of factors such as:

- The rainfall regime in the of construction site area
- Season
- Groundwater level
- Configuration of the surrounding terrain and the like

In defining the structure of protection of this construction pit, it is necessary to create conditions for construction of the building structure and prevent subsidence of the surrounding ground on which the neighboring structure is founded. The design elements specify the construction of two underground levels, and the immediate vicinity of the adjacent structure (addition of the existing one) requires protection of the construction pit with vertical deleveling. The maximum excavation depth is 8.00 m from the foundation level of the existing building.

2. GEOLOGICAL CONDITIONS FOR CONSTRUCTION OF THE CONSTRUCTION PIT

At the subject site, the terrain is made of flysch sediments of the Middle to Upper Eocene (E2,3) as parent rocks, covered in some places with Quaternary silty-sandy deposits, clayey to varying degrees. Flysch deposits consist of clayey marl of brown to gray-brown color and marl, gray in color with intercalations of limestone sandstones. In hydrogeological terms, it can be noted that the silty-sandy deposits have intergranular porosity and precipitation water is filtered through them relatively fast to less permeable deposits of flysch. Four exploratory boreholes were carried out 8-12m in depth. After geological identification of the core, it was established that the ground on which building of the construction pit is planned consists of several different lithological members.

A layer represented by a mixture of silty sand, clay and fragments of rock (limestone and sandstone), brown in color, extends under the surface layer of about 0.20 m thick humus. The thickness of this layer is 0.8 - 1.30 m. In some places, this layer is more strongly clayed and weakly compacted according to the field assessment.

A layer of silty clay, of low plasticity, also occurs in some of the boreholes. This layer contains sharp-edged fragments of rock (limestone, sandstone and marl)

At a depth of 0.40 to 2.20 m there is a marly clay to clayey marl layer, brown to gray-brown in color. This layer contains fine-grained, sharp-edged fragments of rock (limestone and sandstone). The thickness of this layer is not uniform and ranges from 2.0 to 6.50 m.

Below this layer there is fragmented marl rock, gray in color, with intercalations of sandstone.

It is important to emphasize that there is a possibility of degradation and swelling in case of longer exposure to atmospheric agents.

Groundwater was not registered during drilling. For a precise determination of the static water level that is directly dependent on rainfall intensity, or groundwater levels on the subject location, it is necessary to perform longer temporal monitoring in piezometers.

3. GEOSTATIC CALCULATIONS

3.1. Geostatic stability analysis of construction pit wall

Calculations of stability and deformations of the construction pit protection solution with cofferdam and anchors were carried out by geostatic analyses. After that, dimensioning of anchors was performed. The structural analysis of the structure was carried out in the following steps:

- selection of characteristic values of material parameters
- selection of the depth of driving
- dimensioning of protection structure elements
- calculation of active pressures and equivalent forces

Since stability of the construction wall is not satisfactory without appropriate support structures, stability calculation was carried out using the SHEETING CHECK program, with placed cofferdam of a depth of 6.0 m and anchors with working force of 400 kN.

SHEETING CHECK allows us to check stability of the wall, and gives moments and forces acting on the wall.

Characteristic layers of soil have these geotechnical characteristics:

- Layer 1 - CLAYγ = 20.0 kN/m3

  φ = 26 °

  c = 6.0 kN/m2

  ν = 0.2

  d = 1.0 m

- Layer 2 - MARLγ = 20.0 kN/m3

  φ = 29 °

  c = 20.0 kN/m2

  ν = 0.2

  d = 1.5 m

- Layer 3 - ROCKγ = 23.0 kN/m3

$\varphi = 0°$

c = 0.0 kN/m2

d = 5.5 m

The calculation was conducted according to DA1, Eurocode 7, with appropriate coefficients according to combinations 1 and 2. Active pressure and working forces of anchors act behind the cofferdam and passive pressure of soil acts in front of the cofferdam.

The entire system of construction pit is loaded with constant and movable load from the structure. Calculations in the program GEO5 take into account all active and passive forces and loads. The obtained structural calculation results are shown on the following figures:

