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STABILITY ANALYSIS OF THE INTEGRATED WASTE DUMPS OF THE OPEN PITS ŽUTA PRLA AND BRSKOVO NEAR MOJKOVAC[**]

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Abstract

The lead and zinc ore are expected to be mined at the open pits Žuta Prla and Brskovo near Mojkovac, Montenegro. During ore mining and flotation processing, the waste from the open pits and tailings from pre-concentration (DMS) and flotation tailings are produced. Two integrated waste dumps are planned in the immediate vicinity of the open pits for disposal of these materials. This paper presents the geotechnical tests of the base of these waste dumps, as well as the tests of deposited materials, and calculation of their stability in accordance with the current legal regulations.

Keywords: *integrated waste dumps, open pits Žuta Prla and Brskovo, geomechanical tests, stability calculation*

1 INTRODUCTION

The integrated waste dumps are constructed so that the waste from open pits is disposed towards the outer edges of the floors. Between the deposited waste from the open pits and ground, the cassettes are formed of tailings from the pre-concentration (DMS) in which the flotation tailings are deposited. Transport and disposal of waste from the open pits and DMS is carried out by trucks, and delivery of flotation tailings and filling of cassettes is done by hydrotransport.

The integrated Žuta Prla waste dump is formed up to an elevation of K +1.100 m with floors 10 m high. The maximum height of waste dump is 150 m. The Brskovo integrated waste dump is formed up to an elevation of K +1.125 m, also with floors 10 m high. The maximum height of the Brskovo waste dump is 175 m. Figure 1 shows a typical vertical cross-section of a floor of the integrated waste dumps, and Figure 2 shows a typical cross-section of a cassette.

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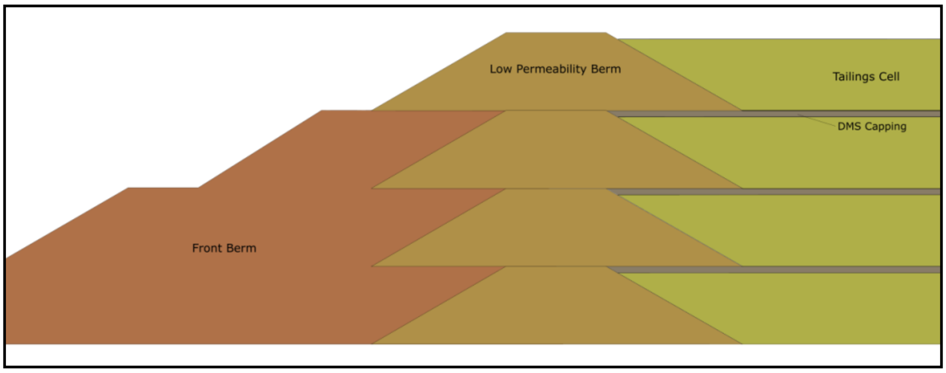

Figure 1 *Typical cross-section of an integrated waste dump floor*

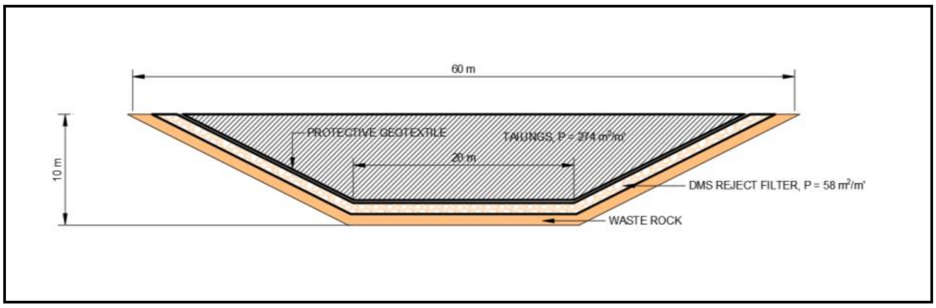

Figure 2 *Typical cross-section of a cassette*

2 GEOTECHNICAL TESTS OF A FOUNDATION

During 2020 year, the geotechnical investigations were carried out at the site of open pits and integrated waste dump sites [1]. The following work program was implemented:

- Realization of a geotechnical drilling;
- Geotechnical logging and characterization of the rock mass and definition of the model;
- Determination of the geotechnical domains;
- Defining the geotechnical input parameters by domain.

