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Geomechanical research into surface coal mining in terms of geotechnical safety substantiation

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Abstract

Purpose. The purpose of the present study is to determine the geomechanical parameters for calculating the stability of side slopes by partial and general angle in the working front to ensure the completeness of coal mining in accordance with geotechnical rules and standards based on the regulations (EC-7) of the Kosovo Energy Corporation, which is the state corporation, producing not only electricity in the Republic of Kosovo.

Methods. In the course of the present study, 60 additional drillings were carried out to a depth of 150 m up to green clay contact to determine the coal thickness. It was realized using a Type EK-650 drilling machine and a drilling diameter of 145/101 mm. To determine the angle φ and cohesion C, two methods were used, such as the Direct test and the Triaxial test. To obtain the most accurate results, a mathematical model was used to derive geomechanical parameters for calculating the slope geometry for the design geometry, where coal is mined to achieve a safety factor according to geotechnical standards.

Findings. The results of this study have demonstrated that there are inappropriate physical-mechanical parameters due to tectonics, especially the presence of groundwater and clay masses. There are locations with coal thickness from 0.5 to 1 m. This entirely affects the decrease in the calorific value of coal, but it also makes difficult to mine coal in the field in terms of geotechnical safety. Therefore it is important to design the slope geometry that can ensure the stability of the mine as well as coal mining in full compliance with market demands.

Originality. A large number of physical-mechanical parameters were analyzed, including a mathematical model, with which the slope geometry was calculated using the design profiles and 9 methods. This has given satisfactory results based on Eurocode EC-7 which can be implemented in the field.

Practical implications. To analyze the numerical and analytical methods for the design slope geometry, geotechnical Eurocodes were used according to two standards: Eurocode EC7-1 for geotechnical designs and Eurocode EC7-2 for field verification. They were tested on two factors: Category of terrain and Category of objects (excavator), to remove the coal cover using technology in compliance with the conditions in the field, such as the presence of surface water, underground waters and tectonics. This whole analysis is time consuming, so a safety factor has been determined based on the numerical analysis data.

Keywords: *geomechanical parameters, geotechnical safety, Eurocode, coal mining*

1. Introduction

The Republic of Kosovo is a country located in Southeastern Europe. A little more than two decades, the war for freedom ended, and it has been independent since 2008. Kosovo, 23 years after the war, is facing serious problems in the electricity supply system, even though the electricity supply has improved and stabilized significantly compared to the first post-war years. The improvement of this situation was directly affected by a series of actions taken, such as: regular maintenance and repair of units in TC Kosovo A and TC Kosovo B, investments in the transmission and distribution network.

However, the geological-geomechanical research into the southwestern Sibovc mine opening was of special importance from the aspect of geotechnical safety, in order for coal mining to meet the requirements of the existing power plants to supply the community in general with electricity due to the increase in demand for electricity generation.

It is also necessary to reorganize existing small hydropower plants, privatize the distribution and supply network, reduce technical and non-technical losses, set the most favorable prices in the regional electricity market and improve the legal and regulatory framework. Despite the considerable investments in this sector and an improvement in the overall situation in the electrical energy system, Kosovo is still an importer of electricity, accounting for about 10% of its demand, and faces serious problems in providing the necessary capacities to cover the maximum energy demand, which is especially important in winter season.

For sustainable economic and social development of the country, based on the contemporary demand for electricity, an uninterrupted supply of sufficient quantity and quality of electricity is a necessary requirement [1], [2]. For this very reason, the regular supply of qualitative and quantitative energy to consumers in Kosovo (individual, commercial and indus-

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trial) is a great challenge for all parties involved in this issue. The solution to this complex problem is not quick and simple, because it depends on many multidisciplinary factors.

The Republic of Kosovo territory is characterized by a complex geological structure, rich in resources and underground wealth. Underground wealth is also coal found in large quantities near the municipality of Obiliq. Kosovo ranks fifth in the world in terms of proven lignite reserves. From a geological point of view, lignite from the Kosovo mines is one of the most favorable lignite sources in Europe. The average removal rate is 1.7 m^3 of cover per 1ton of coal, and, in total, the estimated economically exploitable reserves represent one of the richest in Europe, which would provide the electricity generation for the next decades.

Kosovo's most important energy resource is coal, which provides about 97% of the total electricity generation. The first coal exploration in Kosovo began at the beginning of the 20^{th} century, when it was found that there were large coal reserves in Kosovo. In 1922, underground exploitation of the Hada Mine in Obiliq and then Babush Mine in Lipjan began. Systematic geological research of coals in the Kosovo Basin began in the period 1952-1957. During this period, preparations were made for the transition from underground to surface use of coal in the Kosovo Basin, exploring the possibility of mass use of coal for the needs of power plants during electricity generation and its industrial processing.

Further medium-term development of lignite mining continues in the active mining area of Sibovc (Obiliq) in the southwestern part of the Kosovo Basin, giving great priority to private investments. Based on current research and the status of mineral energy resource reserves according to [3], [4], the Republic of Kosovo has significant reserves of lignite type coal on its territory according to data in Table 1) and a part of them is used for the needs of the country (Fig. 1).

Table 1. Coal reserves in the Republic of Kosovo

Coal-bearing basins	Reserves (bln tons)		
	Geological	Balances	No balances
Kosovo	10.10	8.77	1.32
Dukagjini	2.24	2.05	0.19
Drenica	0.11	0.73	0.33
∑	12.44	10.89	1.55

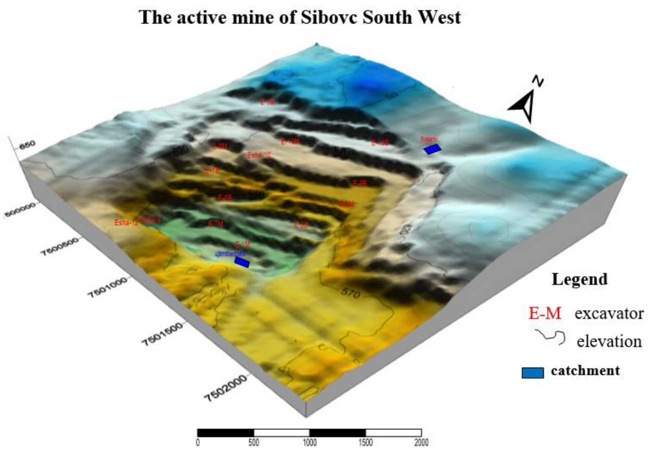


Figure 1. Coal mining with rotary excavators under the open sky [3]