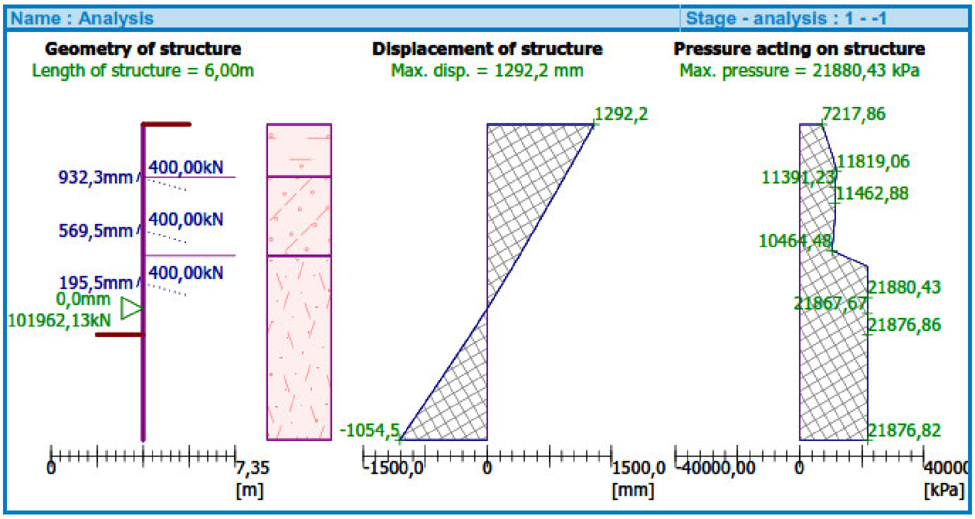

Figure 1. Obtained values of displacements and pressures on the structure

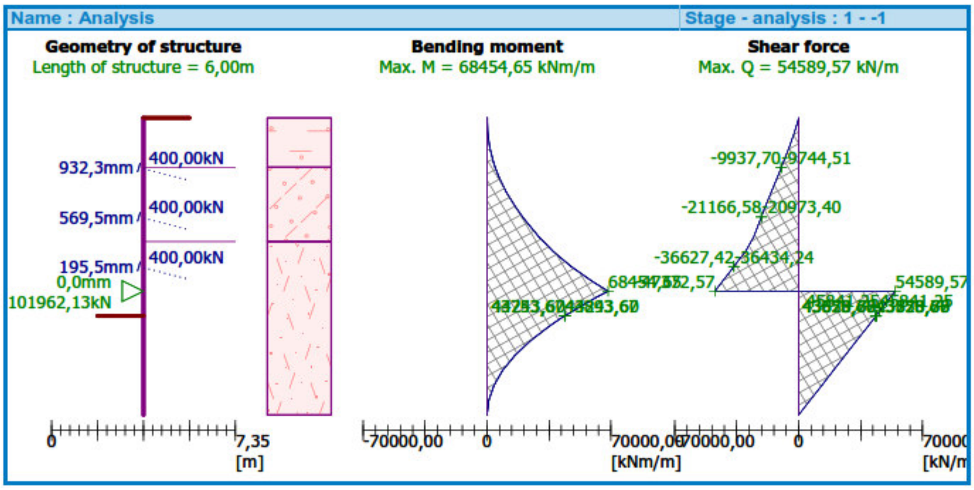

Figure 2. Obtained values of force and moment

The dimensioned construction pit with cofferdam and anchors is calculated with regard to all existing loads and pressures from the ground. The length of the sheet-pile wall is 6.0 m, thickness 0.9 m. It is made of concrete C25/30 and is reinforced with reinforcement B500. The layers of soil behind the wall are marly clay, marl and rock with already specified soil characteristics.

3.2. Determination of cofferdam driving depth

The cofferdam driving depth is determined by using the nomogram from Figure 3.

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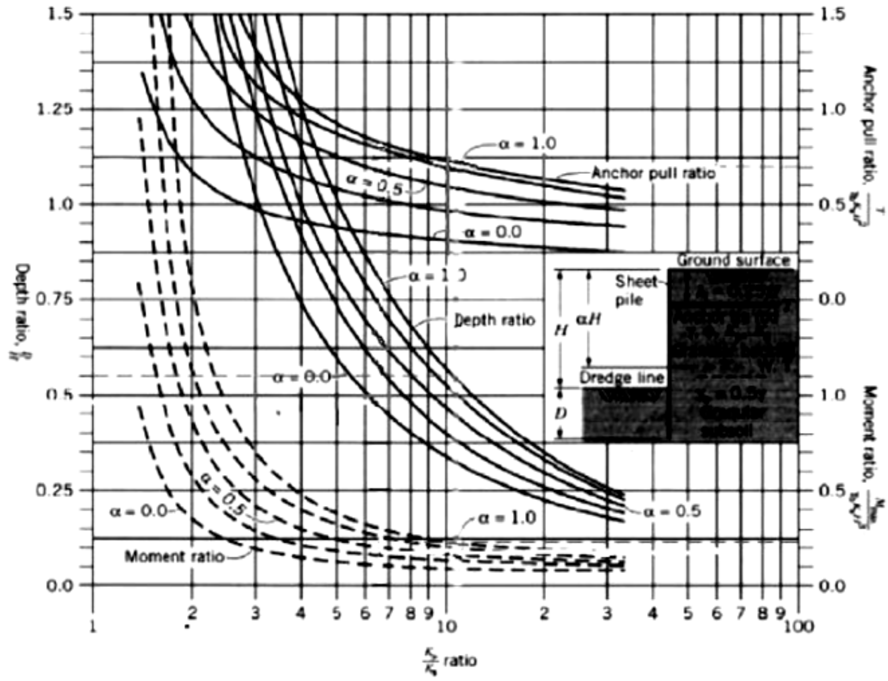

Figure 3. Nomogram for determination of driving depth

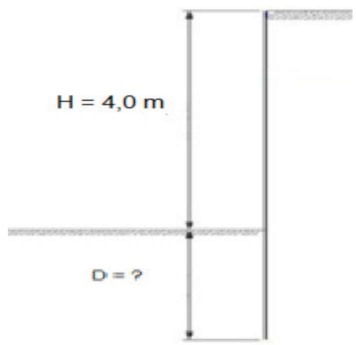

Figure 4. Presumed driving depth

The cofferdam driving depth is determined from the nomogram:

α = Hw/H = 4.0/6.0 = 0.666; ka = 0.39; kp = 2.56

D/H = 0.25 → D = 0.25 · 6.0 = 1.5 m (adopted 2.0 m)

The adopted driving depth is 2.0 m. Calculation of geotechnical anchors is carried out according to the following expressions:

$$\frac{M_{max}}{\gamma * K_a * H_3} = 0.4 \qquad (1)$$

$M_{max} = \gamma * K_a * H_3$ = 0.4* 20*0. 39*6.03 = 673.92 kNm

$$\frac{T}{\gamma * K * H_3} = 0.24 \qquad (2)$$

$T = \gamma * K_a * H_3$ = 0.24*20*0.39*6.03 = 404.35kN →adopted required anchor force T = 400kN

Three anchors are placed at a distance of 1.0 m at the height of the sheet-pile wall. Lengths of the anchors are 20.0 m, 17.5 m and 15.0 m, placed at the depth of 1.0 m, 2.0 m and 3.0 m, respectively. The length of the anchoring section is 3.0, and they are placed at an angle of 15˚. Their diameter is 40.0 mm, modulus of elasticity E = 210000 MPa, and working force of each anchor is 400 kN. Supports are placed up to the depth of 3.5 m.

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The overall stability check is satisfied. The calculation was conducted with working force of anchors of 400 kN, and the maximum allowable forces are greater, which is satisfactory. The minimum allowable force Fmax = 1634.49 kN is greater than F = 400 kN and the condition is satisfied.