Five different working environments have been identified:

- Carbonates and Keratophyres Transition;
- Carbonates and Keratophyres Fresh;
- Volc - sediments Shales & Schists Transition;
- Volc - sediments Shales & Schists Fresh;
- Volc - sediments Shales & Schists Foliation Planes.

The results of these geotechnical tests are shown in Tables 1 and 2. Based on these parameters, the RocLab program, Figure 3, determined the calculation parameters for the stability calculation for each analysis profile.

Table 1 *Geomechanical parameters at the Žuta Prla site*

Domain		Footwall (Carbonates and Keratophyres)		Hanagingwall (Volc-sediments Shales & chists		
Sector		Transiton	Fresh	Transiton	Fresh	Foliation planes
Unit weight	(kN/m^3)	24	26	25	27	27
UCS (MPa)		40 (24-48)	65 (40-80)	18 (12-24)	30 (20-40)	-
GSI		42 (21-63)	57 (43-71)	34 (22-46)	43 (31-55)	-
Mi		10 (7-13)	15 (10-20)	8 (6-10)	12 (9-15)	-
E (MPa)		6 000	10 000	1 926	3 210	-
V		0.27	0.27	0.32	0.32	-
D		-	0.3	-	0.3	-
C		-	-	-	-	60 (40-80)
Phi		-	-	-	-	25 (22-28)

Table 2 *Geomechanical parameters at the Brskovo site*

Domain		Keratophyre		Volc-sediments		
Sector		Transiton	Fresh	Transiton	Fresh	Foliation planes
Unit weight	(kN/m^3)	25	27	25	27	27
UCS (MPa)		22 (10-34)	66 (40-80)	22 (10-34)	38 (18-58)	-
GSI		32 (20-44)	57 (43-71)	32 (20-44)	42 (32-54)	-
Mi		10 (7-13)	15 (10-20)	10 (7-13)	12 (9-15)	-
E (MPa)		2 040	10 000	2 040	3 400	-
V		0.24	0.27	0.24	0.24	-
D		-	0.3	-	0.3	-
C		-	-	-	-	60 (40-80)
Phi		-	-	-	-	25 (22-28)

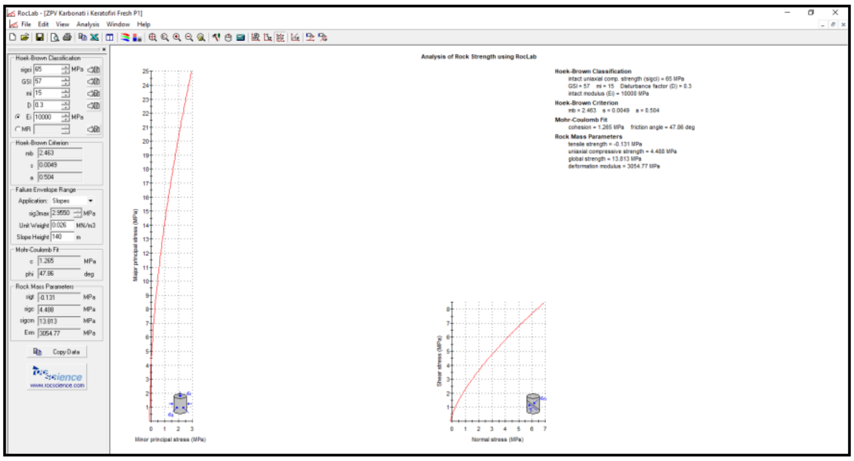

Figure 3 *Determination of calculation parameters for stability calculation in the RocLab program*

3 TESTS OF DISPOSED MATERIAL

During 2021, the tests were carried out on disposed material of in integrated landfills - waste from the open pits, DMS material and flotation tailings [2].

Based on the experience, it is assumed that the waste from the open pits will have a compacted dry density of 2.00 t/m^3. It is expected that the permeability of waste from from the open pits will be of the order of 10 $^{-4}$ to 10 $^{-5}$ m/s.

The DMS material characterization includes the Atterberg limits for material passing through a 425 µm sieve and material passing through a 75 µm sieve. The results in all cases were that the material was non-plastic. The compaction tests indicate the low optimum moisture contents (4 to 5%) and maximum dry densities of 1.87 and 1.90 t/m^3. It is assumed that these densities will also be in the disposed DMS and that the average density will be 1.9 t/m^3. Permeability for this granular material is likely to be 10^{-2} to 10^{-3} m/s on the basis of typical values for sand and gravel mixtures.

