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RESEARCH OF MARLY ROCKS ON THE TERRAIN FORECASTED FOR CONSTRUCTION OF SILOS OBJECTS

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ABSTRACT

Complexity of geological terrain built demands different level of research in order to obtain all necessary characteristics for the establishing of connections between the structure of the objects and the terrain. Frequent changes of rocks in vertical profile and their irregular settling related to creasing of the terrain during geological history makes choosing representative parameters harder. Layers of similar characteristics that are interconnected are separated into geological environments by taking medium values of the parameters within that environment.

During the research, for the purpose of constructing of the silos objects, boreholes were drilled in the axis of each silos to a depth of 10.0 m. In a small area, there is a complex structure of the terrain, which, in addition to changes in the lithological composition, is also dictated by tectonic activity. Directly in the hinterland of the research conducted with boreholes, there is an open terrain profile with a height of about 6.0 m. By connecting the layers from the investigation works and the open profile on the terrain, a clearer picture of their position on the narrow part of the terrain was obtained.

Frequent changes of layers of marly rocks and sandstones and their synclinal deposition demanded separation of certain geological environments with layers of the same characteristics. In addition to taking samples for laboratory tests, field tests of the solubility of marly rocks in the void at different temperatures were also conducted. In parallel with the samples from the investigation works, samples from the open terrain profile were examined. The results showed a shorter dissolution time of marly rocks from the open terrain profile compared to the same rocks taken from the core of the borehole.

Key words: *geotechnical environment, rock solubility, physical and mechanical characteristics of rocks*

INTRODUCTION

Terrain research in marl rocks requires a more detailed approach, given that they often alternate with sandstones, which have more favorable geomechanical characteristics. They behave differently in the presence of water and temperature changes. Depending on the type of facilities being built, it is necessary to adjust the type of research and laboratory tests.

The terrain on which the construction of silos type objects is planned is a steep slope that has been eroded over time. A large plateau was created on which smaller facilities have already been built. Terrain investigation works from the plateau are 6.0 m from the natural elevation of the terrain. Observed wider, terrain in the vertical sense is characterized by a folded shape with a synclinal dip of layers around 45^0. Marl rocks of different characteristics alternate with sandstones whose characteristics are also in a wider range.

The slope of the layers, low mightiness, variable characteristics and everything on a small area requires a specific way of connecting the construction of the objects with the construction of the terrain. The degree of cracking of the rocks reduces their characteristics, so that the separated geological environments represent a smaller complex of rocks with similar characteristics. The assessment of the characteristics of each geological environment is given through the RockLab system, where the parameter values are reduced to the natural estimated state. They are significantly lower compared to the results obtained by laboratory tests, but more realistic than the terrain conditions.

TERRAIN CHARACTERISTICS

The complexity of the terrain's morphological characteristics does not represent favorable locations for the construction of objects. That is why the terrain research is very low. The only data is related to the Basic Geological Map 1 : 100 000 and the interpreter accompanying it. Modest data, but still sufficient for an initial familiarization with the terrain, characteristics of object for construction directed research on that part of the terrain.

Earlier researchers for the basic geological map and its interpreter selected sediments that belong to the upper Eocene (E_3). They analyzed them in more detail as bank quartz sandstones, conglomerates, friable gray, greenish, sometimes ferruginous sandstones, clays, clayey marls and very rarely clays [1]. Rhythmic sedimentation is also observed, with a pronounced presence of sandstone, and to a lesser extent conglomerate and fine-grained sediments of clays and clayey marls. The slope of the layers is about 25^0.

The characteristics of the lithostratigraphic assemblage classify the terrain and the immediate surroundings as conditionally favorable to favorable terrain. From a geotechnical point of view, terrains with a permissible load > 300 kN/m2 belong to terrains of favorable stability, if other factors such as the disintegration or cracking of rocks, the inclination of the slope and layers are favorable. [2,3,4,5].

Directly at the location of the future objects, the terrain in the vertical profile is characterized by layers of variable characteristics due to the presence of soft marly rocks. [6]. The steep slopes of the layers make it difficult to build foundations in the same layer, which is why it was necessary to separate geological environments with the same or similar characteristics. Marly rocks are present in two levels as the first and second marly layers. They are more easily separated on the terrain in a vertical profile, than in the laboratory during more detailed tests.