4. CONCLUSION

The paper presents the calculation and construction method of a supporting structure of construction pit wall carried out by protection with anchors. Although construction pit is a temporary structure that has the primary purpose of allowing construction of a foundation or construction of an underground structure for which it is designed, its importance must not be underestimated because the consequences can be catastrophic. In case when several unfavorable conditions coincide, such as large excavation depth, soil of low strength, proximity to neighboring structures, the construction pit becomes a geotechnical structure for which it is necessary to develop a design like for any other structure.

The vicinity of the neighboring structure in this case is not negligible because an addition to the existing structure is performed. The soil found on the subject location is also not favorable since it is a layer of evenly bedded clay, followed by a layer of marl.

The wall of construction pit is made using the method of cofferdam with anchors. The geotechnical anchors used in this project are anchored at an angle of 15º, with total length of 15 m, 17.5 m, 20 m, with length of anchoring section of 3.0 m. The working force in the anchor realized by pre-stressing is 400 kN.

The dimensions of structural elements are determined on the basis of internal forces obtained by the program package GEO5, and the Eurocodes principles used in the calculation proved the stability of all structural elements in all construction stages.

The stability of the sheet-pile wall was also determined by using the nomogram, where the driving depth of the sheet-pile wall had to be assumed as the initial condition. In the stability calculation, values of maximum bending moments and also the force required in geotechnical anchors were also obtained. The sheet-pile wall was performed with reinforcement using pre-stressed anchors, specifically with 3 anchors per section height spaced at 1.0 m.

An overview of possible construction pit stability solutions is presented using the computer program GEO5. In addition to soil characteristics, calculated driving depth, selection of the protection method, anchors, are included in the analysis of this program package. In addition to calculating and assessing stability of the solution, the solution of geotechnical anchors determined by the calculation method is also confirmed/proposed.

5. REFERENCES

[1] Nonveiller, E. Mehanika tla i temeljenje građevina (Soil Mechanics and Foundation Engineering of Structures), Školska knjiga Zagreb,1979.

[2] Prskalo, M. Zbirka riješenih zadataka iz mehanike tla, s primjenom Eurokoda 7 (Collection of solved problems in soil mechanics with application of EuroCode 7), University of Mostar, 2015.

[3] Selimović, M. Mehanika tla i temeljenje, dio I Mehanika tla (Soil Mechanics and Foundation Engineering, Part I Soil Mechanics), Mostar, 2000.

[4] Selimović, M. Mehanika tla i temeljenje, dio II Mehanika tla (Soil Mechanics and Foundation Engineering, Part II Soil Mechanics), Mostar, 2000.

[5] Stević, M. Mehanika tla i stijena (Soil and Rock Mechanics), Faculty of Mining and Geology, Tuzla, 1991.

[6] https://www.grad.unizg.hr/_download/repository/3_predavanje%5B1%5D.pdf

[7] http://gf.sve-mo.ba/e-zbornik/e_zbornik_01_06.pdf

[8] http://gf.sve-mo.ba/e-zbornik/e_zbornik_04_07.pdf

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PRISTUP ZA ZAŠTITU KOSINA NA PRILAZNOM PUTU ZA LUČNU BRANU „SVETA PETKA“ NA RECI TRESKI, REPUBLIKA MAKEDONIJA

Sažetak:

Poznato je da je problem zaštite kosina u stenskim masama izuzetno težak, jer zahteva kombinovanje geoloških i geotehničkih podataka, primenu odgovarajućih projektnih pristupa i adekvatnih zaštitnih mera u analiziranom regionu. U radu je prikazana metodologija razrađena na osnovu rezultata iz faza istraživanja, projektovanja i izvođenja radova na prilaznom putu za lučnu branu "Sveta Petka" na r. Treski u R. Makedoniji. Date su primenjene metode za analizu stabilnosti zasnovane na teoriji verovatnoće, čime je formirana osnova za projektovanje zaštitnih mera. Na osnovu projektne i benefit-cost analize, definisano je nekoliko tipova zaštita kosina. Posebna pažnja posvećena je benefit-cost analizi sa aspekta tolerantnog nivoa rizika. Sakupljena iskustva mogu poslužiti kao dobar primer pri radu na sličnim problemima u praksi.

Ključne riječi:

zaštita kosina, teorije verovatnoće, benefit-cost analiza, tolerantno nivo rizika.

AN APPROACH FOR SLOPE PROTECTION ON THE ACCES ROAD TO ARCH DAM „SVETA PETKA“ ON RIVER TRESKA, REPUBLIC OF MACEDONIA

Summary:

Slope protection of rock cuts is extremely complex task, where it is necessary to combine geological and geotechnical data, use appropriate design methods and implement protection measures suitable for the specific area of interest. The approach presented in this paper is based on results from phases of investigation, design and performing of slope protection measures for the access road for the arch dam "Sveta Petka" on the river Treska in Republic of Macedonia. Analytical methods for stability analyses that are based on probabilistic theory were used in the design of support measures. Based on design and benefit-cost analyses, several slope protections schemes are defined. The methodology of cost estimation for slope protection types is explained, combined with proposals in definition of tolerable level of risks based on collected experiences during construction. The experiences can serve as a good basis for some future similar projects.

Key words:

slope protection, probabilistic theory, benefit-cost analysis, tolerable level of risk.

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1. GENERAL

Well known fact is that slope protection problem in hard rock is extremely complex task, that requires application of adequate methodology of analyses. It can be noted in the beggining that it is always necessary to combine geological and geotechnical data, followed by application of appropriate design methods, in order to implement protection measures suitable for the specific area of interest ([1], [2], [7], [8]). Applied protection measures need to fulfill both technical and economical criteria and to insure acceptable (tolerable) level of risk during operational phase [5]. From this reasons, all past experiences and case histories are more than welcomed for future scientific and practical analyses. Having this in mind, methodology of working during the design and construction of slope protection measures for the access road for the arch dam "Sveta Petka" on river Treska in Republic of Macedonia, situated in the vicinity of the capital Skopje, about 20 km SW from city (Figure 1), is presented below.