The coal-bearing Kosovo Basin is located in the central part of Kosovo. In terms of geomorphology and geography, the Kosovo Basin is typical lowland, with a longitudinal axis extending from North and North-West to South and South-East, starting from Mitrovica in the far north to Kaçanik in the south. The Kosovo Basin length is about 85 km, while the average width is about 10 km. This basin covers an area of about 850 km^2 and has a developed network of road, rail and air traffic that connects the Republic of Kosovo with all countries in the region and beyond. In coal mining, this road infrastructure and railway traffic is of particular importance, because solutions for their displacement must also be foreseen, especially if they lie on exploited coal deposits. Geologically, the Kosovo Basin is located within a thick Pliocene series, which, in terms of the petrographic composition and facies characteristics, is characterized by variability [5].

In coal mining, this road infrastructure and railway traffic is of particular importance, because solutions for their displacement must also be foreseen, especially if they lie on exploited coal deposits. Geologically, the Kosovo Basin is located within a thick Pliocene series, which, in terms of the petrographic composition and facies characteristics, is characterized by variability [6]. The thickness of this series in separate parts varies within a relatively wide range as a result of the paleo-relief morphology and other conditions of sedimentation processes. Based on current geological research in the coal-bearing Kosovo Basin, only one coal seam with a complicated structure and intercalation, mainly of clays and carbonates, has been identified. The presence of interbeds, especially in the peripheral parts of the basin, often gives the wrong impression that more coal seams occur. The coal seam material is mainly composed of xyl coal and coal. It is economically profitable to mine coal in an open pit mine.

Therefore, the purpose of this research is to study the geological-geomechanical parameters of coal mining for the existing thermal power plants Kosovo A and Kosovo B from the aspect of geotechnical safety using rotoric excavators and conveyor belts.

2. The study area

This coal mine area is located 6 kilometer from Pristina, Kosovo according to (Fig. 2) and has an average elevation of 530-670 meters above sea level. The slopes of these hills lie at an angle of 4 to 10 degrees with a general decline in the direction from southeast to southwest [3], [4]. From a hydrological point of view, surface water includes both rainwater and water sources, which, due to the opening of working fronts, infiltrate the coal seam. The area including part of the coal mining field is about 3 km^2 (300 ha), which is controlled by canals.

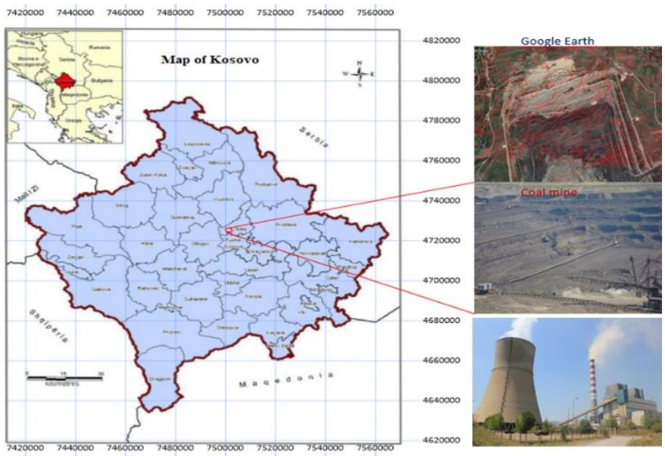


Figure 2. The geographical position of the surface mine [3]

The resources were formed as a result of infiltration of water from the surface into yellow clays with the presence of coarse sands and, in some places, with fossils. These clays are considered water-collecting, but under them there are ash-colored marly clays, which are more water resistant and the possibility of water movement in them under normal conditions is small. However, from recent drilling, it has been observed that these clays are characterized by a number of large fractures that have different angles and directions, and therefore they can also create hydraulic connections between each other, becoming an area with a temporary weak collector. This phenomenon can be expressed in cases where droughts are large and long-term, so that this layer, especially in open fronts, is affected by a system of ruptures. And in those cases when it is followed by high-intensity precipitation, the unimpeded circulation of water through these fractures occurs until these clays are saturated and begin to swell until the fractures are completely eliminated. Through these ruptures, some of these waters infiltrates into the coal seam where mining activity is performed and drains to the lowest levels.

In terms of the hydrogeological model, the location of existing mines, especially in Sibovci-Southwest, is determined by the influence of underground waters. Underground water in yellow clay results in fossils formed by water infiltration from atmospheric precipitation. Underground water in gray clay results in fossils formed as a result of water infiltration through the fracture system. Underground water in the coal series causes tectonic faults, presented according to (Fig. 3) and [5], the water of which comes out in the form of springs through the fractures at the lowest levels in the open profiles of the working front. From the results obtained from the performed drilling (wells), there is a non-uniform leakage coefficient ranging from $1 \cdot 10^{-7}$ to $9 \cdot 10^{-5}$ m^3/s.

Figure 3. View of mining activity with transporting coal with conveyor belts

The Kosovo Basin tectonics is characterized by frequent changes in formations due to pronounced tectonics. In tectonic terms, the Kosovo Basin is a continuation of the Vardar area and specifically belongs to the shale belt of the inner Dinarite and, according to research [6], is divided into three areas. The pre-lacustrine area belongs to the Oligocene-Miocene period, which is characterized by some disconnections of irregular geometric shapes and the impacts of volcanic activities, expressed in the northeastern part of Janjeva and Shushica, shown on the tectonic map of the basin. The rock relief of the surrounding formations at a very close distance from the basin, especially along the western boundary, is severely disturbed. While the lacustrine phase is relatively calmer, since during sedimentation it belongs to the Pliocene series, in which the development of an asymmetric syncline was found. Longitudinal tectonic faults are presented by three blocks according to Figure 4. Transverse and diagonal detachments in the area of coal mining according to [7], in which three main elements are expressed: the extent, the azimuth of the fall and the angle of the fall. Their illustration is presented in Figures 5 and 6, according to [8].