METHODOLOGY

For a more detailed study of the terrain, a research methodology was chosen that supplemented the existing knowledge and studied the location itself in detail. The elements of those methodology are:

- Conducting terrain research that will complement the data of the Basic Geological Map,
- Definition of lithological members and their placement by investigative works along the axis of future objects to the depth of the influence of their load,
- Define their behavior in the state when they are extracted from the parent rock [7,8],
- Examination of the solubility of marl rocks in water at a daytime temperature of 36^0C and 19^0C at night temperature [3,6,9,10,11],
- Determination of time of complete solubility of marly rocks in water, evaluation of the state of dissolved material, and consolidation of dissolved particles in water after their mixing and
- With laboratory tests include standard methods for this type of rock in conditions of 18 – 20^0C, which are
    - rock solubility time,
    - volumetric weight,

- uniaxial compressive strength,
- rock strength index and
- dynamic parameters of strength as well as speed of propagation of UV waves.

During the examination, it is necessary to define whether the quasi-homogeneous sediments of the marly layer of the second and third geological environments can be considered as one layer.

RESULTS

Data from the Basic Geological Map and the open profile of the cut located in the hinterland of the plateau provided initial information about the terrain. The arrangement of the exploration boreholes was dictated by the linear arrangement of the three silos. For each silos, one borehole was drilled in its axis, figure 1. The depth of the borehole was determined by the size of the load on the silos, leaving room for it to be changed during drilling depending on the complexity of the geological structure.

During the drilling process, attention was focused on the quality of the core in order to see the natural state of the massif as realistically as possible. Detailed mapping of the core of the inflated material was carried out and samples were taken from the characteristic layers. Along with monitoring of the presence of underground water in the borehole, the behavior of marls was monitored from the time of the extraction from the rock massif to the time of their decomposition on the surface of the terrain.

Figure 1. Open cut slope profile with silos at the base

In addition to the "natural decomposition" of marls after their extraction from the rock massif, their solubility in water at a daytime temperature of 36^0C and 19^0 at night temperature was monitored [3,6,9,10,11]. Parallel to the samples from the boreholes, samples from the slope in the immediate vicinity were taken from the same rocks and treated in the same way.

The synclinal deposition of the layers is characterized by their different depths between the exploration boreholes, as well as the open profile of the slope in the hinterland, figure 1. The depths of samplings are different but represent the continuity of the same layers. Correlation of data from the Basic Geological Map and the results of exploratory drilling defined the position of the lithological members in terms of vertical occurrence and horizontal extension. According to the engineering geological classification, the separated layers belong to clastic semi-rocks, classified into three geological environments [3].

Environment 1 represents a complex of layers of fine-grained to medium-grained sandstones in several horizons, of different colors. Sandstone rocks are fine-grained to medium-grained, poorly weathered to hard and well - cemented material, varying in color from light gray to gray with occasional shades of reddish brown. The higher horizon is registered at different depths due to the synclinal alignment of the layers. It starts from a depth of 0.40 m and goes up to maximum of 2.7 m deep.

The lower horizons are at greater depths, although due to the synclinal deposition of the layers, they appear in one part from the surface of the terrain. On the terrain profile (figure 2) the middle is marked with the number 1, and the lithological layers are marked with geomechanical sandstone marks. Those are 1-PŠ^1, 2-PŠ^2, 3-PŠ^1, 5-PŠ^1, 9-PŠ^1. At the bottom of the synclinal part, a layer of well - cemented conglomerate, with a lenticular character, was separated and marked as 7-KG. The values of the parameters move in a smaller range, depending on the horizon from which they were taken, and lower mean values were adopted, table 1.