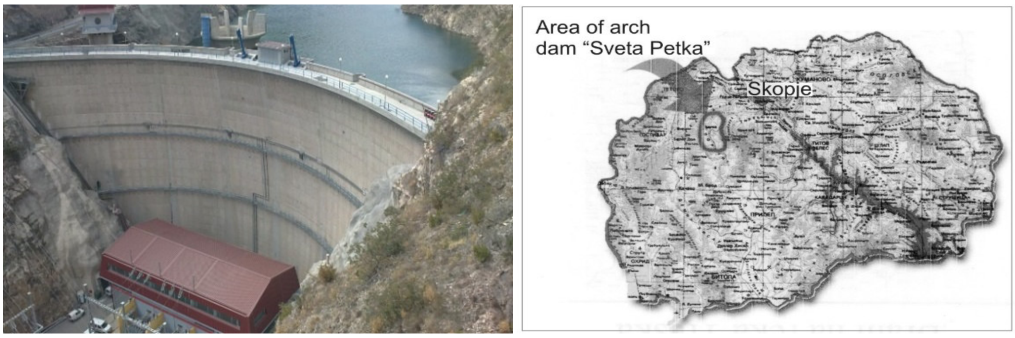

Figure 1. a) Arch dam "Sveta Petka"; b) Position of dam in Republic of Macedonia

The dam has following main elements

- Height of the dam 64 m
- Length in the crownm118 m
- Dam volume (concrete part) 30 689 m^3
- Volume of reservoir area 9,10 x 106m^3

The access road to the dam area with a lentgh of about 11 km is constructed in complex morphological and geological conditions, with slope cuts of extreme heights and gradients, that influence often occurences of talus (scree) zones (Figure 2).

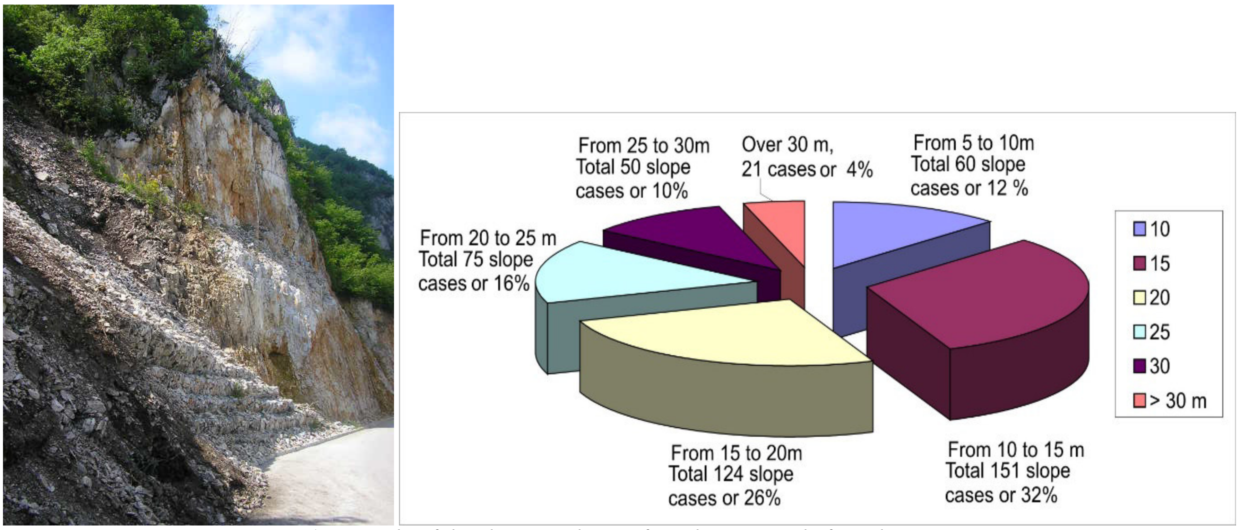

Figure 2. a) Example of the slope conditions for talus section before slope protection;

b) Presentation of slope heights along the access road

The area along the access road route is composed mainly of foliated or masive Rifej-Cambrian marbles, jointed and tectonically affected. There are local occurences of caves and other karst phenomena, followed by talus deposits with quaternary age.

As a result of such geological and geomorphological conditions, during the construction and exploitation phase, occurences of rockfalls and local slides were recorded very often. Unfortunately, in some of the cases there had been injuries. From this reasons, the investor, Public Electicity Entrprise „ELEM“ from Skopje, went in the procedure of preparation of slope protection design documentation. Main design criteria was to raise the safety level of the traffic and working conditions, and to minimise the costs for maintenance of the road. Having this in mind, this article presents basic elements for applied slope protection measures, while the approach in the design is presented elsewhere ([9]-[11]).

2. METHODOLOGY FOR DESIGN OF SLOPE PROTECTION MEASURES

Methodology of analyses during design process was based on the fact that the access road was already constructed without special protective measures. So, most information is collected from the exposed cut slope faces that give excellent information on current geological conditions. Back-analysis of past failures were also used in order to insure most reliable parameters for prognosis of future modes of failure, estimation of shear strength along joints, etc. As a first step in the evaluation, an inventory of slopes on the base of formerly executed geological field works, existing detailed geological maps and field observation was used. An important step in analyses were special rockfall risk analyses in order to predict rockfall size, block trajectories and kinetic energy from rock falls. Results from such analyses of rock fall trajectories and application of Rockfall Hazard Rating System (RHRS) [12] are presented in Figure 3 and Figure 4.