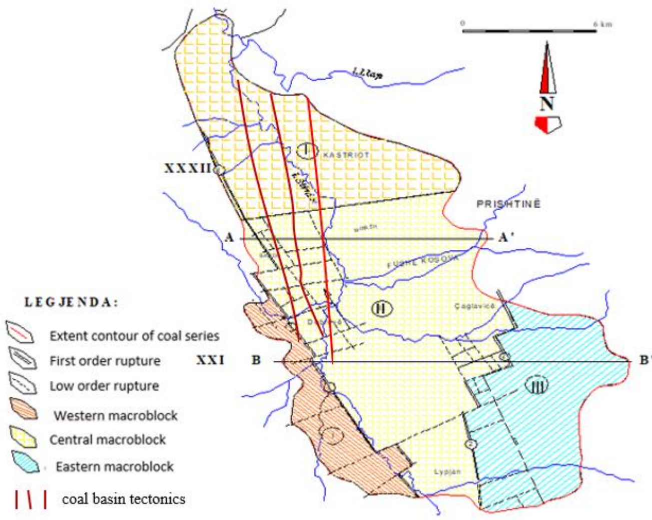


Figure 4. Tectonic map of the Kosovo coal basin

	Color	Trend	Plunge	Label
User Planes				
1		247	24	
2		252	18	
3		65	26	

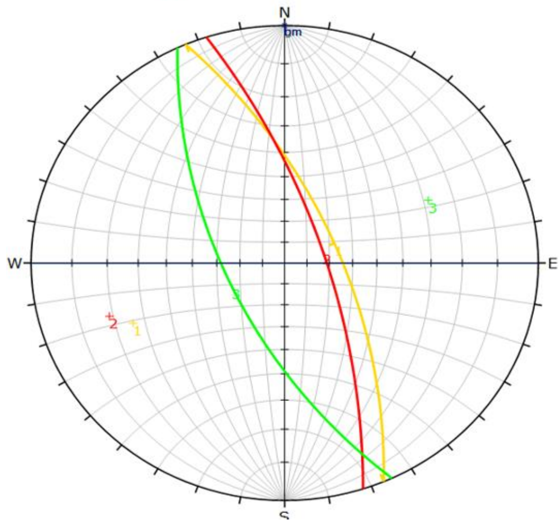


Figure 5. Direction of alignment according to stereographic projection

Longitudinal tectonic faults have an extension direction parallel to the longitudinal axis of the VVP-JJL basin. Along them, the last step-by-step lowering of the basin took place. One of them is the Qyqavice tectonic fault, which lies in the western part of the basin, along which the deepest subsidence of the coal series occurred. Transverse and diagonal tectonic faults are less pronounced, but movements along them are also expressed in the form of coal blocks, thus forming a parquet structure, with is confirmed by research data and analysis of the research drillings. This basin has also been affected by disjunctive tectonic movements.

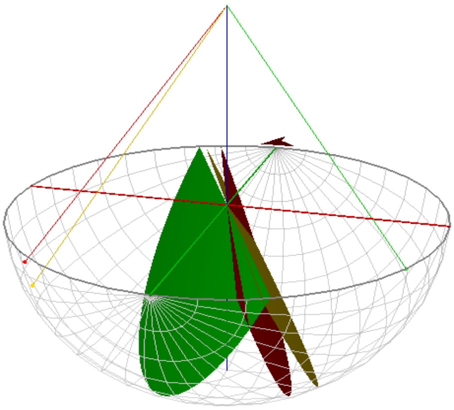


Figure 6. Tectonic presentation in 3D stereographic projection

Based on the analysis it has been concluded that the coal seam is divided into several micro- and macroblocks arranged in the form of triangles and parallelopipeds, forming a parquet structure. The lower and upper boundaries of the coal seam were taken as the main element of the tectonics interpretation. The difference in the change of the coal seam subsidence, based on the drilling, reaches from 3m to 5m, which is explained as tectonic fluctuations. Due to the tectonic complications in this part, detachment phenomena (of coal blocks) occurred and also the presence of methane gas (CH_4). The post-lacustrine phase is characterized by tectonic activity in the area of coal mining.

3. Methodology

In the process of mining coal for the use of mineral raw materials, with increasing depth of mining, problems of a different nature often occurred, such as loss of stability of slopes. All this happened due to geological, hydrogeological and geomechanical characteristics. To accurately determine these phenomena, in the course of additional field studies in an open-air mine, about 60 drillings were performed according to [2], [4] on sites with dislevels of 550-670 m to a depth of up to 120 m. To determine the coal seam thickness before contact with green clay, a drilling machine of the Type EK-650 with a drilling diameter of 145/101 mm was used for sampling for the analysis of geomechanical parameters. Their comparison was made according to [5], [6], and the number of samples by layers is presented in Tables 1, 2 and 3.

Tables 1-3 show the number of samples taken while drilling according to Figure 7. For each layer, physical parameters were extracted in the geomechanics laboratory, and their statistical processing was applied according to Figure 7 [9]. The definition of micro- and macrotectonic blocks is presented in Figure 4. Their presentation is determined by Figures 5 and 6 to represent the geological layers. The map of the situation with the position of the drills according to Figure 7 is used, and geological-geomechanical profiles are presented in Figure 8 according to [9], [10].

To determine mechanical parameters (hardness), two methods were used, known as: direct test and triaxial test.

Table 1. Statistical parameters for yellow clay

	Volumetric weight (γ), kN/m^3	Humidity (W), %	Specific weight (G_S)	Porosity (n), %	Porosity coefficient (e)
Number of values	123	123	123	123	123
Sum	2156.137	2823.342	322.286	4400.230	70.741
Minimum	11.009	5.437	2.300	26.428	0.359
Maximum	45.396	45.396	3.017	55.464	1.245
Range	34.386	39.958	0.717	29.036	0.886
Mean	17.529	22.954	2.620	35.774	0.575
Median	17.463	20.000	2.614	34.433	0.533
Mode	15.649	35.000	2.6149	32.000	0.589
First quartile	0.3818	15.591	2.5805	31.730	0.458
Standard error	0.7565	0.873	0.0076	0.5512	0.015
95% confidence interval	17.930	1.730	0.0150	1.0921	0.030
Variance	2.733	93.802	0.0071	37.371	0.028
Average deviation	4.234	8.057	0.0561	4.373	0.118
Standard deviation	0.241	9.685	0.0843	6.113	0.168
Coefficient of variation	123.000	0.421	0.03219	0.170	0.292
Skew	2156.137	0.775	0.855	1.560	1.550
Kurtosis	11.009	-0.339	5.715	1.946	2.786