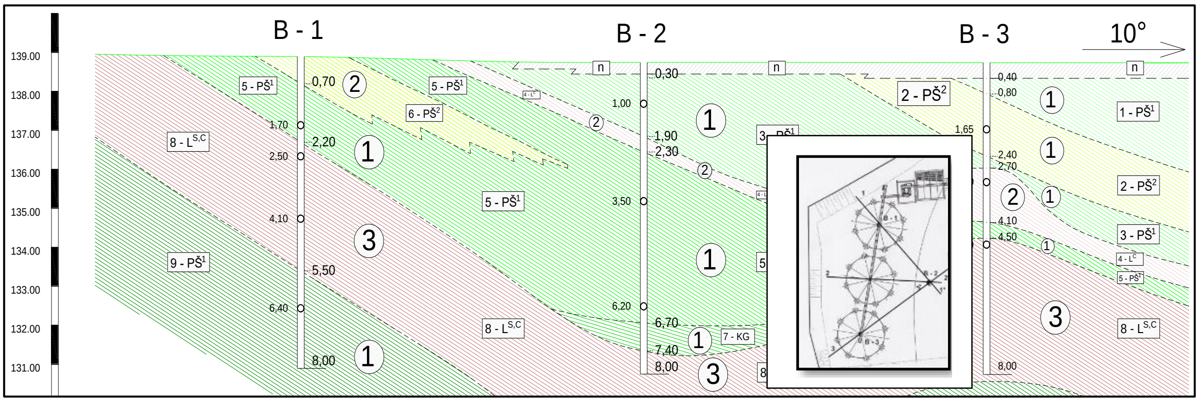

Figure 2. Terrain profile along the axis of the future objects
1,2,3, separated geological environments

Environment 2 has no continuity but is separated as a special one with presence of clayey marl and fine – to medium – grained sandstone. It appears from the surface of the terrain and sinks synclinally up to 4.5 m, with a thickness of about 3.0 – 4.0 m, and in the extreme part of the syncline it decreases to 0.4 m (figure 2). On the terrain profile, it is marked with the number 2 and with geomechanical label of the layer 4-L^C. Values of parameters are given in table 1. The environment is conditionally favorable for objects foundations. In its natural state, it is stable and has a satisfactory load capacity.

Table 1. Parameters for geotechnical environments

Geol. envir.	Profile mark	Lithological type	Physical – mechanical parameters	Adopted environment parameters
1	1-PŠ^1 2-PŠ^2 3-PŠ^1 5-PŠ^1 9-PŠ^1	Fine-grained to medium-grained sandstone, poorly weathered to hard and well-cemented material	γ = 23,66 – 26,30 kN/m³	γ = 24,00 kN/m³
			φ = 27,0 – 32,0^0	φ = 29^0
			c = 2,10 – 2,70 MPa/m^2	c = 2,40 MPa
			σ = 12,80 – 29,97 MPa	σ = 21,00 MPa
			ν = 0,20 – 0,26	ν = 0,23
			E_{din} = 22403 – 36816 MPa	E_{din} = 29000 MPa
	Average RQD 63 – 76%			
2	4-L^C	Clay marl, worn out, brittle	γ = 24,06 kN/m³	γ = 24,00 kN/m³
			φ = 26º	φ = 25^0
			c = 2,10 MPa/m^2	c = 2,0 MPa
			σ = 5,23 MPa	σ = 5,0 MPa
			ν = 0,22	ν = 0,21
			E_{din} = 15782 MPa	E_{din} = 15500 MPa
	Average RQD around 55%			
3	8-L^{SC}	Clay marl, sandy, worn out, brittle	γ = 23,57 – 25,50 kN/m³	γ = 24,50 kN/m³
			φ = 25º	φ = 25^0
			c = 2,30 MPa/m^2	c = 2,2 MPa
			σ = 3,64 – 4,91 MPa	σ = 4,0 MPa
			ν = 0,25 – 0,31	ν = 0,27
			E_{din} = 11552 – 11661 MPa	E_{din} = 11600 MPa
	Average RQD around 69%			

Engineering activities may come into contact with the water from atmospheric precipitation, which can very quickly deteriorate its physical and mechanical characteristics to the limit of soft marly clay. At the same time, it is transformed into an unfavorable environment for the foundation of objects. If the foundation of the objects is carried out in the environment 2, it is necessary to isolate it from the contact with the water.

Environment 3 forms the substrate of the terrain with the characteristics of a quasi - plastic environment, built of fine clastic rocks - marl of clayey, sandy, brittle, dark red-brown color with rare inclusions of gray hard sandstone. It appears from the surface of the terrain and goes to a greater depth from 2.2 m to 7.4 m, that is, it follows the synclinal deposition of contact layers. The center has an average thickness of 2.5 - 3.5 m in the area of the silos facilities (figure 2). On the terrain profile, it is marked with numerical code 3 and geomechanical code of layer 8-L^{SC}.

The values of the parameters are given in table 1. The environment is favorable for the foundation of objects in its natural state. It represents a stable environment, where the rock is weakly compressible to incompressible with a permissible bearing capacity that corresponds to the designed silos facilities. In contact with water, the physical and mechanical characteristics are reduced and it passes into a conditionally favorable environment. During the execution of the works, it is necessary to take measures to protect the rocks from contact with the water.