Flotation tailings are defined as a slime-clay-sized material that is expected to have a low permeability, most likely on the order of 10^{-7} to 10^{-8} m/s. Based on the previous experience, it was assumed that the dehydrated tailings after consolidation reaches a dry density of the order of 1.55 t/m^3.

Calculation parameters for calculating the stability of disposed materials are shown in Table 3.

Table 3 *Calculation parameters for calculating the stability of disposed materials*

Material	Volume weight, kN/m^3	Cohesion, kPa	Angle of natural hold, °	Pore water coefficient
Open pit waste	20.0	0	35	0.1
DMS	18.6	0	26	0.0
Flotation tailings	15.2	0	29	0.4

4 STABILITY CALCULATION

The stability calculation of integrated landfills was done with the Slide v6.0 program from the company Rocscience, under the conditions of limit equilibrium, according to the methods of Bishop and Morgenstern-Price [3 - 9].

The stability was checked in the static and dynamic conditions for an earthquake occurence with a return period of 475 years according to the Eurocod 8. The calculation was made on two profiles for the most unfavorable case, that is, for the highest height of the landfill. The geological profiles, on which the stability calculation was performed, are shown in Figures 4 and 5.

Figures 6-9 show the output interface of the Slide v6.0 program for stability calculation using the Morgenstern-Price method. Figures show the sliding planes for which the stability coefficient is the smallest. For all other sliding planes on each profile, the stability coefficient is higher than shown one. A summary of the stability calculation results is shown in Table 4.

