

НАУЧНО-ТЕХНИЧЕСКИ СЪЮЗ ПО МИННО ДЕЛО, ГЕОЛОГИЯ И МЕТАЛУРГИЯ
SCIENTIFIC AND TECHNICAL UNION OF MINING, GEOLOGY AND METALLURGY
НАУЧНО-ТЕХНИЧЕСКИЙ СОЮЗ ПО ГОРНОМУ ДЕЛУ, ГЕОЛОГИИ И МЕТАЛЛУРГИИ



PROCEEDINGS

of the

XII INTERNATIONAL GEOMECHANICS CONFERENCE

7 – 11 September 2026
Astor Garden Hotel, Sts. Constantine and Helena
Varna, Bulgaria

Proceedings of the XII INTERNATIONAL GEOMECHANICS CONFERENCE



**7 – 11 September 2026
Varna, Bulgaria**

EDITORIAL BOARD

**Prof. DSc Nikolay Nikolaev, Prof. Dr. Krastyo Dermendzhiev,
MSc Eng. Tzvetan Dilov, Prof. Dr. Chavdar Kolev,
Assoc. Prof. Dr. Nikolay Milev, Prof. Dr. Georgi Mihaylov,
Assoc. Prof. Dr. Veliko Parushev, M.Sc. Eng. Georgi Petrov,
Dr. Eng. Maria Topalska, Prof. Dr. Andrey Totsev**

**SCIENTIFIC AND TECHNICAL UNION OF MINING, GEOLOGY AND METALLURGY
2026, Bulgaria**

ISSN: 1314-6467

GOLDEN SPONSOR

GEOTECHMIN GROUP



SILVER SPONSOR





***Dear Ladies and Gentlemen,
Dear Colleagues,
Dear Guests,***

I am pleased on behalf of the Organizing Committee to congratulate the participants in the **XII International Geomechanics Conference**.

This year's edition of the conference is the twelfth, and the conference has been held for more than 27 years, which proves the authority and significance of this scientific forum. The theme of the conference this year is **"Geomechanics in a Changing Engineering Environment"**.

The conference topics include the entire spectrum of fundamental issues related to the physical and mechanical properties of rocks and soils, the stress-strain state of rock massifs and soils, measurements in geomechanics and remote methods, stability assessment, blasting and seismic impacts, dynamic manifestations of rock pressure, ecology and environmental protection, and artificial intelligence. This actual thematic topics provoked your interest again and we suggest to your attention these scientific papers, presented on the conference.

I would like to express my sincere gratitude to the Golden Sponsor Geotechmin Group - Geotechmin OOD, Ellatzite-Med AD, Geotrading AD, Geostroy AD and Silver Sponsor - Assarel Medet AD.

The discussion of research results during the conference will provide opportunities for the application of geomechanical methods related to the development and use of underground space in the mining industry, construction, industrial and public buildings, transport facilities, and others.

We look forward to meeting you at the **XIII International Geomechanics Conference!**

Be healthy and good luck!

**Assoc. Prof. Dr. Eng. Kremena Dedelyanova
Chairperson of the Organizing Committee**



АСАРЕЛ МЕДЕТ - АД

МИННО-ОБОГАТИТЕЛЕН КОМПЛЕКС - ГР. ПАНАГЮРИЩЕ



www.asarel.com

МИННО-ОБОГАТИТЕЛЕН КОМПЛЕКС

„Асарел-Медет“ АД

4500 Панагюрище, България

e-mail: pbox@asarel.com

www.asarel.com





С иновации и опит, ръка за ръка, градим заедно бъдещето

ГЕОСТРОЙ
ГРУПА ГЕОТЕХМИН

Инфраструктурно

Промислено

Гражданско строителство



THE
PARTNER
YOU
CAN **RELY ON**

Reliable Supply Chain Solutions
for Mining Industry



УСТОЙЧИВО РАЗВИТИЕ - СТАНДАРТ ЗА КАЧЕСТВЕН ЖИВОТ



ЕЛАЦИТЕ МЕД

ГРУПА ГЕОТЕХМИН



УПРАВЛЕНИЕ

с. Мурково 2086, Тел: (02) 923 77 21,
e-mail: office@ellatzite-med.com

РУДОДОБИВЕН КОМПЛЕКС

гр. Етрополе 2180, Тел: (02) 923 76 72,
e-mail: mine.complex@ellatzite-med.com

ОБОГАТИТЕЛЕН КОМПЛЕКС

с. Мурково 2086, Тел: (02) 923 77 29,
e-mail: flotation.complex@ellatzite-med.com