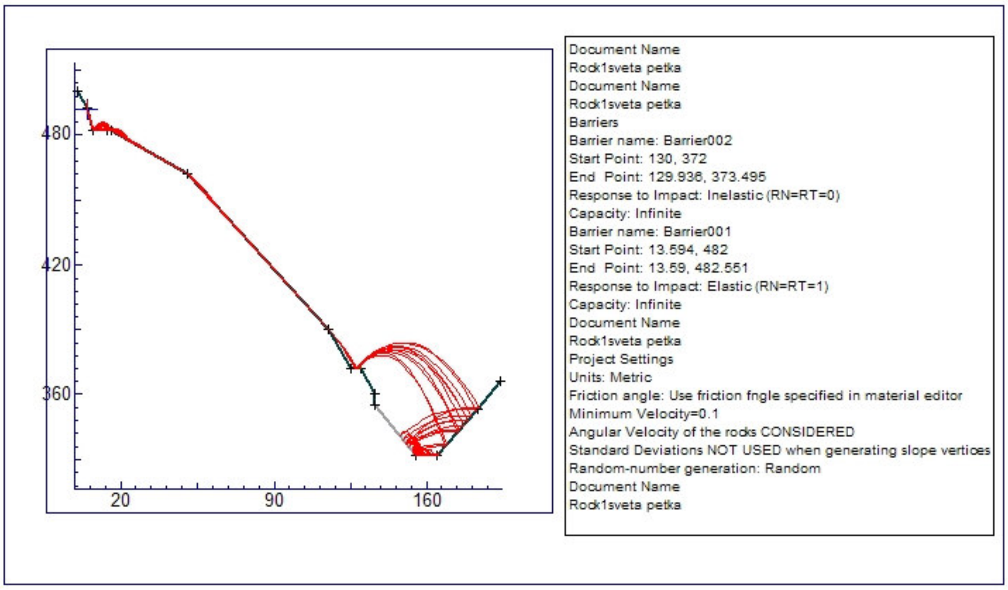

Figure 3. One case of rockfall hazard analyses by using sofware ROCFALL [10], (Note: The upper left section is the zone of the road, while the lower right section is the working zone for excavations for the arch dam foundations)

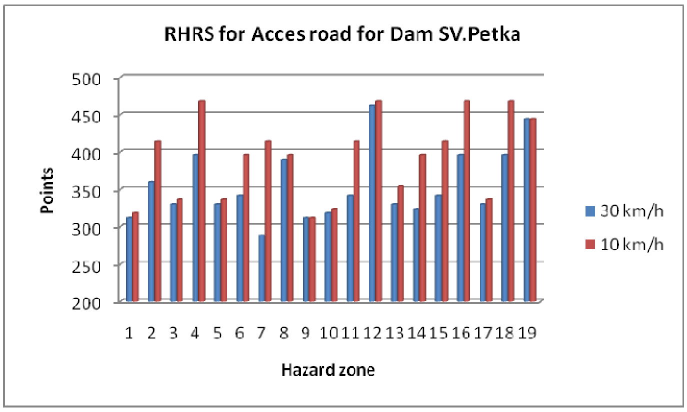

Figure 4. Graph of total scores from RHRS for traffic speeds of 30 and 10 km/h [11]

Based upon these concepts, in addition, during the design, detailed slope stability analyses were prepared, using following aproaches:

- Analyses of possible kinematic failure modes.

- Statistical analyses in order to define probability distribution functions for all input geotechnical parameters.
- Defining of Safety Factor (SF) with limit equilibrium methods applicable for soils (talus zones), plane or wedge failure (for jointed hard rock masses).
- Defining probability of failure, which are expressed as probability distributions of SF.
- Numerical analyses with Finite Element Method for some cases.

Typical input structural and geotechnical parameters are assumed from the well known empirical methods, direct tests in large scale for the zone of arch dam, and back analyses. Some examples are presented in Figure 5 and Figure 6.

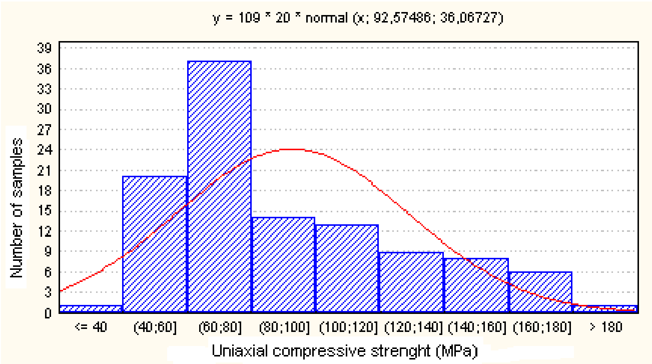

Figure 5. Diagram presenting statictical analyses of results from Uniaxial Compresssive Strength [9]

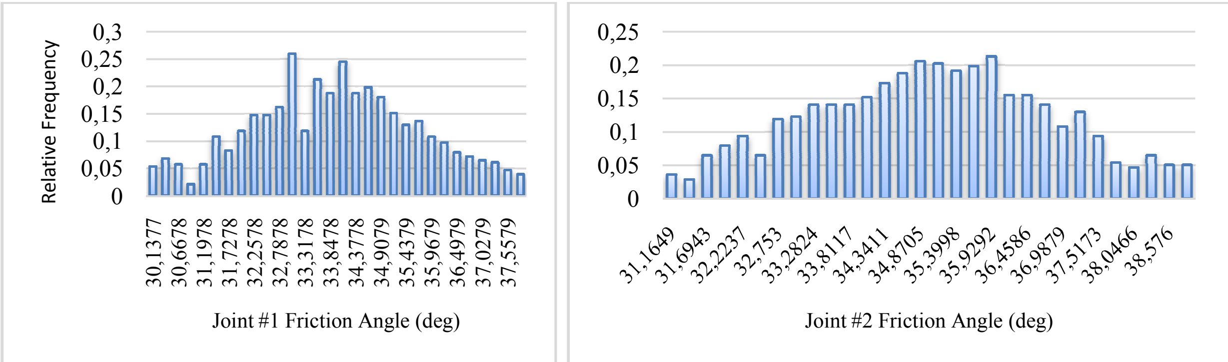

Figure 6. Statictical analyses of shear strentgh along joints forming kinematic mode for wedge failure analyses using software SWEDGE (case for one of analysed slopes)

In definition of SF the probabilistic technique for analyses is used, not only to define their mean value, but also Probability of Failure (PF). Only some data for a slope where wedge failure was expected along joints with friction angles defined in Figure 6 (see Table 1) is presented here.