The layers of lithological members in all environments alternate rhythmically, forming an incomplete flysch sequence with the absence of certain members in the vertical column. They are characterized by frequent changes in thickness as well as lateral changes of lithological members over a short distance.

The solubility of marly rocks in water was carried out on the terrain during exploratory drilling, by hand without previously prepared equipment. It arose from the need to look at the behavior of marly rocks in water at different temperatures. Pieces of marl rock were taken from boreholes and the open terrain profile and submerged in water in different containers. Tests were performed several times at daytime and nighttime air temperatures.

Three samples were taken from the open terrain profile at a distance of about 10.0 m, which is how far the exploration boreholes are from each other. All samples were placed at the same time, under the following conditions:

- samples observed at daytime temperature 36^{0}C
- initial water temperature 13^{0}C
- final water temperature 16^{0}C

The time of complete solubility ranged from 24 to 30 minutes.

- samples observed at night time temperature 19 – 20^{0}C
- initial water temperature 12^{0}C
- final water temperature 12^{0}C

The time of complete solubility ranged from 52 to 63 minutes.

From each borehole, samples were taken from two layers at different times. Every day, testing was done on a different borehole, which was dictated by the time of exploratory drilling. The samples were observed under the same conditions, given that the day and night temperatures did not change during that period.

The marly layer of geological environment 2 under daytime conditions is characterized by values of complete solubility of 32-41 minutes. The time of complete solubility in night conditions is 58 – 74 minutes.

The marly layer of geological environment 3 under daytime conditions is characterized by values of complete solubility of 35 – 43 minutes. The time of complete solubility in night conditions is 62 – 77 minutes.

Common to the marly layer of geological environments 2 and 3 is that they show slower solubility with depth. There is no direct linear dependence between day and night solubility on all samples, given the partially different characteristics of the samples and terrain test conditions. The results are shown in table 2.

Table 2. Review of the results of the terrain tests of the solubility of marly rocks in water

<table>
<tr><th colspan="3" rowspan="2">Place of sampling</th><th rowspan="2">Conditions of research</th><th colspan="2">Time of complete solubility (min)</th></tr>
<tr><th>Day cond.</th><th>Night cond.</th></tr>
<tr><td rowspan="3">Open terrain profile of the slope cut</td><td colspan="2">Sample 1.</td><td rowspan="9">Day time temperature 36⁰C
Initial water temperature 13⁰C
Final water temperature 16⁰C

Night time temperature 19 – 20⁰C
Initial water temperature 12⁰C
Final water temperature 12⁰C</td><td>24</td><td>57</td></tr>
<tr><td colspan="2">Sample 2.</td><td>30</td><td>63</td></tr>
<tr><td colspan="2">Sample 3.</td><td>26</td><td>52</td></tr>
<tr><td rowspan="6">Boreholes</td><td rowspan="3">First layer</td><td>B – 1</td><td>37</td><td>61</td></tr>
<tr><td>B – 2</td><td>32</td><td>58</td></tr>
<tr><td>B – 3</td><td>41</td><td>74</td></tr>
<tr><td rowspan="3">Second layer</td><td>B – 1</td><td>35</td><td>67</td></tr>
<tr><td>B – 2</td><td>43</td><td>77</td></tr>
<tr><td>B – 3</td><td>37</td><td>62</td></tr>
</table>

Dissolved marl rocks are of dark grey color, resulting in a grey silty material where the particles float in the water during mixing. It was not possible to monitor the consolidation of floating particles in the water, nor to measure the total sediment in relation to the sample that was immersed in water, as well as the solidification of the sediments in a function of time. Also, the granulometric or mineral composition was not determined, which would be significant for comparison with tests in laboratory conditions.

The geotechnical properties of the terrain were determined from the aspect of the terrain's properties as a working environment in which the objects will be based. For the analysis of the geotechnical conditions for the design and construction of silos facilities, the construction of the terrain was analyzed in detail in relation to the lithological types of rocks, their position within the studied depth of the terrain as well as their mutual position, then their condition, composition, engineering geological and hydrogeological characteristics, and physical - mechanical and resistant - deformable characteristics [10,11,12,13].

Correlation of the data obtained by exploratory drilling was carried out with the data of the open terrain profile in the hinterland located a few meters from the planned objects (figure 1). The subvertical section of the slope shows all the complexity of the geological structure, which is also confirmed by exploratory drilling.