Table 2. Statistical parameters for gray clay

	Volumetric weight (γ), kN/m^3	Humidity (W), %	Specific weight (G_S)	Porosity (n), %	Porosity coefficient (e)
Number of values	150	150	150	150	150
Sum	2925.461	5523.683	395.029	6134.385	87.326
Minimum	16.007	10.000	2.530	26.428	0.321
Maximum	22.083	83.859	3.017	56.000	1.245
Range	6.075	73.859	0.486	29.571	0.924
Mean	19.503	36.824	2.633	40.895	0.5821
Median	19.824	29.104	2.614	38.000	0.541
First quartile	18.631	19.115	2.580	34.786	0.458
Standard error	0.110	1.868	0.006	0.6663	0.012
95% confidence interval	0.219	3.696	0.012	1.3180	0.024
Variance	1.844	523.888	0.0064	66.595	0.023
Average deviation	1.081	19.227	0.0562	7.1520	0.116
Standard deviation	1.358	22.888	0.08020	8.1606	0.154
Coefficient of variation	0.069	0.621	0.03045	0.199	0.265
Skew	-0.622	0.810	2.064	0.419	1.381
Kurtosis	-0.177	-0.759	6.278	-0.982	2.435

Table 3. Statistical parameters for green clay

	Volumetric weight (γ), kN/m^3	Humidity (W), %	Specific weight (G_S)	Porosity (n), %	Porosity coefficient (e)
Number of values	124	124	124	124	124
Sum	2267.061	7448.285	326.215	4836.790	75.013
Minimum	10.069	21.734	2.500	26.428	0.3592
Maximum	22.344	87.137	3.0172	65.000	–
Range	12.275	65.402	0.5172	38.571	0.620
Mean	18.282	60.066	2.6307	39.006	0.604
Median	18.543	59.219	2.6149	36.700	0.564
First quartile	16.867	44.203	2.5805	33.400	0.485
Standard error	0.2153	1.531	0.0065	0.721	0.013
95% confidence interval	0.4265	3.035	0.0130	1.430	0.026
Variance	5.7479	291.000	0.0053	64.634	0.022
Average deviation	1.8578	14.805	0.0517	6.419	0.120
Standard deviation	2.3974	17.058	0.073	8.039	0.151
Coefficient of variation	0.1311	0.284	0.0277	0.206	0.250
Skew	-1.021	-0.118	1.787	1.031	124.000
Kurtosi	1.444	-1.067	6.525	0.637	75.013

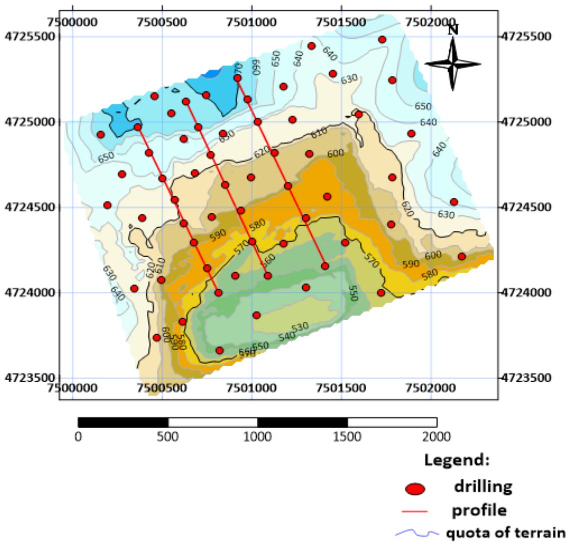


Figure 7. Map with the position of drillings and profiles

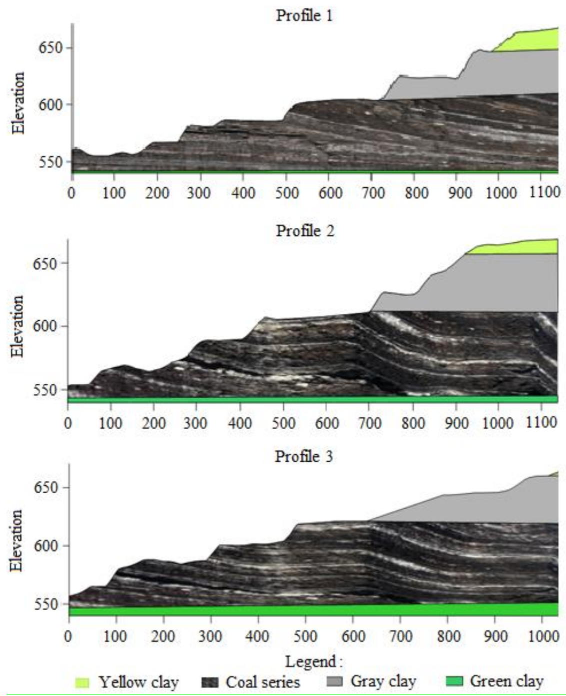


Figure 8. Geological-geomechanical profiles for the existing and design state

As can be seen from Figures 9 and 10, according to [4], the mathematical model [11]-[13] was used to find the angle φ^o and cohesion C for calculating the slope stability for the existing and design state. Thus, we have the best opportunities for coal mining from a geotechnical aspect and a long-term stability according to [14], [15] for the safety of workers and technological equipment.

