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SIMULATION OF THE IMPACT OF SEISMIC WAVES ON THE STABILITY OF ACTIVE BENCHES IN THE SIBOVC MINE

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Abstract: *For all mines, the stability of the slopes is an important aspect for the safety of the workers and for the continuous operation of the mine. If the slope is not stable, there is a risk that mobile materials will slide and endanger the life and health of the employees, besides this it has a direct impact on the productivity of the mine. Calculation of the influence of dynamic forces on the stability of mining slops involves the use of specialized mathematical and engineering methods.*
From these simulations, for gray clay the maximum height of the benches with a safety factor above 1.05 is 8m, an angle of 30^o and seismic simulation 0.3 according to Bishop's method, while for green clays the maximum height of the benches with a safety factor over 1.05 is 8m, angle of decline 45^o and seismic stimulation 0.3.

Key words: *Slope stability, seismic forces, factor of safety, benches.*

СИМУЛАЦИЈА НА ВЛИЈАНИЕТО НА СЕИЗМИЧКИТЕ БРАНОВИ ВРЗ СТАБИЛНОСТА НА АКТИВНИТЕ ЕТАЖИ ВО РУДНИК „СИБОВЦ“

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Апстракт: *За сите рудници, стабилноста на косините е важен аспект за безбедноста на работниците и за континуираната работа на рудникот. Доколку наклонот на етажите не е стабилен, постои ризик да се лизгаат подвижните маси и да го загрозат животот и здравјето на вработените, а покрај тоа има и директно влијание и на продуктивноста на рудникот. Пресметката на влијанието на динамичките сили врз стабилноста на рударските етажи вклучува употреба на специјализирани математички и инженерски методи.*
Од овие симулации, за сива глина максималната висина на етажите со безбедносен фактор над 1,05 е 8 m, агол од 30^o и сеизмичка симулација 0,3 според методот на Бишоп, додека за зелените глини максималната висина на етажите со безбедносен фактор над 1,05 е 8m, аголот на паѓање е 45^o и сеизмичка симулација 0,3.

Клучни зборови: *Стабилност на косини, сеизмички сили, фактор на безбедност, етажи.*

1. INTRODUCTION

Coal is a mixture of organic mineral material produced by a natural process of growth and decay, or an accumulation of debris both vegetal and mineral with some sorting and stratification.
Based on the geological map, the Kosovo Basin is mainly a tectonic area filled with tertiary sediments. Old rocks represent the Basin area, in the west Paleozoic age and in the east by Upper Cretaceous sediments. In the Coal Basin of Kosovo, along with Tertiary sediments, Quaternary sediments that have a hydrogeological character are developed.

2. METHODS

First, we did an analysis of the literature on the stability of swords in mines, then we defined the research questions that we want to answer in our study. When it became clear what is intended in this work, then we started with the collection of data, which included laboratory tests of the work environment and simulations of possible situations were made using computer software.
Data analysis: Processing and analyzing the data we have collected to answer the research question. Statistical methods, analytical models, and other techniques to draw conclusions and make interpretations are reviewed. In addition to the data analysis, we also conducted interviews with mining professionals including miners, mining engineers and other industry related people to get their opinions and experiences regarding the durability of swords.
Analysis of layers of materials: In order to evaluate the influence of layers of different materials on durability, deep analyzes of their physical, chemical and mechanical characteristics must be done.

2.1. Slope stability

The stability of mine slopes is a concept related to the ability of the mine slope to hold and resist various forces that may affect it. Essentially, it is the ability of geological material not to slide, or collapse after being exposed to pressure, weight, ground movements and other causes.
For mines, the stability of the slopes is an important aspect for the safety of the workers and for the continuous operation of the mine. If the slope is not stable, there is a risk that mobile materials will slide and endanger the life and health of the employees, besides this it has a direct impact on the productivity of the mine.
In order to guarantee the stability of the slopes, detailed research and analysis of the geological structure of the mine is necessary. In some cases, remedial measures such as the installation of retaining walls, the use of slope monitoring technologies and other measures to control the risk of material slides may be necessary. Slope stability is an important issue to ensure that mining operations are carried out safely and efficiently.
We have different types of slides that can appear on the ground: toppling, rotational slide, planar slide, rock fall and slump.
Instability in a mine slope and the occurrence of landslides occur because of a combination of various geological, environmental and human action factors. Some of the main factors that can cause instability and landslides in a mine slope are geological characteristics, the presence of joints, ground movements, specific gravity of

materials, environmental stresses, overloads, human actions, atmospheric conditions, water, and lack of monitoring and management of landslides.