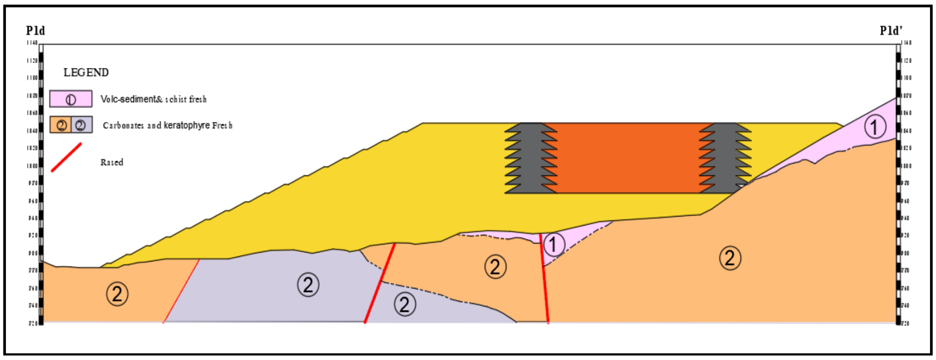

Figure 4 *Geological profile of the Žuta Prla integrated landfill*

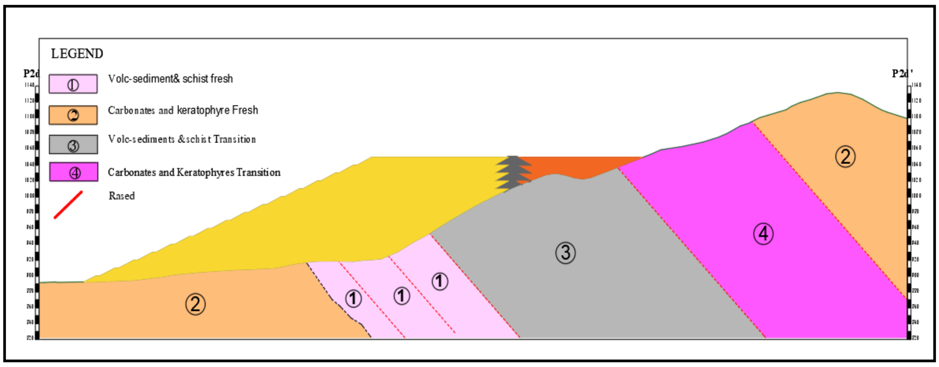

Figure 5 *Geological profile of the Brskovo integrated landfill*

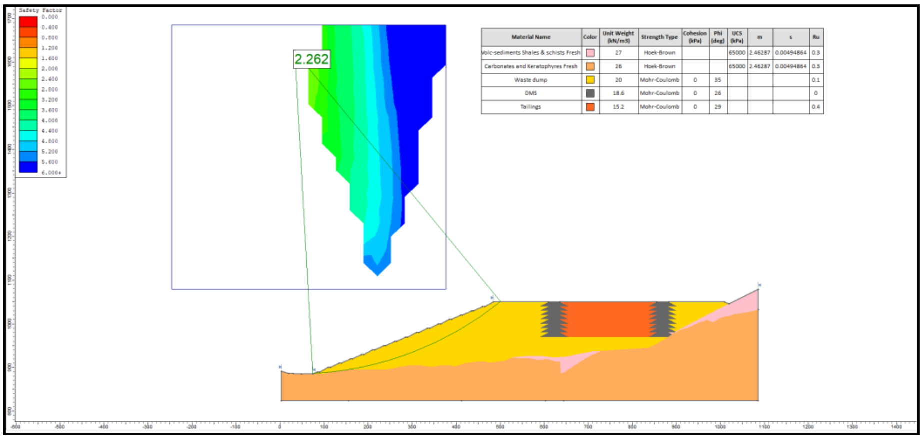

Figure 6 *Stability calculation of the Žuta Prla integrated landfill in static conditions*

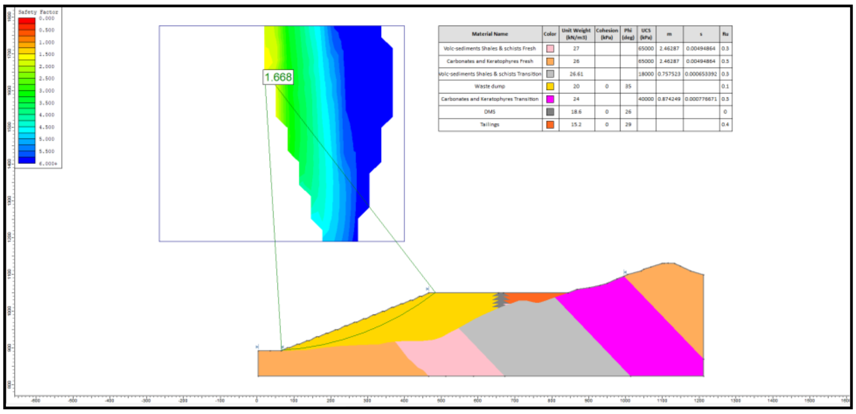

Figure 7 *Stability calculation of the Brskovo integrated landfill in static conditions*

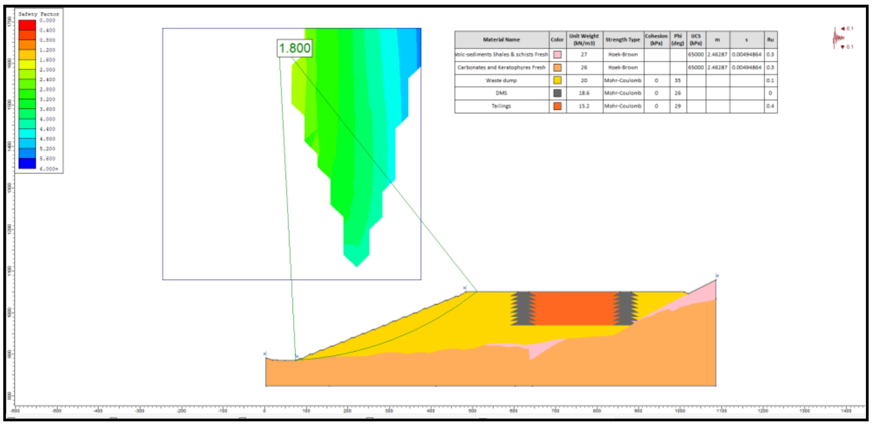

Figure 8 *Stability calculation of the Žuta Prla integrated landfill in dynamic conditions*