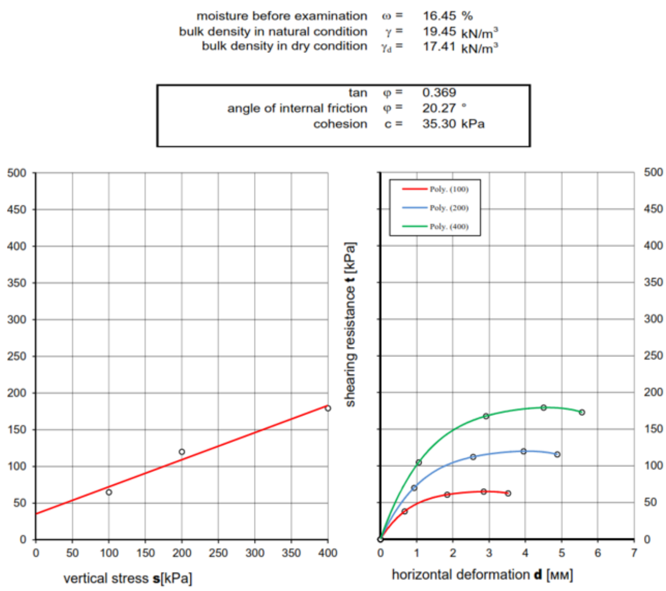
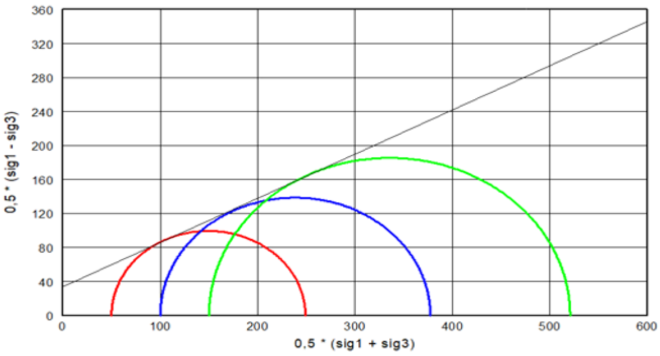


Figure 9. Direct test for determining angle φ^o and cohesion C

Geotechnical analysis and assessment of natural state problems are achieved by determining geomechanical parameters obtained in a laboratory. After analyzing a large number of samples extracted from wells, and in particular, statistical processing from [5], [9] is applied [16]-[19] for each layer according to Equations (1)-(11). An analysis of the geological-engineering conditions of the coal mine, performed with the aim of creating the geometry of the lateral and final slopes, gave the following results, presented in Tables 1-3 and 4-6.

Tables 4-6 show the number of samples from the drilling according to Figures 7 and 8. For each layer, depending on the drilling depth, the number of samples is analyzed to determine the moisture content.



Test no.	1	2	3
Normal stress [kN/m²]	249.0	377.2	520.7
Shear stress [kN/m²]	50.0	100.0	150.0
Shear velocity [mm/min]	5.07	5.07	5.07
Consolidation stress [kN/m²]	50	100	150
w (before) [%]	22.9	22.9	22.9
w (after) [%]	1.521	1.521	1.521

Friction angle =	27.5 degrees
Cohesion =	33.5 kN/m²
Correlation =	1.000

Figure 10. Triaxial test for determining angle φº and cohesion C

Using statistical processing according to the Equations (1)-(5), for each layer, based on the values obtained for the types of layers, different moisture content values have been determined.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i ; \quad (1)$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i . \quad (2)$$

Varianca:

$$V = \frac{\sum (x_i - \bar{x})^2}{n} ; \quad (3)$$

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} . \quad (4)$$

Coefficient of variation:

$$CV = \frac{\sigma}{\bar{X}} \cdot 100\% . \quad (5)$$

Table 4. Natural moisture of coal (w), %

Number of values	Geological description	Sums $\sum X_i$	Min	Max	Mean X	Standard deviation S^2	Coefficient of variation V
35	Coal	2205.579	26.208	87.137	63.016	19.133	0.303
15	Mainly coal	997.977	44.232	83.484	66.531	11.839	0.177
21	Dust with dust mass	1236.292	27.743	83.771	58.871	18.001	0.305
9	Dust-coated / coal-fired	393.550	17.997	68.138	43.727	16.534	0.378
12	Altered coal with clay powder	646.252	43.253	61.6399	53.854	6.058	0.112
20	Dusty mass	973.585	28.341	67.052	48.679	9.900	0.203
14	Powdered charcoal dust	716.625	28.117	64.310	51.187	12.967	0.253
10	Coal-fired dust mass	543.753	40.710	68.335	54.375	9.923	0.182
13	Soil coal	781.697	33.871	689.043	60.130	20.619	0.342
12	Dusty coal	742.654	45.114	83.805	61.887	13.743	0.222
11	Clay coal	768.155	45.925	87.076	69.832	13.832	0.198

Table 5. Volume weight of coal (γ), gr/cm³

Number of values	Geological description	Sums $\sum X_i$	Min	Max	Mean X	Standard deviation S^2	Coefficient of variation V
35	Coal	43.754	1.101	1.578	1.250	0.109	0.0877
15	Mainly coal	18.274	1.168	1.298	1.218	0.038	0.0317
21	Dust with dust mass	26.069	1.063	1.463	1.241	0.127	0.1025
9	Dust-coated / coal-fired	11.382	1.204	1.416	1.264	0.068	0.0541
12	Altered coal with clay powder	15.522	1.206	1.412	1.293	0.075	0.0582
20	Dusty mass	25.288	1.171	1.440	1.264	0.080	0.0637
14	Powdered charcoal dust	18.640	1.153	1.518	1.331	0.111	0.0838
10	Coal-fired dust mass	12.492	1.133	1.402	1.249	0.092	0.0741
13	Soil coal	15.190	1.026	1.334	1.168	0.109	0.0936
12	Dusty coal	14.863	1.143	1.346	1.238	0.059	0.0479
11	Clay coal	13.438	1.185	1.258	1.221	0.023	0.0189

$$Kurtosis = \frac{\sum (x_i - \bar{x})^4}{(n-1)^4} ; \quad (6)$$

$$Skewness = \frac{\sum (x_i - \bar{x})^3}{(n-1)\sigma^3} ; \quad (7)$$

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2}} = \frac{S_{xx}}{\sqrt{S_{xx} \cdot S_{yy}}} ; \quad (8)$$

$$S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2 = n s^{-2} x ; \quad (9)$$

$$S_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2 = n s^{-2} y ; \quad (10)$$

$$S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) = \sum_{i=1}^{n} x_i y_i - n\bar{x}\,\bar{y} . \quad (11)$$

Table 7 shows the hardness parameters for determining the angle (γ^o) and cohesion (C) analyzed for each layer by direct test and triaxial test.