2.2. Safety factor (FOS)

The geotechnical reviews are based on the geophysical notes, which are available from the research conducted, by INKOS as well as their laboratory analyses.

Table 1. Geotechnical parameters considered for stability calculations of slopes (benches)

Lithological layers	Physical-mechanical parameters		
	φ[°]	C [kN/m^2]	γ_m [kN/m^3]
Gray clay	16.2	21.3	17.7
Coal layer	35	30	12.0
Green clay	17.8	28.0	19.5

To ensure a safe and efficient operation of open pit mines, the following safety factors are considered necessary from geotechnical aspects for specific facilities. It should be taken into account that the safety factor chosen is strongly determined by the level of knowledge about the geological and hydrological situation as well as by the geophysical calculation parameters that may or may not be statistically valid, physically valid or invalid. The better the knowledge of the relevant object, the lower the necessary safety factor should be chosen, (RWE, [9]).
A different selection of the safety factor may also be possible between the working front and the folding slopes as well as the side slopes. In many cases, low safety factors are possible if the working front and folding slopes have only a short time using ([8]).

Active benches FOS > 1.05
Partial slopes FOS > 1.20
The total system FOS > 1.20
Objects to be protected FOS > 1.30 (roads, buildings) ([8], RWE, [9]).
Some of most popular slope stability analysis methods are: Limit equilibrium method (LEM), Slice method, Fellenius method (1927), Bishop method (1955), Method of Morgenstern e Price (1965), Janbu method (1967), Spencer method (1967), Bell method (1968), Sarma method (1973), Method of Zeng e Liang (2002). (Y.M. Cheng and C.K. Lau, 2014)

3. EVALUATION OF THE SEISMIC ACTION

Calculation of the influence of dynamic forces on the stability of mining slops involves the use of specialized mathematical and engineering methods. Here are some of the most common methods we can use: Finite element method, Time domain finite element method, Mode superposition method, Equation of motion method, Difference equation method, Boundary element method and Analytical method.
The slope stability against seismic action is checked with the pseudo-static method. For soils, that under the action of a cyclic loading can develop high pore-water pressure is considered an increase in percent of pore-water pressures that takes account of this factor of loss of resistance.
For the assessment of the seismic forces are considered the following:

$F_h = k_h \cdot W$
$F_v = k_v \cdot W$
Where:

- F_h and F_v respectively the horizontal and vertical component of the inertial force applied to the center of gravity of the slice.
- W slice weight;
- K_h horizontal seismic coefficient;
- K_v vertical seismic coefficient.

In earthquake prone areas, horizontal and vertical seismic coefficients, k_h and k_v respectively, are used to compute the horizontal and vertical forces caused by a potential earthquake, as shown in Figure 1, (Melo.C and Sharma. S [1]).