140
ГОДИНИ

ФЕДЕРАЦИЯ
НА НАУЧНО-ТЕХНИЧЕСКИТЕ
СЪЮЗИ В БЪЛГАРИЯ



CONTENTS

	Topic A	1
	Physical and mechanical properties of rocks and soils	
	Физико-механични свойства на скали и почви	
<u>A-1</u>	PHYSICAL - MECHANICAL CHARACTERISTICS OF SECONDARY QUARTZITES FROM THE LOCALITY "CRN VRV" AS A MATERIAL FOR ROAD TAMPON	3
	Blagica Doneva, Gorgi Dimov, Radmila Karanakova Stefanovska	
	Topic B	9
	Stress and strain state of rock massifs and soils. Interaction between massifs and structures	
	Напрегнато и деформирано състояние на скален масив и почви.	
	Взаимодействие между масива и конструкциите	
<u>B-1</u>	ИЗСЛЕДВАНЕ НА ФРИКЦИОННИ АНКЕРИ ТИП „СПЛИТ СЕТ- Н“ В УСЛОВИЯТА НА РУДНИК „МИЛИН КАМЪК“	11
	Г. Стоянчев, Кр. Дерменджиев, Ир. Михайлова	
<u>B-2</u>	ДЕФОРМАЦИОНЕН ПРЕХОД ПРИ ЗОНИРАНО ЛОКАЛНО ПОДОБРЯВАНЕ НА ЗЕМНАТА ОСНОВА С КОРАВИ ВКЛЮЧЕНИЯ: БЪЛГАРСКИ ПРИМЕР ОТ ПРАКТИКАТА	17
	Цветан Лозанов, Николай Милев	
<u>B-3</u>	УТОЧНЕНИЕ НА ГЕОМЕХАНИЧНАТА ТЕОРИЯ ЗА ЕКСТРЕМНИ ДЪЛБОЧИНИ	27
	Николай Жечев, Рафаил Рафаилов	
	Topic C	35
	Measurements in geomechanics. Contact and remote methods. Monitoring	
	Измервания в геомеханиката. Контактни и дистанционни методи.	
	Мониторинг	
<u>C-1</u>	MODERN GEOTECHNICAL INVESTIGATIONS OF SOILS	37
	Wojciech Sas	
<u>C-2</u>	ПРИЛОЖЕНИЕ НА ДИСТАНЦИОННО ГЕОТЕХНИЧЕСКО КАРТИРАНЕ ЧРЕЗ UAV-БАЗИРАНА ФОТОГРАМЕТРИЯ В РУДНИК ЕЛАЦИТЕ	44
	Iv. Vasilev	
<u>C-3</u>	ПРЕДИЗВИКАТЕЛСТВА ПРИ НАЗЕМНОТО ЛАЗЕРНО СКАНИРАНЕ В ПОДЗЕМНОТО МИННО СТРОИТЕЛСТВО И ПРАКТИЧЕСКИ ПОДХОДИ ЗА ТЯХНОТО ПРЕОДОЛЯВАНЕ	52
	Марко Марков	
<u>C-4</u>	ANALYSIS OF OUTLIER DETECTION METHODS IN RTK-GNSS DEFORMATION MONITORING	57
	Roumen A. Ivanov, Nevena I. Babunska-Ivanova	
<u>C-5</u>	ГЕОТЕХНИЧЕСКИ И КОНСТРУКТИВЕН МОНИТОРИНГ В ПОДЗЕМНОТО ГРАДСКО СТРОИТЕЛСТВО	63
	Борислав Борисов	

Topic D

73

Stability assessment. Dynamic impacts. Manifestations of rock pressure. Probabilistic approach. Hazard and risk in geomechanics. Artificial intelligence

Оценка на устойчивото състояние. Динамични въздействия. Прояви на скалния натиск. Вероятностен подход. Опасност и риск в геомеханиката. Изкуствен интелект