Table 6. Determination of cohesion value (C), kN/m²

	Direct shear test	Triaxial test
Number of values	30	30
Sum	944.8	968.3
Minimum	19.5	20.0
Maximum	58	62
Range	38.5	42.0
Mean	31.493	32.276
Median	28.5	29.5
First quartile	24	25
Standard error	1.807	1.812
95% confidence interval	3.6960	3.7059
Variance	98.004	98.520
Average deviation	8.3053	8.0786
Standard deviation	9.8997	9.9257
Coefficient of variation	0.3143	0.3075
Skew	0.819	1.056
Kurtosis	0.163	1.231

Table 7. Parameters for calculating the geometry of side slopes for clays and coal

Lithological layers	Friction angle, γ^o	Cohesion (C), kN/m²	Unit weight (γ), kN/m³
Yellow clay	14.3	9.5	17.52
Gray clay	13.3	11.25	19.5
Green clay	15	12	18.3
Coal	25	32	13.3

According to Figures 9, 10, statistical processing is also used to determine the most realistic values of these two parameters. The importance and purpose of these parameters is that on their basis it is possible to determine the design geometry of the mine with a geotechnical safety factor for the protection of workers and technological equipment. Also, coal mining will be conducted in accordance with market requirements and more completely [7], [15], [16].

Slide, SLOPE/W and GGU-Slope Stability DIN 4084 software was used to compare results according to existing and design state using two calculation forms according to the circular shape presented in Table 8 from Equations (12) and (13) and polygonal shape from Equations (14) and (15) presented in Table 9.

Circular slip surfaces:

$$\eta = \frac{r \cdot \sum T_i + \sum M_s}{r \cdot \sum G_i \cdot sin\vartheta_i + \sum M}; \quad (12)$$

$$T_i = \frac{\left[G_i - \left(u_i + \Delta u_i \right) \cdot b_i \right] \cdot \tan\varphi + c_i \cdot b_i}{cos\vartheta_i + \frac{1}{\eta} tan\varphi_i \cdot sin\vartheta_i}. \quad (13)$$

Polygonal slip surfaces:

$$\eta = \frac{\sum T_i + \sum H_s}{\sum G_i \cdot tan\vartheta_i + \sum H}; \quad (14)$$

$$T_i = \frac{\left[G_i - \left(u_i + \Delta u_i \right) \cdot b_i \right] \cdot \tan\varphi_i + c_i \cdot b_i}{cos\vartheta_i + \frac{1}{\eta} tan\varphi_i \cdot tan\vartheta_i}. \quad (15)$$

Analyzing the comparative methods for calculating the lateral slope according to [20]-[22] and simultaneously the planned geometry of folding, measures should be taken where the coal was mined, backfilling the space with humus.

Table 8. Method: existing state circular shape

Analysis method	Slide	SLOPE/W	GGU-stability DIN 4084
Bishop Simplified	0.776	0.778	0.777
Janbu Simplified	0.758	0.758	0.758
Janbu Corrected	0.775	–	–
Corps of Engineers #1	0.775	–	–
Corps of Engineers #2	0.777	–	–
GLE/Morgensten-Price	0.777	–	–
Lowe-Karafiath	0.775	–	–
Spancer	0.766	0.766	–

Table 9. Method: design state polygonal shape

Analysis Method	Slide	SLOPE/W	GGU-stability DIN 4084
Bishop Simplified	1.534	1.535	1.533
Janbu Simplified	1.421	1.422	1.420
Janbu Corrected	1.528	–	–
Corps of Engineers #1	1.653	–	–
Corps of Engineers #2	1.657	–	–
GLE/Morgensten-Price	1.660	–	–
Lowe-Karafiath	1.614	–	–
Spancer	1.665	1.666	–

Rehabilitation of land to its previous state, based on the design task provided by the law on minerals [23]-[27], should be carried out in order to have a clean environment for the population of the districts and beyond.

These parameters give different values, especially in the presence of moisture, they are high, and due to the presence of tectonics (fractures in coal blocks dominate). Therefore, coal mining should be conducted according to geomechanical parameters and design geometry, with a safety factor corresponding to the geotechnical standards Fs>1.2.

4. Results and discussion

Based on the data of samples, it has been concluded that we are dealing with weak physical-mechanical parameters due to the tectonics expressed in this area. Based on drilling and geomechanical analysis, it was concluded that in the coal seams there are intercalations of clay masses with a thickness of 0.2m to 0.5m, which negatively affects the coal quality. During the research, the presence of underground water was also found, and, taking in to account this phenomenon, the stability of the side slopes for the existing state was calculated according to Figure 11. In this case, the safety factor is less than FS < 1, which means that under this condition, the condition for using coal is not met. At the same time, as in the case of the condition calculated according to Figure 12, with a safety factor higher than FS > 1.2 and according to mine's geotechnical standards, the condition for using coal is met. Two methods were used to calculate the geological formations.

The circular shape are used to the coal cover according to the clays (Figs. 11, 14) by Equations (12), (13) and polygonal shapes according to the clays (Figs. 12, 13) by Equations (14), (15), and according to [20]-[22]. Based on laboratory analysis data, as well as field data, it has been revealed that the above mentioned parameters correspond to the average for the study area, which can be determined for further calculations according on lithological members. The parameters used in geomechanical calculations for lithological members are presented in Table 7 through Geotechnical Design Eurocodes EC7-1 and EC7-2.

Figure 11 presents the existing state of the coal and cover. The sliding plane mechanism is applied depending on the existing state (geological, hydrogeological, geomechanical parameters and technology) that will be integrated into the geomechanical model, presented in Table 7.

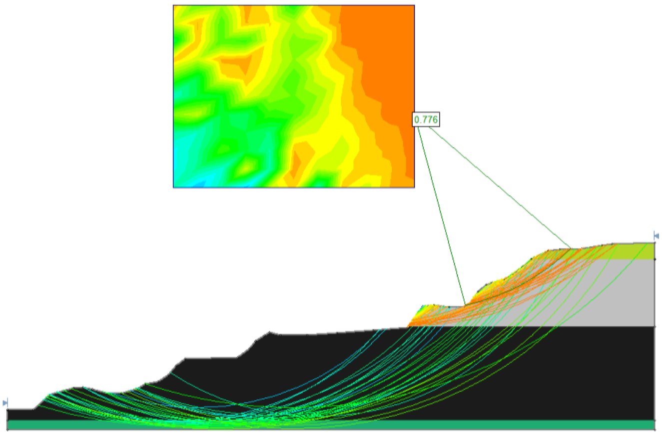


Figure 11. Calculation of the existing state according to Slide

The coal seam has been analyzed for design state using the polygonal shape (Fig. 12). This shape is suitable for these types of formations, since in the coal seam, based on drilling and analysis of the geomechanical coal samples, the presence of tectonic faults has been revealed. This tectonic phenomenon is also observed in the open profiles directly in front of the site where the rotary excavator operates. The results are satisfactory with a safety factor according to geotechnical design standards.