Table 1. Some geometric and input data for one case of wedge failure analyses using software SWEDGE

Data about analysis type and loading cases	Current Wedge Data - Mean Wedge
Probabilistic analyses	Wedge height(on slope) =23 m
Sampling method=Monte Carlo	Wedge width(on upper face) =10.3005 m
Number of samples=1000	Wedge volume=1618.94 m^3
Number of valid wedges=1000	Wedge weight=4241.63 tones
Water Pressure Data: Percent Filled Fissures=30%	Wedge area (slope)=655.483 m^2
Seismic Data: Seismic coefficient=0.1	Wedge area (upper face)=268.177 m^2

As a results of series of analyses, the output is definition of mean value of SF and value of PF for cases of slopes without or with some applied protection measures. The definition of PF is explained by Hoek [6], and it comes from defined statistical distribution and relative frequency of SF. For a presented wedge in Table 1, examples are given in Figure 7, Figure 8 and Figure 9.

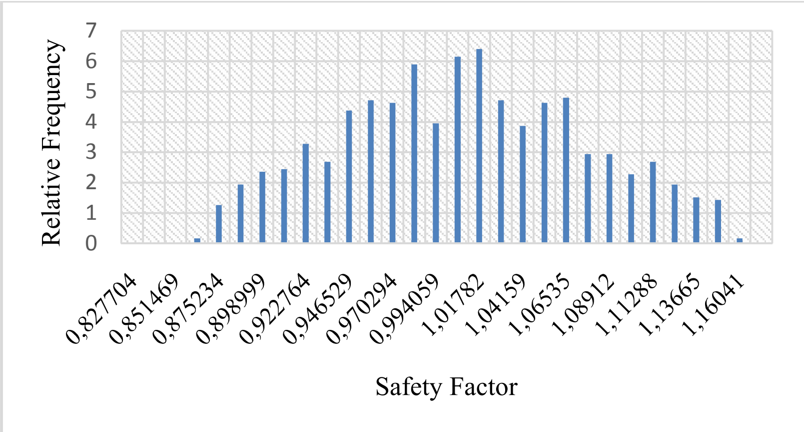

Figure 7. Output from analyses of one slope without protection with mean value of SF=1.008 and PF=44.8%

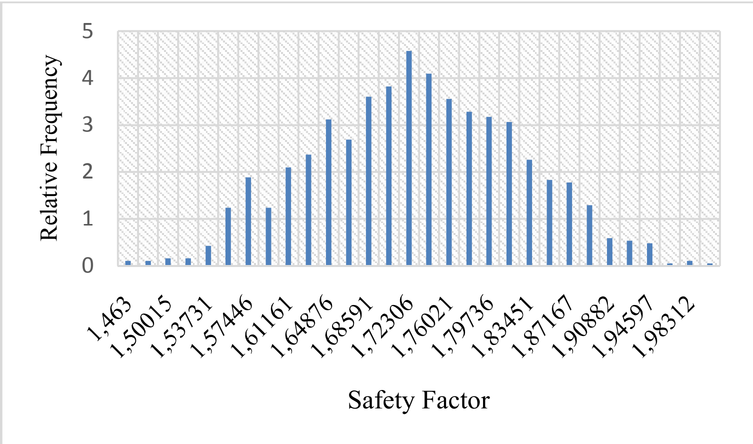

Figure 8. Output from analyses of one slope with shotcrete thickness 10 cm (mean value of SF=1.73; PF=0%)

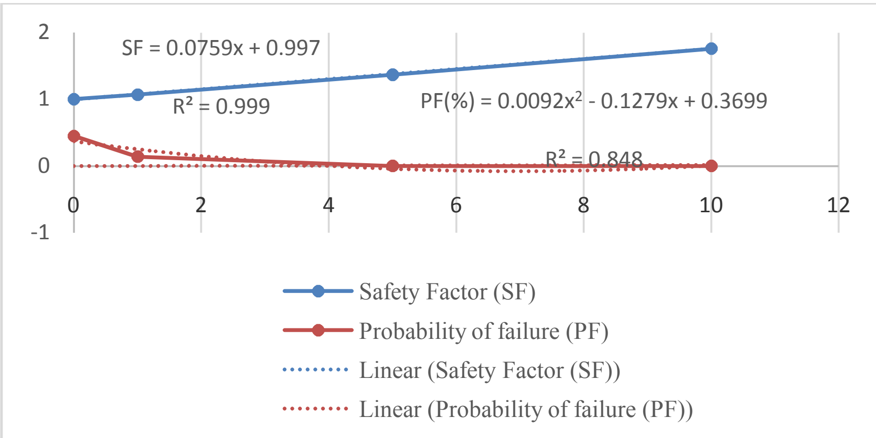

Figure 9. Diagram that illustrates effect of protection with different shotcrete thicknesses of 0; 1; 5 and 10 cm

The Figure 9 illustrates very well the effect of applying support measures in increasing of SF, and important decreasing of PF from PF=44,8%=0.448 to PF=0. Such analyses were basis for choosing appropriate protection measures depending on geologial and geotechnical conditions along the road.

3. APPLIED PROTECTION MEASURES

Based on the detailed analyses, several possible slope-protection methods were defined as typical Slope Protection Types (SPT) along the access road. For example, SPT1 is combination of wire mesh, local removal of unstable blocks and non-systematic application of rock bolts. This type is used for zones where block with smaller dimensions appear. SPT2 is recommended for talus sections, where partial removal (unloading) of the upper sections, installing of fence barriers on several levels and gabion walls is applied (if necessary application of shotcrete combined with wire or chain link mesh is additionally applied).

Details are presented elsewhere [9], so only some typical data for most used Slope Protection Type 3 are presented here. This is protective system where a combination of rock bolts, wire mesh and shotcrete is applied. The thickness of the shotcrete, as well as length of rockbolts varies from case to case, depending on structural elements of the joints and volumes of potential unstable blocks. The elements of the solution are given on Figure 10, while the actual application is shown in Figure 11. Works were carried out in the period 2016-2017.