- D-1 MACHINE LEARNING-BASED PREDICTION OF PERMEABILITY IN ANTHROPOGENIC AGGREGATES: TOWARDS SIMPLIFIED ENGINEERING MODELS** 75
Justyna Dzięcioł
- D-2 IMPACT OF EXTREME RAINFALL RISKS ON OPENCAST MINES PLANNED DEWATERING AND SLOPE STABILITY** 83
Pavlovic N., Petrovic B., Subaranovic T., Pavlovic V.
- D-3 FORECASTING THE MANIFESTATIONS OF ROCK PRESSURE IN COAL-BEARING MASSIFS BASED ON CHANGES IN GAS MIXTURE PARAMETERS** 90
Nataliia Vergelska, Victoriia Vergelska
- D-4 ENGINEERING-GEOLOGICAL ANALYSIS OF THE STABILITY OF THE FINAL SLOPES IN MARL MINES** 93
Radmila Karanakova Stefanovska, Zoran Panov, Risto Popovski, Blagica Doneva
- D-5 АНАЛИЗ И ОПТИМИЗАЦИЯ НА ПАРАМЕТРИТЕ НА „ПВР“ В ОТКРИТ РУДНИК „ЕЛАЦИТЕ“ ЗА ОГРАНИЧАВАНЕ НА ПРЕХВЪРЛЯНЕТО НА ВЗРИВЕНА СКАЛНА МАСА КЪМ ПО-ДОЛНИ РАБОТНИ ХОРИЗОНТИ** 101
Радослав Асенов
- D-6 ГЕОМЕХАНИЧНА СЪЩНОСТ НА БАРИЕРНИТЕ ЦЕЛИЦИ И ПОДХОДИ ЗА ТЯХНОТО ОРАЗМЕРЯВАНЕ** 110
Георги Михайлов
- D-7 APPLICATIONS OF NEURAL NETWORKS TO SLOPE STABILITY PREDICTION** 125
Kremena Arsova, Dimitar Kaykov
- D-8 ХВОСТОХРАНИЛИЩАТА В БЪЛГАРИЯ: ИСТОРИЧЕСКО РАЗВИТИЕ, ТЕХНОЛОГИИ НА ИЗГРАЖДАНЕ И ЗНАЧЕНИЕ НА СТРУКТУРАТА НА ХВОСТА ЗА ОЦЕНКАТА НА ВТЕЧНЯВАНЕТО** 132
Момчил Бояджиев, Николай Милев
- D-9 ГЕОМЕХАНИКАТА – ОСНОВА ПРИ ПРОЕКТИРАНЕ, ОСНОВА ПРИ ИЗБОРА В ПАРАМЕТРИТЕ НА СИСТЕМИТЕ НА РАЗРАБОТВАНЕ, ОСНОВА ПРИ ОСИГУРЯВАНЕ НА ДЪЛГОВРЕМЕННА УСТОЙЧИВОСТ НА ИЗЗЕТИТЕ ПРОСТРАНСТВА, ОСНОВА НА ПОДЗЕМНИЯ ДОБИВ НА ПРИРОДНИ РЕСУРСИ** 143
Георги Дачев

Topic E

151

Environmental protection. Sustainable development. Geotechnical aspects of cultural heritage

Опазване на околната среда. Устойчиво развитие. Геотехнически аспекти на културното наследство

<u>E-1</u>	CARBON FUNCTIONS OF PEATLAND GEOSYSTEMS IN THE NORTH-WESTERN REGION OF UKRAINE: A REGIONAL ASSESSMENT IN THE CONTEXT OF EUROPEAN EVIDENCE	153
	Andrii Pokshevnytskyi	
<u>E-2</u>	ЕКСПЕРИМЕНТ ЗА НАМАЛЯВАНЕ НА ОБЕМА НА МЕЛНИЧЕН ОСТАТЪК ПОДАВАН ЗА ПОВТОРНО СМИЛАНЕ	157
	Цветан Дилов, Иванина Сергеева	
<u>E-3</u>	ЕТИЧНИ ПОСЛАНИЯ ЗА ЧОВЕШКОТО ПОВЕДЕНИЕ В УСЛОВИЯТА НА ОБЩЕСТВЕНИЯ И ДИГИТАЛНИЯ ПРЕХОД	163
	Веселина Александрова, Ваня Тагарева, Виолета Василева	
<u>E-4</u>	ПОЛИТИКАТА ЗА ЗДРАВЕ, БЕЗОПАСНОСТ И ОКОЛНА СРЕДА	172
	Владислав Стойков	



TOPIC A

Physical and mechanical properties of rocks and soils

Физико-механични свойства на скали и почви

ENGINEERING-GEOLOGICAL ANALYSIS OF THE STABILITY OF THE FINAL SLOPES IN MARL MINES

Radmila Karanakova Stefanovska¹, Zoran Panov¹, Risto Popovski¹, Blagica Doneva¹

¹University Goce Delcev, Faculty of natural and technical science, Stip, Republic of Macedonia,
radmila.karanakova@ugd.edu.mk

ABSTRACT

The stability of final slopes represents one of the key factors for the safe and economically sustainable exploitation of mineral resources in surface mines. This paper presents an analysis and assessment of the stability of final slopes in a mine of marl, with particular emphasis on the geomechanical properties of the material and the influence of hydrogeological conditions. Interactive limit equilibrium methods were applied using the student version of the GeoStudio (Slope/W) software, with the aim of determining the factor of safety and enabling more effective and reliable recultivation of final slopes of the open pit.

Keywords: marl, slope stability, Geostudio, engineering-geological analysis, final slopes

INTRODUCTION

Slope stability represents one of the key factors for the safe and economical operation of surface mines. Particular attention should be given to the analysis of final slopes, which remain as permanent geomorphological features after the completion of mining activities and may represent a potential source of geotechnical hazards. Their stability directly affects environmental safety, the protection of surrounding infrastructure, and the potential of land reclamation.