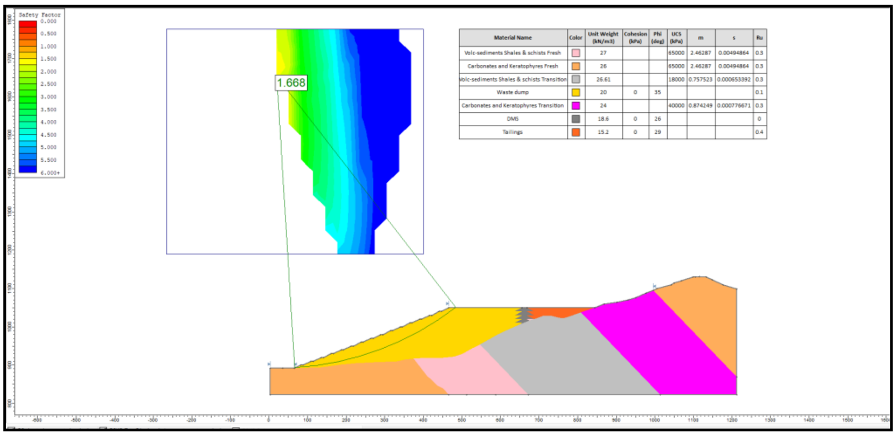

Figure 9 *Stability calculation of the Brskovo integrated landfill in dynamic conditions*

Table 4 *Stability calculation results*

Profile	F_s by Janbu method	F_s by Morgenstern-Price method
1d-1d' static	2.153	2.262
2d-2d' static	1.665	1.668
1d-1d' dynamic	1.697	1.800
2d-2d' dynamic	1.110	1.156

5 CONCLUSION

By comparison the calculated safety coefficients with the minimum allowed values defined by the Rulebook on technical norms for the open pit exploitation of mineral deposits ("Official Gazette of SFRY", Nos. 4/86 and 62/87), the conclusion is that all the obtained values are above the legal minimum which for the final slopes of the landfill is F_{smin} = 1.30.

By comparison the obtained safety coefficients of flotation tailing dump dams with the permitted minimum coefficients, prescribed by the technical conditions for the design of embanked dams and hydrotechnical embankments - SRPS U.C5.020 (former JUS), which for the embanked dams over 15 m in height is a minimum of F_s = 1.50 in the case of constant static load, that is, F_s = 1.00 in the case of occasional dynamic load for an earthquake occurence, it can be concluded that the safety coefficients for the static and dynamic loads are above the minimum prescribed values according to the analysis profiles of combined landfills.

REFERENCES

[1] A Geotechnical Pre-Feasibility Study on the Brskovo and Zuta Prla deposits, Montenegro, SRK Consulting 2020

[2] Report - Integrated Waste Management Facility - Conceptual Solution, Golder Associates (UK) Ltd 2021 (in Serbian)

[3] Rajković R., Obradović Lj., Kržanović D., Mikić M., Stability of the Dam “Prevoj Šaška” of the Flotation Tailing Dump “Valja Fundata” in Majdanpek, Mining and Metallurgy Engineering Bor, 1-2 (2019) 9-18, DOI 10.5937/mmeb1902009R

[4] Rajković R., Kržanović D., Mikić M., Jovanović M., Stability of the Ash and Slag Landfill “Maljevac” – Pljevlja for Overtop to the Peak Elevation K+832 m, Mining and Metallurgy Engineering Bor, 1-2 (2018) 17-26, DOI 10.5937/mmeb1802017R

[5] Rajković R., Kržanović D., Mikić M., Stability Dump Pit Mine “Cerovo Cementacija 1”, 46th International October Conference on Mining and Metallurgy, 01-04 October 2014, Bor Lake, Serbia; pp. 309-313.

[6] Rajković R., Kržanović D., Mikić M., Stability of Flotation Tailings in Leposavić Using Software Package GeoStudio2007, Proceedings, Mining 2014, Vrnjačka Banja, 2014, pp. 390-397.

[7] Rajković R., Bugarin M., Marinković V., Stability Analysis on Dumping “Oštreljski planir” of the Open Pit Mine “Bor” in a Function of Water Quantity, Mining and Metallurgy Engineering Bor, 3 (2013) 49-64, DOI: 10.5937/MME1303049R.

[8] Rajković R., Kržanović D., Mikić M., Marinković V., Stability of Ash and Slug Dump on Thermal Power Plant Gacko with the Software Geostudio 2007, Mining 2013 - Plans for Development and Improvement of Mining, Veliko Gradište, Srebrno jezero, 28-31 May 2013, pp. 227-231.

[9] Rajković R., Kržanović D., Lekovski R., Stability Analysis of Inner Waste Dump "Kutlovaca" of the Coal Open Pit Mine "Potrlica"– Pljevlja Using the GeoStudio 2007 Software, Mining Engineering, 1 (2010) 69-80.