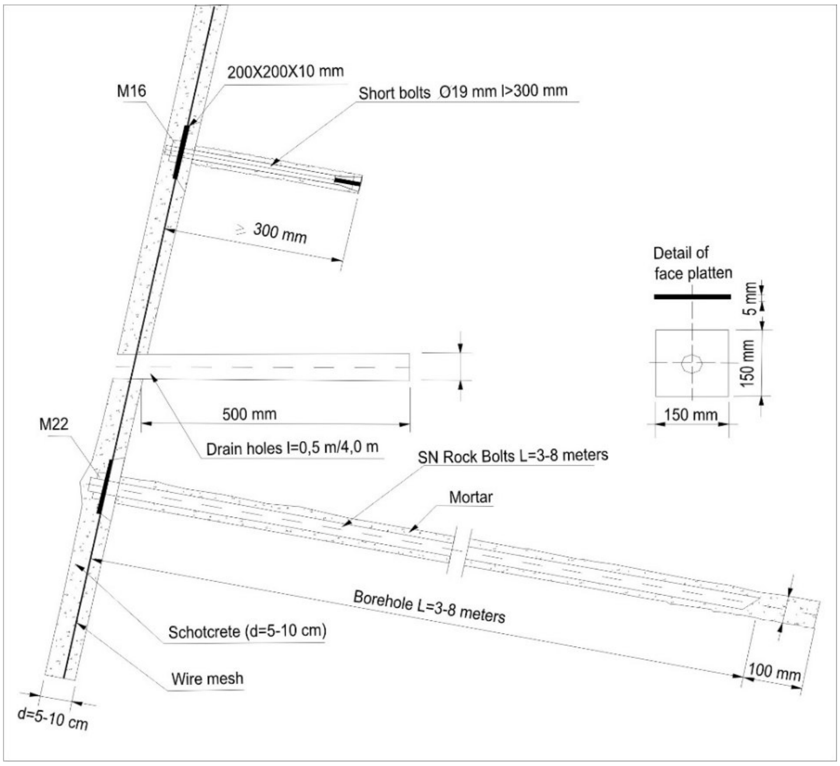

Figure 10. Typical section for Slope Protection Type 3

Figure 11. Illustration of phase of application of slope protection measures for Slope Protection Type 3

During the slope protection measures works, one of the main problems was connected with the fact that the slopes were earlier constructed almost without protection. Therefore, great amount of effort was put in order to secure the safety of the workers!

4. SUGGESTED METHODOLOGY FOR DEFINITION OF ACCEPTABLE LEVEL OF RISK

Following scientific outcomes, authors note that main result from this project is the conclusion that engineering problems cannot be analyzed separately, and in technical and economical analyses it is necessary to observe things in interaction of different aspects in order to reduce risks to an acceptable level. At the moment, in geotechnics, there is still not clearly defined what can be considered as (acceptable) tolerable level of risk. Some recommendations are given in [6] and [11], but still this is an open area for further investigation. The ALARP concept (As Low As Reasonably Practicable) in definition of tolerable level of risks as it is explained in [3] and [4] can also be good tool in engineering analyses.

So, here, some directions in direction how it is possible to improve known methods are given. For example, it is useful to prepare diagrams for fast Cost Estimation for Slope Protection Types (Figure 12).

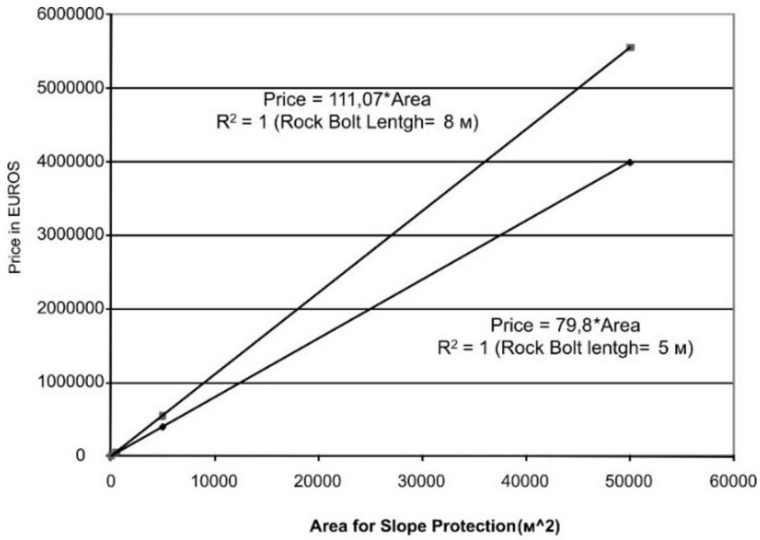

Figure12. Cost estimation for Slope Protection Type 3 for different rock bolt length [9]

The diagram is constructed according to the preparation of detailed Bill of Quantities for different lengths of rock bolts, and for common thickness of shotcrete of 10 cm, including all necessary concrete, reinforcement, earth works etc. Using similar approach, the whole access road is divided in several sub-sections, and according to the types of protection, a detailed analyses of the costs is prepared. Without going into details, the estimation for all works on slope protection is about 5.000.000 €. Compared with the costs in an annual level for cleaning of the road, it comes out that the annual present costs are about 110.000 €. It is also suggested to use concept for defining of Benefit-Cost Ratio (BCR) analyses, where beside technical costs and benefits, the analyses costs for possible loss of life prevention shall be assumed. Some data is given in Table 2, where the obtained ratio between investment and risk reduction from instabilities using ALARP concept principles in definition of tolerable level of risks is presented.