Marl, as a sedimentary rock composed of varying proportions of clay and carbonate materials, exhibits specific engineering-geological and geomechanical characteristics. Its pronounced sensitivity to water, susceptibility to weathering, and reduction of strength parameters under saturated conditions make this material particularly critical in the design and construction of mine slopes. Furthermore, the presence of discontinuities, bedding planes, and tectonic disturbances may significantly reduce the stability of slopes in marl deposits.

The formation of final slopes is influenced by numerous factors, including geological structure, hydrogeological conditions, slope geometry, mining technology, and various external influences. Therefore, the application of modern engineering-geological investigation methods and geomechanical modelling techniques is essential to obtain a realistic assessment of the factor of safety and to define appropriate stabilization measures.

The aim of this study is to perform an engineering-geological analysis of the stability of final slopes in marl surface mines by determining the relevant geological and geomechanical parameters and incorporating them into analytical and numerical models. The research examines the key factors affecting slope stability, evaluates the factor of safety through stability analyses, and proposes technical measures to improve the long-term stability of final mine slopes.

GEOLOGICAL AND ENGINEERING-GEOLOGICAL CHARACTERISTICS OF MARL AS A GEOLOGICAL MEDIUM

Marl is most commonly found within sedimentary basins, where it forms stratified sequences of varying thickness and continuity. It consists of a mixture of clay minerals and calcite, and the proportion of these components determines its classification and engineering properties. An increase in the clay content makes the material less resistant and more plastic, whereas a higher carbonate content results in greater strength and brittleness.

From a stratigraphic perspective, marl occurs as layers of different thicknesses, frequently interbedded with clay, limestone, or sandstone. These interlayers create a heterogeneous geological environment, which represents an important factor in slope stability analyses. The marl rock mass is commonly affected by various tectonic structures, such as joints, faults, and bedding discontinuities. These discontinuities reduce the overall strength of the rock mass and may act as potential slip surfaces. Of particular importance are weak zones that

can be activated by external factors such as water infiltration, blasting-induced vibrations, and other dynamic loads.

In general, marl exhibits low to moderate permeability; however, its mechanical behaviour changes significantly when saturated with water. The presence of water leads to a reduction in shear strength parameters, an increase in plasticity, and progressive degradation of the marl structure. Infiltration of surface water, together with the presence of groundwater, may generate pore water pressure, which directly reduces the effective stress within the rock mass and consequently decreases the stability of mine slopes.

GEOMECHANICAL CHARACTERISTICS OF MARL

In slope stability analyses, the most influential factors are the physical-mechanical parameters, strength parameters, and deformation characteristics of the rock mass. These parameters serve as input data for analytical and numerical models used to calculate the factor of safety.

Physical-mechanical parameters

The most important physical-mechanical parameters include natural density, unit weight, porosity, moisture content, degree of saturation, and permeability. These properties primarily depend on the relative proportions of the carbonate and clay components, as well as on the degree of compaction of the material.

Strength parameters

The **Mohr–Coulomb failure criterion** is most commonly used to define the shear strength of marl. According to this criterion, shear strength is determined by two fundamental parameters:

- Cohesion (c)
- internal friction angle (ϕ)- the component of shear strength generated by friction between particles.

In engineering practice, the following approximate values are commonly adopted for marl:

Parameter	Typical range
Cohesion (c)	50-300 kPa
Internal friction angle (ϕ)	20°-35°

Deformation characteristics

Deformation properties are essential for evaluating the displacements and stress distribution within a slope. The most important deformation parameters include:

- **Young's modulus (E);**
- **Poisson's ratio (ν);**
- **Deformation modulus;**
- **Compressibility.**

Young's modulus represents the stiffness of the material. The higher the value of Young's modulus, the smaller the deformations under the same loading conditions. In marl, Young's modulus may vary considerably, typically ranging from **0.5 to 10 GPa**, depending on the degree of fracturing and the compactness of the rock mass.

Poisson's ratio generally ranges between **0.20 and 0.35**, indicating a moderate degree of lateral deformation under loading. Due to the pronounced heterogeneity of marl, these parameters are usually determined through laboratory testing and in-situ geotechnical investigations. Accurate determination of these properties is essential for reliable numerical modelling and for obtaining realistic assessments of slope stability under various geological and hydrogeological conditions.

Factor of safety

Every slope stability analysis produces a single numerical value that indicates the degree of safety against slope failure or sliding under the specified conditions. This value is referred to as the **factor of safety (FoS)**, **safety coefficient**, or **safety factor**. The factor of safety can be expressed as the ratio of resisting forces to driving forces or, alternatively, as the ratio of resisting moments to driving moments.