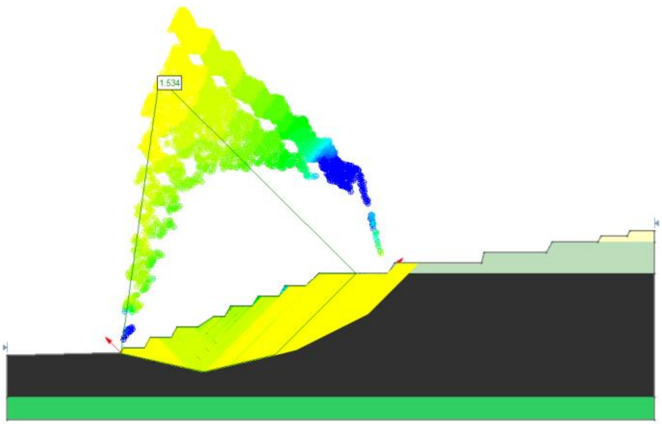


Figure 12. Calculation of the design state according to Slide polygonal shape

Figure 13 shows the geologic-geomechanical profile for the coal seam design state by using the GGU-slope DIN 4084 software program. This profile uses a polygonal shape. This shape corresponds to these formations based on the results. This design geometry meets the conditions for this type of formation. The safety factor is FS > 1.2, which is within the range of the geotechnical standard values.

In Figure 14, based on the situation map (Fig. 7), which indicates the position of the drills to determine the physical-mechanical parameters. Based on the drilling data, the cross-sectional geologic-geomechanical profile is constructed. The design state $H = 100$ m with angle $\alpha \leq 10°$ is analyzed using the GGU stability DIN 4084 and slope/W software program.

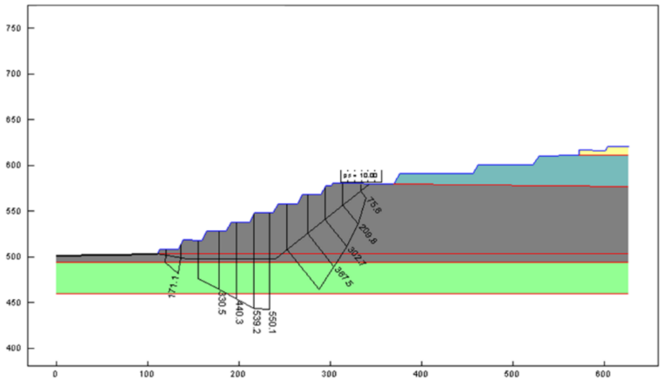


Figure 13. Calculation of the design state according to GGU-stability DIN 4084 polygonal shape

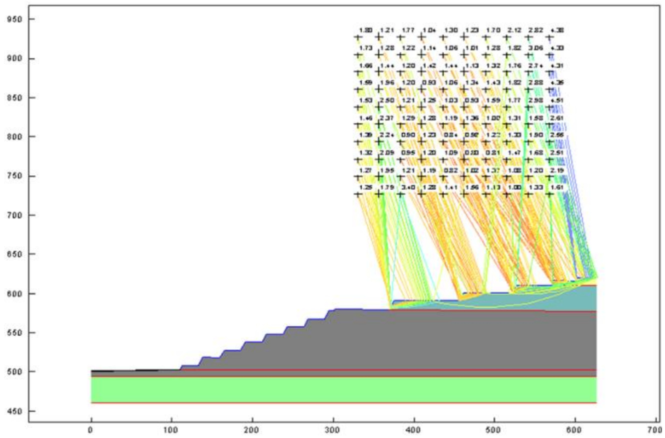


Figure 14. Calculation of the design state in the cover GGU-stability DIN 4084 circular shape

Calculations are performed adapting to the geological formations on the ground. In this case, the circular cylindrical shape is analyzed according to Equations (12) and (13). Based on the above geomechanical parameters, the safety factor is FS > 1.2. In a specific case, coal mining can be conducted up to the lower coal quota. After mining, part of the pit must be filled with clay (humus) to rehabilitate the area where coal was mined according to [10], [26], [27].

Figures 15 and 16 show a graph of the numerical data distribution for this case. In addition, a histogram with the number of distribution of geomechanical samples containing a large amount of data is presented.

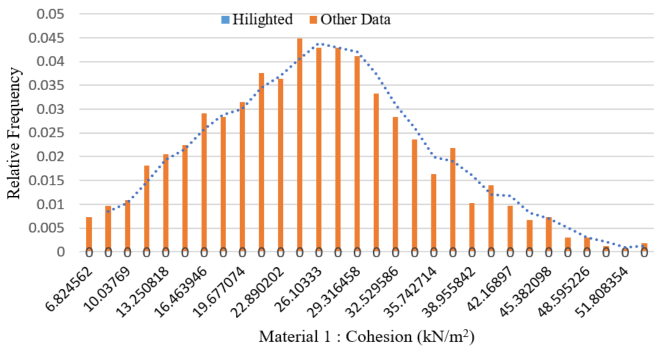


Figure 15. Histogram with the number of cohesion samples

The histogram provides a visual representation of the data distribution, showing the distribution of cohesion values and volumetric weight values in relation to the number of frequencies.

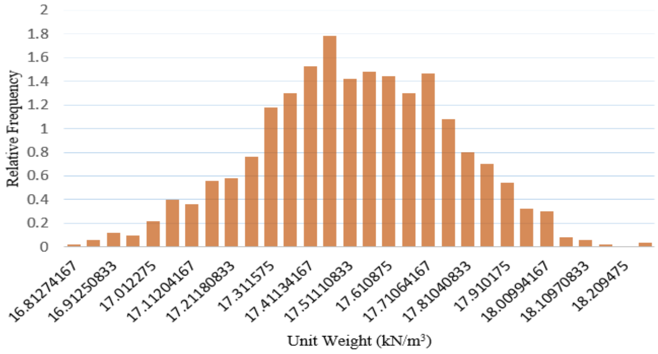


Figure 16. Histogram with the number of volumetric weight samples

The bar graph shows the frequency or number of observations within different numerical intervals.