By analyzing rock strength using RocLab, lower parameter values were taken for input data. The degree of reliability of the input data of terrain and laboratory research in the part of investigative works is satisfactory. The data for the rock mass taken from the RocLab program package are quite well chosen [14,15,16,17]. The characteristics of the environments recalculated in RocLab are given in table 3 and in figure 3.

Table 3. Parameters of geotechnical environments recalculated in the RocLab massif

Parameters	Geological environment 1		Geological environment 2		Geological environment 3	
	Intact rock	RocLab massif	Intact rock	RocLab massif	Intact rock	RocLab massif
γ (kN/m³)	24	24	24	24	24,5	25,4
φ = (^{0})	29	37	25	31	25	28
c = (MPa)	2,4	1.343	2,0	0.255	2,2	0.178
σ = (MPa)	21	1.559	5,0	0.268	4,0	0.179

GSI	-	59	-	48	-	45
m_i	-	19	-	12	-	9
σ_{RM}	-	5.418	-	0.911	-	0.594
E_{din} (MPa)	29000	6.510	15500	1.250	11600	1.000
ε_{RM} (MPa)	-	2.518	-	339	-	224
γ – volumetric weight				m_i – constant that depends on the characteristics of the rock		
φ – angle of internal friction				σ_{RM} – total strength of the rock mass		
c – cohesion				E_{din} – dynamic modulus of elasticity		
σ – uniaxial compressive strength				ε_{RM} – modulus of deformation		
GSI – geological strength index						