In geotechnical engineering, the analysis of slope stability and bearing capacity begins with the assumption of a potential failure surface or slip surface, after which the resisting forces acting along that surface are calculated and compared with the forces promoting failure.

Table 1 presents the recommended ranges of the factor of safety for different types of geotechnical structures, as proposed by Jumikis, Terzaghi i Peck.

Table 1 Recommended Factors of safety

Type of structure	F
Cut slope	1.1-1.5
Dam	1.15-1.7
Waste dump	1.0-1.5
Surface mine slope	1.1-1.5

Several methods are available for the geotechnical analysis of slope stability, including the **Method of Slices**, the **Bishop method**, the **Janbu method**, and the **Spencer method**. Among these, the **Bishop simplified method** is one of the most widely used limit equilibrium methods due to its balance between computational efficiency and accuracy, making it particularly suitable for the analysis of circular failure surfaces in homogeneous and moderately heterogeneous slope conditions.

STABILITY ANALYSIS OF FINAL SLOPES IN A MARL SURFACE MINE

One of the primary objectives of this study is to evaluate the geotechnical stability of the final benches in a marl surface mine. A case study of a typical open-pit marl mine was considered, where the highest bench elevation is **450 m above sea level (a.s.l.)**, while the lowest bench is located at **390 m a.s.l.**. The bench height was set at **10 m**, the working bench face angle was adopted as **42°**, whereas the overall final slope angle of the inactive slopes was designed to be **less than 30°**. During the formation of the final pit limits, **8 m wide safety berms** were incorporated to improve long-term slope stability. Temporary haul roads were designed with a maximum longitudinal gradient of **7%** and a minimum curve radius of **20 m**, in accordance with standard surface mining practice.

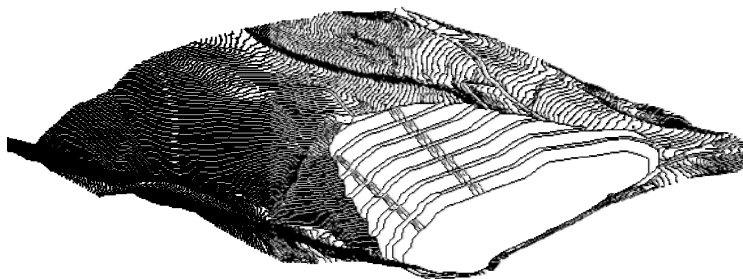


Fig.1 View of the surface mine slopes from southwest

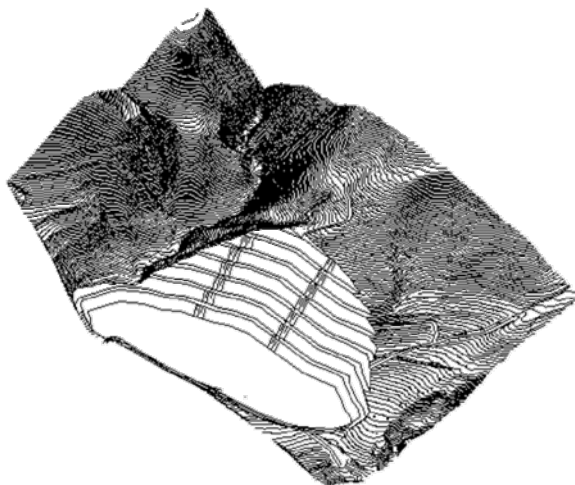


Fig.2 View of the surface mine slopes from the southeast

The geotechnical stability analysis of the final pit slopes was carried out using the **student version of the GeoStudio Slope/W** software package. The calculations were performed using the **Bishop simplified method**, one of the most widely applied limit equilibrium methods for circular slope stability analysis.

Two separate analyses were conducted to evaluate the stability of the final slope under different hydrogeological conditions. The first analysis considered a **dry slope condition**, assuming no groundwater influence and using the predefined geomechanical properties of the marl. The second analysis included a **hypothetical piezometric line**, representing groundwater conditions within the slope, in order to assess the influence of pore water pressure on slope stability. The geomechanical parameters adopted for the stability analyses were as follows:

$c=5\text{kPa}$, cohesion

$\varphi=49^\circ$, internal friction angle

$\gamma=18\text{ kN/m}^3$ Unit weight

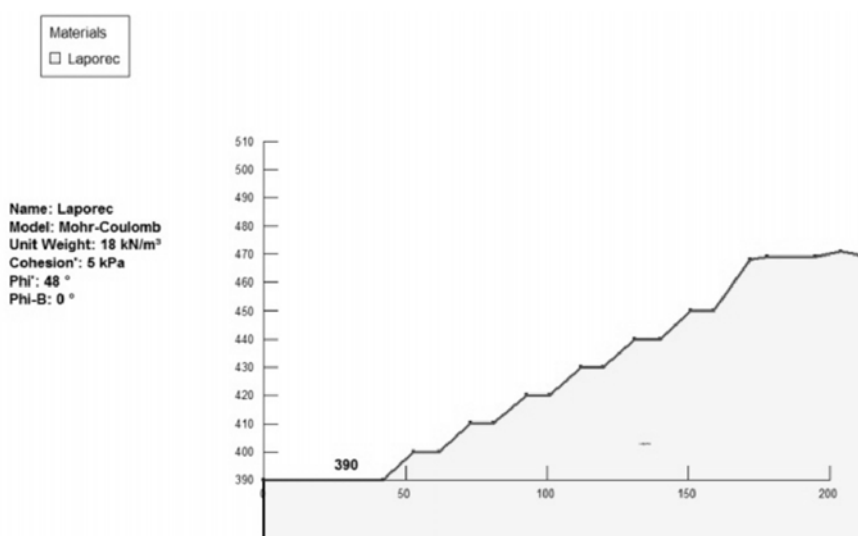


Fig.3 Geotechnical model of the final slope with defined geometry and physical-mechanical properties of marl

Figure 3 presents the geotechnical model of the final slope of the marl surface mine developed using the **GeoStudio Slope/W** software package. The model represents the actual geometry of the final slope, consisting of several benches with a height of **10 m**, resulting in a total elevation difference of approximately **80 m** (from elevation **390 m** to approximately **470 m**). The slope is composed of working benches and safety berms, with the geometry designed to ensure the long-term stability of the open pit after the completion of mining operations.

The analysis was performed using the **Mohr–Coulomb failure criterion**, one of the most widely applied constitutive models in engineering-geological and geotechnical analyses of rock masses. The model incorporates the physical and mechanical properties characteristic of marl, which define the shear strength of the rock mass and serve as the primary input parameters for calculating the factor of safety.

The model shows a continuous slope geometry without abrupt changes in inclination, contributing to a more uniform distribution of stresses within the rock mass. The incorporation of safety berms reduces the overall effective slope angle, provides storage for potential rockfall material, and facilitates surface water drainage, thereby reducing the likelihood of localized slope failures.

This model represents the initial stage of the geotechnical stability analysis, in which both the geometric configuration and the geomechanical properties of the open pit are defined.

Based on this model, the subsequent analysis involves the determination of the critical slip surface and the calculation of the factor of safety using the **Bishop simplified method**. The obtained results provide an

assessment of the stability of the final slope and serve as the basis for optimizing the slope geometry and defining appropriate measures to ensure the long-term safety and stability of the surface mine.

Figure 4 shows the computational mesh and the search radii used to generate the potential slip surfaces for which the factors of safety of the final slope will be calculated

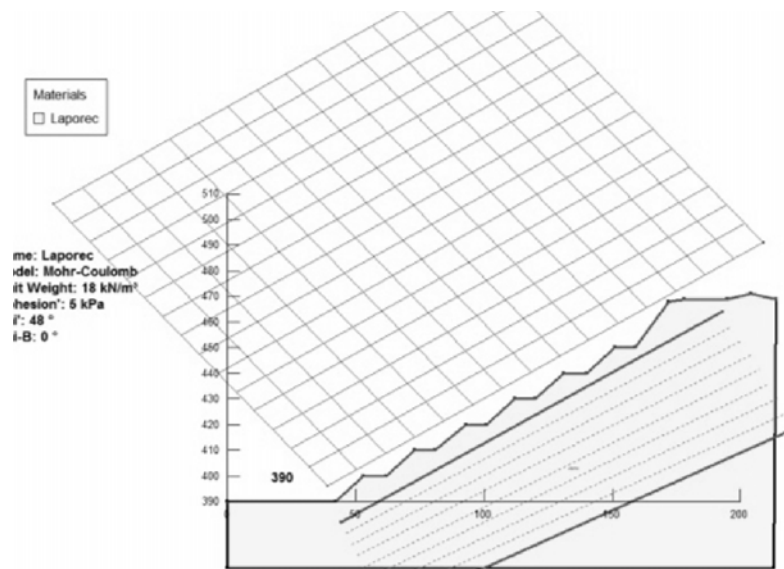


Fig.4 Geotechnical model with computational mesh and potential slip surfaces in GeoStudio Slope/W

Figure 4 presents the geotechnical model of the final slope prepared for stability analysis using the **GeoStudio Slope/W** software package. After defining the slope geometry and assigning the physical and mechanical properties of the marl, the model was discretized using a computational mesh, enabling a more accurate numerical evaluation of the stress distribution and potential failure mechanisms within the rock mass. The lines shown in the model represent the potential slip surfaces generated by the software during the search for the critical failure mechanism. By automatically generating a large number of possible slip surfaces, the program identifies the one associated with the lowest factor of safety, which represents the most critical stability condition. This approach provides a realistic assessment of the possible failure mechanisms and allows for reliable identification of the critical state of the rock mass.