Table 2. Benefit-Cost Ratio analysis related to reducing of risk for loss of life

Protection type	Life duration of applied measure in years	Potential Loss of life PLL	Reducing of PLLr	Value of life (VL)	Benefits from application of measures	Costs for application of measures	Benefits / Costs ratio	Implied cost of averting a statistical fatality (ICAF)	ICAF< VL
		PLL	PLLr	€	€	€	BCR	€	
1.Without protection		0,04							
2.Support with protective measures (gabions only)	50	0,036	0,0036	2240000	407277	400000	1,01	2199978	Yes
3.50% installation	50	0,008	0,032	2240000	3584000	2500000	1,43	1562500	Yes
4.100% installation	50	0,002	0,038	2240000	4256000	5000000	0,85	2631579	No

*Benefit Cost Ratio = (PLLr **x** Value of life **x** Life duration of applied measures) / Costs for application of measures

*ICAF=Costs for application of measures / (PLLr **x** Life duration of applied measures)

It is evident that for cases 2 and 3 in Table 2, the suggested measures have a positive value which leads towards reducing the risk of potential loss of life, but further investments in the future are necessary in order to reach suggested values of PLL=10^{-4}, as suggested in [4]. However, in definition of tolerable level of risks, very useful is a simple analysis of so-called Protection Effect defined with following formula:

$$Es = \frac{Fs(san) - Fs(prir)}{Fs(prir)} * 100(\%)$$

where:

PE - Effect from applied measures in SF increasing;

Fs(san) - Safety factor obtained with applied measure;

Fs(prir) - Initial safety factor without applied measure.

Application of this concept for a case of wedge given in chapter 2 is presented in Figure 13.

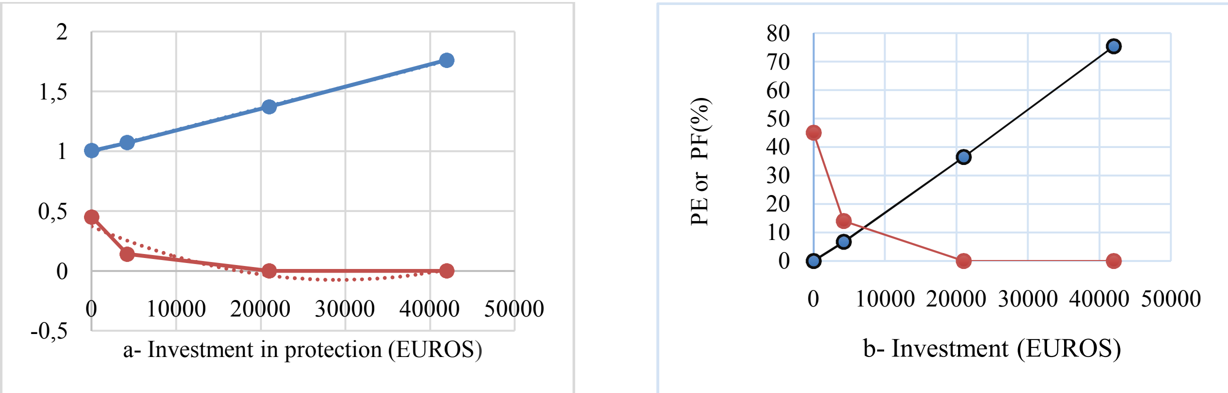

Figure13. a) Diagrams that present the influence of investment on SF and PF for a slope from Table 1; b) Influence of investment in increasing of PE and decreasing of PF

This „simple" analysis give a clear view on the complexity of the problem. This is a theme for further occupation and developement by the authors for the future.

5. CONCLUSIONS

From the given analyses, it is clear that each slope protection design is unique and has to be considered in terms of the particular set of circumstances, such as: rock types, design loads and end uses for which it is intended. The responsibility of the geotechnical engineer is to find a safe and economical solution which is compatible with all the constraints which apply to the project. Solutions should be based upon detailed analyses, but also on engineering judgement guided by practical and theoretical studies that shall be combined with probability theories and risk assesment methods. The presented experiences are good prove that knowledge of geological, tectonical, structural geological and geotechnical conditions is the sole basis for all analytical and numerical analyses for support measures design. The main conclusion is that there is urgent need for improved communication between geotechnical, geological, traffic, blasting specialists and project managers in order to find optimal solutions for similar problems.

6. REFERENCES

[1] Barton N.: Physical and discrete element model of excavation and failure in jointed rock, NGI, Oslo, 1994

[2] Federal Highway Administration (US), Rock Slopes: Design, Excavation, Stabilization. FHWA, US Department of Transportation, 1989.

[3] Fell R.: Landslide risk assessment and acceptable risk, Canadian Geotechnical Journal, 31, 1994, 261-272.

[4] Fell R., Hartford D.: Landslide Risk Management, in "Landslide Risk Assessment", Cruden and Fell (eds.), Balkema, Rotterdam, 1997, 51-110.

ISSN 2303-8403 Broj 3, 2017

[5] Health and safety executive: The tolerability of risk from nuclear power stations. HMSO, London, 1998

[6] Hoek E.: Practical Rock Engineering, http://www.rocscience.com, 2000

[7] Hoek E., Bray J. W.: Rock slope engineering, Institution of Mining and Metallurgy, London, 1997, pp.402

[8] Hudson J. A., Harrison, J. P.: Engineering rock mechanics, Pergamon, Amsterdam, 1997, pp.444.

[9] Jovanovski M., Dimitrov B., Experiences, methodology and principles for rock slope stabilisation, case for a road to arch dam "Sveta petka", Naucni skup, Savremena gradjevinarska praksa, Novi Sad, 2010

[10] Jovanovski M., Gjorgevski S.: Main design book for Slope protection along road to arch dam „Sv. Petka", Skopje, 2009

[11] Peshevski I., Jovanovski M., Guy M., O'Hare N.: Rockfall hazard assessment for access road to dam „Sveta Petka" using rockfall hazard rating system, Geologica Macedonica, 25(1-2), 11-20., 2011

[12] Pierson L. A., Davis S. A., Van Vickle R.: Rockfall Hazard Rating System – Implementation Manual, Federal Highway Administration (FHWA), Report FHWA-OR-EG-90–01, FHWA,U.S. Dep. of Transp., 1990