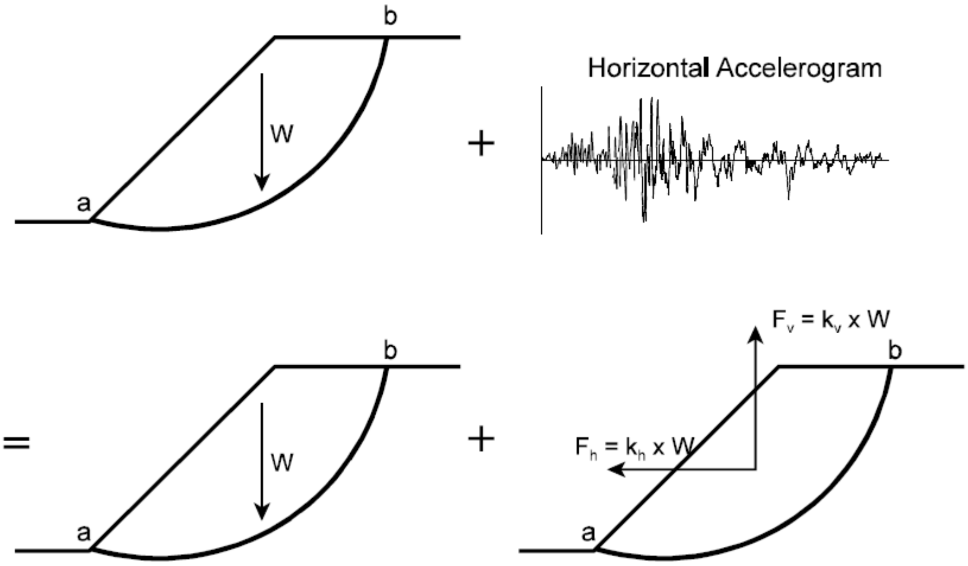

Figure 1. Seismic simulation analysis approach

Table 2. Shows horizontal seismic coefficient values that have been recommended for design

Horizontal Seismic Coefficient, k_h	Description	
0.05 - 0.15	In the United States	
0.12 - 0.25	In Japan	
0.1	“severe” earthquakes	Terzaghi [4]
0.2	“violent, destructive” earthquakes	
0.5	“catastrophic” earthquakes	
0.1 - 0.2	Seed [2], FOS ≥ 1.15	
0.10	Major Earthquake, FOS > 1.0	Corps of Engineers [5]
0.15	Great Earthquake, FOS > 1.0	
$1/2$ to $1/3$ of PHA	Marcuson [6], FOS >1.0	
$1/2$ of PHA	Hynes-Griffin [7] , FOS > 1.0	
FOS = Factor of Safety. PHA = Peak Horizontal Acceleration, in g’s.		

As shown in Table 2, there are no specific rules for selection of an appropriate seismic coefficient for design. However, the different selection criteria suggest that the seismic coefficient should be based on the anticipated level of acceleration within the failure mass and should correspond to some fraction of the anticipated peak acceleration (Kramer [3]).

In our case, we have analyzed the seismic impact in several cases, for different heights of benches and angles of decline of 30^{o} and 45^{o}. Dynamic analysis has done through the software program, which incorporates the following methods:

- Ordinary / Fellenius
- Bishop
- Janbu simplified
- Janbu corrected
- Spencer etc.

Table 3. Present the calculation of the safety factor with two methods (Fellenius and Bishop) under the influence of seismic forces, for different heights of benches at an angle of 45^{o}

	Bench height h (m)	Degree $(^{o})$	Safety factor Static		Horizontal Seismic load 0.1		Horizontal Seismic load 0.15		Horizontal Seismic load 0.2		Horizontal Seismic load 0.25		Horizontal Seismic load 0.3	
			Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop
Gray Clay	8	45	1.45	1.48	1.29	1.25	1.20	1.16	1.00	1.12	1.01	1.04	0.95	0.97
	7.5	45	1.52	1.56	1.32	1.35	1.22	1.25	1.14	1.17	1.05	1.08	0.97	1.00
	7	45	1.59	1.62	1.38	1.41	1.28	1.31	1.18	1.21	1.10	1.13	1.01	1.05
	6.5	45	1.67	1.71	1.45	1.48	1.35	1.38	1.26	1.29	1.17	1.20	1.08	1.11
	6	45	1.77	1.80	1.53	1.56	1.41	1.45	1.31	1.34	1.22	1.25	1.14	1.17
	5.5	45	1.87	1.90	1.16	1.64	1.50	1.53	1.40	1.43	1.30	1.33	1.21	1.24
	5	45	2.04	2.07	1.73	1.77	1.61	1.64	1.50	1.53	1.40	1.42	1.30	1.32
Green Clay	8	45	1.68	1.72	1.45	1.49	1.35	1.38	1.26	1.29	1.18	1.21	1.10	1.13
	7.5	45	1.78	1.81	1.53	1.57	1.42	1.45	1.32	1.35	1.21	1.25	1.12	1.16
	7	45	1.85	1.89	1.61	1.64	1.48	1.52	1.38	1.41	1.27	1.31	1.17	1.21
	6.5	45	1.95	1.98	1.69	1.73	1.58	1.61	1.46	1.50	1.36	1.39	1.25	1.28
	6	45	2.07	2.10	1.78	1.82	1.65	1.68	1.53	1.56	1.43	1.46	1.32	1.36
	5.5	45	2.19	2.21	1.88	1.92	1.75	1.79	1.63	1.66	1.52	1.54	1.39	1.44
	5	45	2.38	2.41	2.03	2.06	1.88	1.92	1.75	1.78	1.63	1.66	1.51	1.54