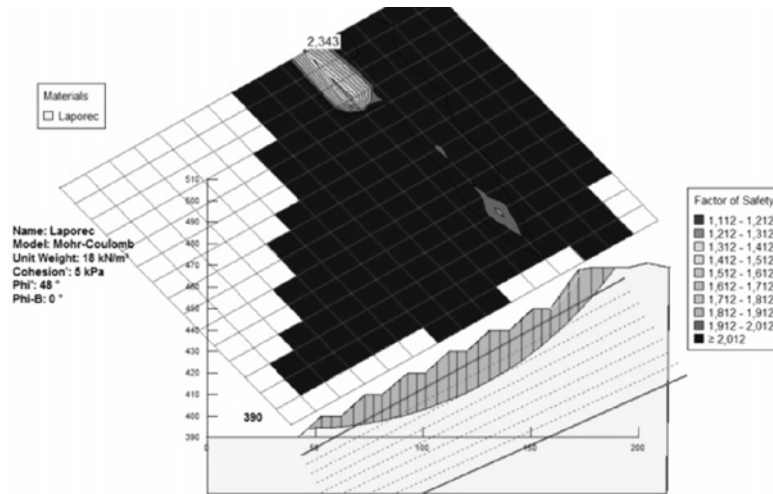
The model indicates that the potential slip surfaces develop mainly through the toe and the central part of the slope, which is characteristic of homogeneous materials analyzed using circular slip surfaces according to the **Bishop simplified method**. This type of analysis makes it possible to evaluate whether the selected geometry of the final slope provides an adequate level of stability during the operational phase of the mine as well as after mine closure.

The developed numerical model serves as the basis for determining the final factor of safety and evaluating the overall stability of the final slope. The results obtained from this analysis can be used to optimize the slope geometry, modify the slope angle where necessary, implement appropriate drainage systems, and introduce other engineering measures aimed at ensuring the long-term stability and safety of the surface mine.

Figure 5 presents the results of the slope stability analysis under dry conditions, showing the factor of safety of the potential slip surfaces in the absence of groundwater.

Figure 5 presents the results of the stability analysis of the final slope, in which the factor of safety was calculated for multiple potential slip surfaces under **dry ground conditions**, i.e., in the absence of groundwater and without the influence of pore water pressure. The analysis was performed using the **Bishop simplified method**, whereby the software automatically generated a large number of possible circular slip surfaces and identified the most critical failure mechanism. The contour plot illustrates the distribution of the factor of safety, with different colors representing different levels of slope stability. Most of the analyzed model is shown in dark black, indicating high values of the factor of safety and a stable slope condition.

The results indicate that the **minimum factor of safety is $FS = 2.343$** , which is significantly higher than the minimum recommended values for permanent slopes in surface mines (typically $FS \geq 1.30\text{--}1.50$). This demonstrates that, under dry conditions, the rock mass possesses sufficient shear strength and that there is no risk of global failure of the final slope.



Сл.5 Резултати од анализата на стабилност на завршната косина во суви услови (без присуство на подземни води).

The high factor of safety is attributed to the appropriately selected slope geometry, the relatively favorable slope angle, and the adopted geomechanical properties of the marl. In the absence of water infiltration, no pore water pressure develops to reduce the effective stresses within the rock mass, allowing the shear strength to remain at its maximum value. The obtained results indicate that the designed geometry of the final slope satisfies the criteria for long-term stability under dry conditions.

However, this represents an idealized scenario, since in actual field conditions rainfall infiltration and groundwater may significantly reduce the factor of safety. Therefore, the subsequent analysis considers the influence of the groundwater table and the saturation of the marl in order to obtain a more realistic assessment of the long-term stability of the final slope.

Figure 6 presents the results of the stability analysis of the final slope under **groundwater conditions**, represented by an assumed piezometric line incorporated into the geotechnical model. The analysis evaluates the influence of pore water pressure on the stability of the rock mass.