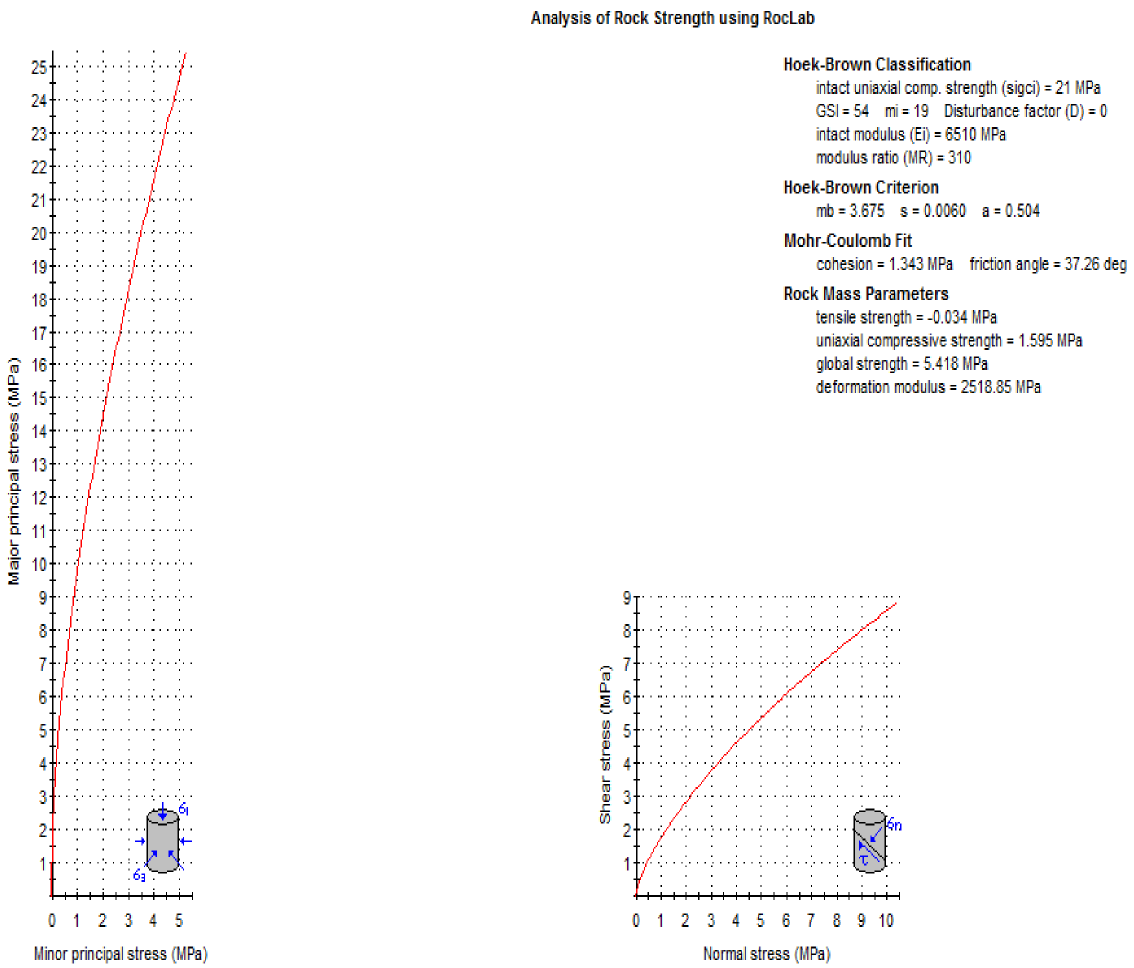

Figure 2. Values obtained by analysis in RocLab for the analyzed environments (example of environment 1)

DISCUSSION

The obtained values of the parameters for the isolated geological environments are in a wider range, and they were adopted on the basis of laboratory tests and evaluation of the quality of the rock during its mapping. Average lower values were taken, which are realistic for monolithic samples [18,19,20]. The rocks in the narrower and wider area do not represent continuity, since there are mechanical discontinuities along which can be a complete absence of cohesion forces. A closer look shows the difference in strength between the monolithic parts of the rock mass and the real rock mass. Conducted terrain research and terrain - laboratory tests show that marly rocks at the location of the future silos are found in the entire range of the group of weak sedimentary rocks [2,17,21,22].

The geotechnical environments that were engaged as working environments with their parameters were selected on the basis of laboratory tests of representative samples of solid rocks. The real properties of the marl complex and the sandstone complex were considered (lithological heterogeneity, structural - textural properties, degree of cracking and characteristics of cracks, degree of surface degradation, presence of groundwater, etc.). Existing correlations between physical - mechanical properties, structural properties and rating of rock mass were analyzed (analysis of Roc/Soil Strength using RocLab). In general, the quasi-homogeneous sediments of the marly layer of the second and third geological environments can be considered as one layer.

The solubility of marly rocks taken from the open profile of the cut terrain is shorter in time compared to the same rocks from boreholes. In the case of rocks on an open terrain profile, their structure has been damaged due to temperature oscillations over the past few years. Over time, the rocks will break down and gradually threaten the stability of the slope in that part. Terrain testing of rock solubility by immersing a sample in water is a handy method for assessing rock characteristics under altered conditions.

The ISO - 1997 standard could not be applied, where the stability of rock material in water can be determined by submerging the sample for one week. The behavior of the sample is determined descriptively in three classes. According to the state of stability in class III, the unstable state of the rock is distinguished, for the complete decomposition of rocks in water. The time of decomposition of marl rocks at the studied location is significantly shorter, which places them in this class [12,14].

The results of the state of stress in the rock massif as a whole and the rocks taken in the exploration works always differ, considering that the exploration works show the real state in the point section along the vertical. It is more or less different from the situation in the immediate surroundings, which depends from the structural - geological characteristics of the terrain.

The values obtained by the analysis in RocLab for the analyzed environments are significantly lower and they reflect the actual situation in the complete block of the rock massif. More detailed research, both in a narrower and wider location, would provide more reliable data for a more realistic view of the massif.

Separated parameters for geotechnical environments provided the starting point for geotechnical calculations for the foundation of silos objects on the investigated site.

CONCLUSION

The complexity of the geological structure of the terrain required a larger scope of research work for silos type objects. By using the data of earlier researchers in the preparation of the Basic Geological Map 1 : 100 000, data from exploratory boreholes and the open profile of the terrain in the hinterland, basic data of its characteristics were obtained. They are not highly reliable, but they represent a starting point for geotechnical calculations.

The alternation of layers in a small area and their synclinal deposition do not give the possibility of choosing a specific layer for the foundation of the building. Layers were grouped into geological environments, taking into account their similar characteristics and lower average parameter values. Three geological environments were separated, which, in addition to the parameters of laboratory tests, were also processed through the RocLab system.

Terrain - laboratory tests using auxiliary methods showed that the rocks from the open profile of the cut terrain have worse characteristics compared to the rocks found in the package of existing rocks at a certain depth. The characteristics of marly rocks change with depth, and their depth is variable due to the folded forms in which the rocks are found.