Table 4. Present the calculation of the safety factor with two methods (Fellenius and Bishop) under the influence of seismic forces, for different heights of benches at an angle of 30^{o}

	Bench height h (m)	Degree (^{o})	Safety factor Static		Horizontal Seismic load 0.1		Horizontal Seismic load 0.15		Horizontal Seismic load 0.2		Horizontal Seismic load 0.25		Horizontal Seismic load 0.3	
			Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop	Fellenius	Bishop
Gray Clay	8	30	1.77	1.86	1.45	1.52	1.32	1.39	1.20	1.27	1.10	1.16	1.02	1.07
	7.5	30	1.84	1.92	1.50	1.57	1.37	1.43	1.25	1.31	1.14	1.20	1.05	1.11
	7	30	1.91	2.00	1.57	1.64	1.42	1.49	1.30	1.36	1.19	1.25	1.09	1.15
	6.5	30	2.00	2.09	1.61	1.71	1.47	1.55	1.34	1.43	1.24	1.32	1.15	1.22
	6	30	2.11	2.20	1.72	1.80	1.55	1.64	1.42	1.50	1.30	1.38	1.20	1.27
	5.5	30	2.24	2.34	1.82	1.90	1.64	1.73	1.48	1.57	1.36	1.44	1.25	1.32
	5	30	2.39	2.48	1.93	2.02	1.74	1.84	1.57	1.67	1.43	1.52	1.31	1.40
Green Clay	8	30	2.05	2.15	1.67	1.75	1.52	1.60	1.39	1.46	1.27	1.34	1.17	1.24
	7.5	30	2.13	2.23	1.73	1.81	1.58	1.65	1.44	1.52	1.32	1.39	1.22	1.28
	7	30	2.22	2.32	1.81	1.90	1.64	1.73	1.50	1.58	1.37	1.45	1.26	1.33
	6.5	30	2.32	2.43	1.87	1.97	1.70	1.80	1.56	1.65	1.44	1.52	1.33	1.41
	6	30	2.45	2.55	1.99	2.08	1.80	1.90	1.65	1.74	1.51	1.60	1.40	1.48
	5.5	30	2.60	2.71	2.11	2.21	1.89	2.00	1.72	1.82	1.57	1.66	1.45	1.53
	5	30	2.78	2.89	2.24	2.35	2.02	2.13	1.82	1.93	1.66	1.76	1.52	1.62

4. RESULTS AND DISCUSSION

In table 3, the FOS safety factor is calculated with two methods (Fellenius and Bishop) for different heights of benches from 5m to 8m at an angle 45^{o}, as can be seen in the table; the seismic impact is stimulated by 0.1 to 0.3. From these stimulations, we can conclude that for gray clay the maximum height of the stairs with a safety factor over 1.05 is 7.5m, at an angle 45^{o} and seismic stimulation 0.25, while for green clays the maximum height of the benches with a safety factor over 1.05 is 8m, angle of decline 45^{o} and seismic stimulation 0.3.

In table 4, the FOS safety factor is calculated with two methods (Fellenius and Bishop) for different heights of stairs from 5m to 8m at an angle of 30^{o}, as can be seen in the table, the seismic impact is stimulated by 0.1 - 0.3. From these stimulations we can conclude that for gray clay the maximum height of the benches with a safety factor above 1.05 is 8m, an angle of 30^{o} and seismic stimulation 0.3 according to Bishop's method, also for green clays the maximum height of the ladder with a factor of safety over 1.05 is 8m, an angel 30^{o} and seismic stimulation 0.3.

Comparing the slop stability under static and dynamic force shows that in addition to the changes in analysis and modeling techniques, the requirements and risks of their use also change. Ensuring stability under static force is essential to prevent structures from breaking, while under dynamic force; safety becomes much more complex due to various periodic impacts.

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