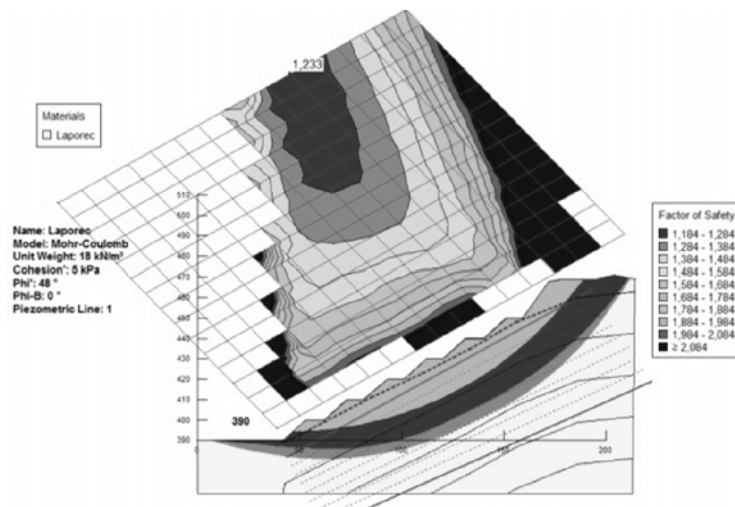


Fig.6 Results of the stability analysis of the final slope with an applied piezometric lines

By introducing the piezometric line into the model, a condition is simulated in which part of the rock mass is saturated with water. Under such conditions, pore water pressure occurs, which reduces the effective stresses in the material and consequently decreases its shear strength. As a result, the factor of safety is reduced, and the probability of slope instability increases.

From the results shown in the figure, it can be observed that the minimum factor of safety is **FS = 1.233**, which represents a significant reduction compared to the dry condition analysis, where the factor of safety was **FS = 2.343**. This reduction is a direct consequence of the influence of groundwater, which decreases the strength of the marl and facilitates the activation of potential slip surfaces. The contour plot of the factor of safety shows that the most unfavorable conditions occur at the toe and the central part of the slope, where the highest pore pressures are concentrated and where there is the greatest potential for the development of a critical slip surface. These zones are indicated by warm colors (red and orange), while the stable parts of the model are represented by green and blue shades.

The obtained factor of safety value is lower than the recommended value for permanent final slopes (**FS ≥ 1.30–1.50**), indicating that under such hydrogeological conditions there is an increased risk of instability. Although the slope is not in a state of immediate failure, its stability is significantly reduced and additional stabilization measures should be considered.

The results clearly confirm the high sensitivity of marl to the presence of water. Therefore, in the design and operation of surface mines, it is of particular importance to ensure an efficient surface and groundwater drainage system, control of atmospheric water infiltration, and continuous geotechnical monitoring. The implementation of such measures enables the reduction of pore pressures, an increase in the factor of safety, and the long-term stability of final slopes.

CONCLUSION

The engineering-geological analysis of the stability of final slopes in a marl open-pit mine has shown that slope geometry, geomechanical properties of the rock mass, and hydrogeological conditions are key factors determining its long-term stability. Due to the specific properties of marl, particularly its sensitivity to the presence of water, it is necessary to consider these factors already in the design phase of the final slopes.

By applying the limit equilibrium method (Bishop) in the GeoStudio Slope/W software package, two characteristic conditions were analyzed: a dry slope and a slope with an assumed piezometric line. Under conditions without groundwater presence, a minimum factor of safety of **FS = 2.343** was obtained, indicating that the designed geometry of the final slope provides a high level of stability and meets the criteria for safe operation and long-term security.

On the other hand, the analysis with an applied piezometric line showed a significant reduction in the factor of safety to **FS = 1.233**. This result confirms that the presence of groundwater and the development of pore water pressure have a considerable negative impact on the stability of marl, as they lead to a reduction in effective stresses and shear strength. Although the analyzed slope does not show an immediate failure condition, the obtained value indicates that under such conditions additional stabilization measures are necessary. The results of the study emphasize the importance of proper definition of slope geometry, accurate determination of geomechanical parameters, and adequate assessment of hydrogeological conditions in the design of open-pit mines.

The obtained results confirm that the application of modern numerical methods, such as GeoStudio Slope/W, represents a reliable and efficient tool for assessing the stability of final slopes. Such analyses enable timely identification of potential risks, optimization of slope geometry, and the development of engineering solutions that ensure safe, economical, and long-term sustainable exploitation of marl open-pit mines.

REFERENCES

1. Brown, E.T. and Hoek, E. 1978. Trends in relationships between measured rock in situ stresses and depth. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 15, 211-215.



Proceedings of the XII International Geomechanics Conference
7 – 11 September 2026, Varna, Bulgaria

2. Crouch, S.L. and Starfield, A.M. 1983. Boundary element methods in solid mechanics. London: Allen and Unwin
3. Hoek, E. and Bray, J.W. 1981. Rock Slope Engineering, 3rd edn. London: Institution of Mining and Metallurgy, 402 pages
4. Hoek, E. and Brown, E.T. 1997. Practical estimates of rock mass strength. Intl. J. RockMech. & Mining Sci. & Geomechanics Abstracts. 34(8), 1165-1186.
5. Panov, Z., 2011. Rock mechanics, "Goce Delcev" University – Stip, pp. 235 pages