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LITERATURE

[1] Basic geological map of SFRY, sheet Zvornik, R 1: 100000, and OGK interpreter, Belgrade. Federal Geological Survey, 1980. *[Serbian language].*

[2] Djukić, D. (2004). "Geotechnical classifications for surface works in mining and construction". Tuzla. Tuzla Mining Institute. *[Serbian language].*

[3] Đurić, N. (2011). "Hydrogeological and engineering geological research". Subotica, Bijeljina. Faculty of Civil Engineering, Technical Institute. *[Serbian language].*

[4] Šestanović, S. Engineering–geological characteristics of marl from Eocene flysch in the City of Split. In Proceedings of the Second. International Symposium on Hard Soils–Soft Rocks: The Geotechnics of Hard Soils–Soft Rocks, Naples, Italy, 12–14 October 1998; Evangelista, A., Picarelli, L., Eds.; Balkema: Rotterdam, The Netherlands, 2000; pp. 311–314.

[5] Sabatakakis, N., Koukis, G., Tsiambaos, G., Papanakli, S. (2008). "Index properties and strength variation controlled by microstructure for sedimentary rocks", Engineering Geology, Elsevier, 97, 80-90.

[6] Study on the geomeganical characteristics of the terrain for the need to build a silo within the complex of facilities of the Mill "Molaris", Kozluk near Zvornik, 2019. *[Serbian language].*

[7] Sonmez, H., Gokceoglu, C., Ulusay, R. (2004). Indirect determination of the modulus of deformation of rock masses based on the GSI system. Int J Rock Mech Min Sci 41(5):849–857.

[8] Zhang, L., Einstein, HH. (2004). Using RQD to estimate the deformation modulus of rock masses. Int J Rock Mech Min Sci 41(2):337–341.

[9] Djuric, N., Besevic, M., Bursac, S., Djuric, D. (2022). Characteristics of lapory rocks at the silos location within the "Molaris" mill complex, in Kozluk near Zvornik in the Republic of Srpska. The 8thInternational Conference "Civil Engineering – science of practice". GNP 2022, Koalšin, Montenegro.

[10] Admassu, Y., Shakoor, A., Wells, N.A. (2012). "Evaluating selected factors affecting the depth of undercutting in rocks subject to differential weathering", Engineering Geology, 124, pp. 1–11.

[11] Stevanic, D., Miscevic, P. (2007). "The Durability Characterization of Selected Marls from Dalmatian Region in Croatia", Proc. of XVIII EYGEC, Ancona (Portonovo), Italy, 17-20.

[12] P. Miscevic, P., Vlastelica, G. (2011). "Durability Characterization of Marls from the Region of Dalmatia, Croatia", Geotechnical and geological engineering, Vol. 29, No. 5, pp. 771-781.

[13] Fookes, P.G., C. S. Gourley, C.S., Ohikere, C. (2008). "Rock weathering in engineering time". Quarterly Journal of Engineering Geology, London, Vol. 21, pp. 33-57.

[14] Kanji, A.M. (2014). "Critical issues in soft rocks", Journal of Rock Mechanics and Geotechnical Engineering, Vol. 6, No. 3, pp. 186-195, 2014. http://dx.doi.org/10.1016/j.jrmge

[15] Bieniawski, Z.T. (1976) Rock Mass Classification in Rock Engineering, In: Exploration for Rock Engineering, Proc. of the Symp.

[16] Bieniawski, Z.T. (1989). Engineering Rock Mass Classification, New York: John Wiley & Sons.

[17] Tziallas, G.P., Tsiambaos, G., Saroglou, H. (2009)."Determination of rock strength and deformability of intact rocks", Electronic Journal of Geotechnical Engineering, 14 G, 1-12.

[18] Hoek, E., Kaiser, P.K., Bawden, W.F. (1995). Support of Underground Excavations in Hard Rock, Rotterdam: A.A. Balkema.

[19] Hoek, E., Carranza-Torres, C.T., Corkum, B. (2002). Hoek Brown failure criterion - 2002 edition. In: Proceedings of the 5th North American Rock Mechanics Symp., Toronto, Canada, pp. 267–73.

[20] Hoek, E., Carter, T.G., Diederichs, M.S. (2013). Quantification of the Geological Strength Index Chart 47th US Rock Mechanics / Geomechanics Symposium, San Francisco.

[21] Najdanović, N. (1979). Soil mechanics and engineering practice. Mining Institute Zemun, Belgrade. *[Serbian language].*

[22] Maksimović, M. (2005). Soil Mechanics, II Edition. Construction book, Belgrade. *[Serbian language].*