Safety factor for the number of samples and the ratio for the safety factor and volumetric weight are presented in Figures 17 and 18. It is clear that the results obtained for each layer are reliable for the maximum number of samples analyzed. But according to the "Student" criterion, with a reliability of 95%, the minimum number of analyzed samples should be over 30 samples. This is fully confirmed in our case, where the safety factor value is almost unchanged when a number of analyzed samples is over 30.

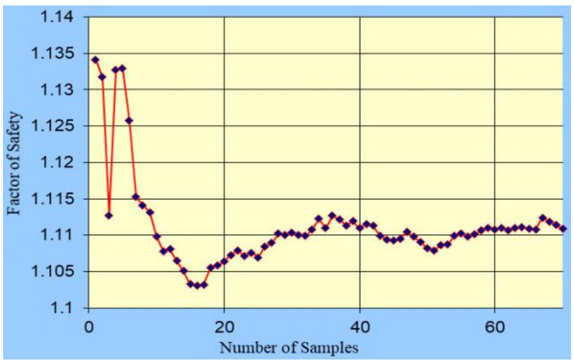


Figure 17. Safety factor in relation to the number of samples

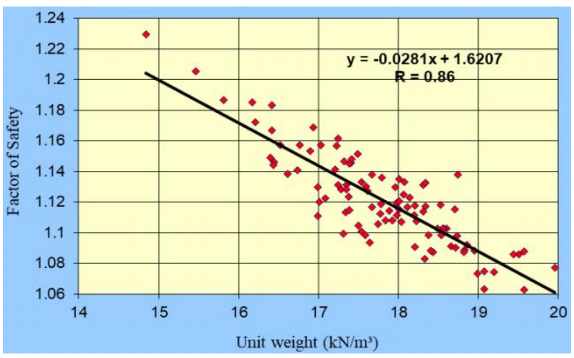


Figure 18. Correlation in relation to the safety factor and volumetric weight

Based on the graph shown in Figure 18, geomechanical sample analyses are represented by a correlation coefficient in a mathematical way according to the equation Equations (8)-(11). Using the ratio between the two variables as specific cases in this part of the graph, we obtain the volumetric weight in relation to the safety factor. Based on the result, it can be seen that we have a high correlation between them and that this linear correlation is negative. So, with an increase in the volumetric weight value, we have a decrease in the safety factor value.

5. Conclusions

The main purpose of this research was to identify a coal seam by means of additional drilling inside a coal mine to determine and analyze geomechanical parameters for each seam while analyzing a large number of samples. In a specific case, three softwares were used to calculate of the slopes. The results for the design state with a safety factor according to geotechnical standards were compared in such a way that coal mining is performed in accordance with the design standards for surface mining with the priority of labor safety, where workers are involved, and taking into account of technological consequences. Based on the results obtained above and according to the design state, the safety factor of the mine with geomechanical parameters for the design state is within the geotechnical values and standards. Coal mining can be conducted according to the demands of the existing power plants, where electricity is produced for the community in general.

Based on the calculation results and according to the profiles, the design geometry of the slopes is stable for conditions with natural moisture. In the course of geomechanical calculations, all available information such as (geology, hydrogeology, geomechanical research and technology) was integrated. The results of the design state profiles show that the slopes are as stable as the rest.

For yellow clays, the optimal slope height is $H = 10$ m with a slope angle of $\alpha \leq 25^{\circ}$. For ash-colored clays, the optimal height at the working front is 12 m with a slope angle of $\alpha \leq 25^{\circ}$, while for the general slope, the height should be $H = 100$ m with an angle of $\alpha \leq 10^{\circ}$.

For coal, the maximum height for each level of the open pit is 12 m and the slope angle is $\alpha \leq 65^{\circ}$, while the general slope height for coal seam can reach a height of $H = 80$ m, with a general slope angle of not more than $\alpha \leq 20^{\circ}$.

In conclusion, it can be confirmed that coal mining for the design geometry is expedient with a safety factor FS > 1.2. As for the calculations, they fully comply with the condition of geotechnical safety, so that coal mining is conducted in accordance with market requirements, both for existing power plants and beyond, while maintaining the design geometry of the side slopes.

After all, after the use of coal, it is recommended to recultivate the mine in order to preserve the environment for the Community at the same time and further according to the permitted European Union standards.

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Геомеханічні дослідження відкритого видобування вугілля з погляду обґрунтування геотехнічної безпеки

Х. Ахметі, Е. Малікі

Мета. Визначення геомеханічних параметрів для розрахунку стійкості бічних укосів по частковому та загальному куту у фронті виробки для забезпечення повноти видобутку вугілля згідно з геотехнічними правилами і стандартами на підставі нормативних документів (ЕС-7) Косівської енергетичної корпорації.

Методика. Проведено 60 додаткових бурових свердловин на глибину 150 м до контакту із вологою необробленою глиною для визначення товщини вугілля з використанням свердлильного верстата типу ЕК-650 і діаметра свердління 145/101 мм. Для визначення кута *φ* та зчеплення *C* було використано два методи, зокрема прямий і тривісний тести. Для отримання найбільш точних результатів застосована математична модель для встановлення геомеханічних параметрів та геометрії укосів з метою досягнення запасу міцності за геотехнічними нормами.

Результати. Встановлено наявність невідповідних фізико-механічних параметрів через тектоніку, особливо наявність ґрунтових вод та глинистих мас. Визначено, що мають місце ділянки з потужністю вугілля від 0.5 до 1 м, що цілком позначається на зниженні теплотворної здатності вугілля, але також ускладнює видобуток вугілля на родовищі з точки зору геотехнічної безпеки. Визначено, що необхідно спроектувати таку геометрію укосу, яка зможе забезпечити стабільність шахти, а також видобування вугілля у повній відповідності до вимог ринку.

Наукова новизна. Розроблено математичну модель, за допомогою якої було розраховано геометрію укосів за розробленими профілями та 9 методиками. Це дало задовільні результати на основі Єврокоду ЕС-7, які можуть бути застосовані у польових умовах.

Практична значимість. Проведені розрахунки технології видобування вугілля з рекомендованою геометрією повністю відповідають умові геотехнічної безпеки, завдяки чому видобуток ведеться відповідно до вимог ринку як для існуючих електростанцій, так і за її межами зі збереженням розрахункової геометрії бічних укосів.

Ключові слова: *геомеханічні параметри, гетехнічна безпека, Єврокод, видобування вугілля*