Studia Geotechnica et Mechanica, Vol. XXXV, No. 1, 2013 DOI: 10.2478/sgem-2013-0001

SLOPE STABILITY ANALYSIS OF WASTE DUMP IN SANDSTONE OPEN PIT OSIELEC

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Abstract: This paper presents the slope stability analysis for the current as well as projected (final) geometry of waste dump Sandstone Open Pit "Osielec". For the stability analysis six sections were selected. Then, the final geometry of the waste dump was designed and the stability analysis was conducted. On the basis of the analysis results the opportunities to improve the stability of the object were identified. The next issue addressed in the paper was to determine the proportion of the mixture containing mining and processing wastes, for which the waste dump remains stable. Stability calculations were carried out using Janbu method, which belongs to the limit equilibrium methods.

1. INTRODUCTION

The waste dump No. 1 is located in the eastern part of the mining site in Sandstone Open Pit Osielec beyond the Osielec II mine-area, nearby the Skawa River. The waste dump consists of two levels. The lower level (470 m AMSL) is composed of material derived directly from mining operations such as shale and sandstone blocks of varying size. Gravity segregation which took place during disposal caused that large and the most isometric bodies were located in the lower part of the slope, which also improves stability of waste dump. The smallest fraction of the waste rock was therefore located in the upper part of the level. The second level (490 m AMSL) is formed from processing wastes. On the top of the object there is a processing plant and finished products are stored. It is estimated that the waste dump in this area has been operating since the 1940's. Currently, the waste dump contains about 2.1 million m^3 of rock. The average annual increase of rock waste in the object is about 32 000 m^3 and 20 000 m^3 on the first and second level, respectively [1]–[3].

During the study visit to the waste dump, which was in early September 2012, the erosion processes on the slopes were observed. The leaching of rock waste mass was caused by rainfalls. In addition, on the south-east side of the waste dump, on the slope without shelf cutting it into two levels, the indicators of landslides were observed (deformed tree trunks at the slope ground called "drunk trees").

According to the final geometry of the object, which was presented in the Technical Documentation of the waste dump [4], each level should be formed at the inclination of 45° (natural angle for the slope formation), and the slope should be cut by a shelf with at least 15 m in width. The final height of the first level is expected to reach 40–50 m and two subsequent ones about 20 m each.

A great commercial attractiveness of the material which is deposited on the first level caused that the mining company is not able to maintain definite increase of this level. Thus, an idea appeared to deposit on the first level a mixture consisting of material from mining works mixed with processing waste (which currently are stored on the second level). The proportion of components in the mixture should be chosen such as to ensure slope stability of the object.

The slope stability analysis of waste dump was conducted on the request of the Magura Sandstone Open Pit Osielec. Owing to this, the analysis of the current stability was made and the final geometry of the object estimated. Further, the proportion of the mixture (relation of processing waste to the waste mass quantity) was indicated, for which the stability of the object is assured.

2. DETERMINATION OF MECHANICAL PROPERTIES OF ROCK DEPOSITED IN WASTE DUMP – LABORATORY TESTS

The samples for the laboratory tests have been taken directly from the surface of the waste dump (material from processing waste stored on the second level and native soil – clay with crushed sandstone – from the lower level of the object). The results of the natural moisture content are presented in Table 1.

Table 1

Natural moisture content

Soil type	Sample No.	Dish mass	Dish with damp soil mass	Dish with dry soil mass	Natural moisture content	Average natural moisture content
		m_t (g)	m_{wt} (g)	m_{st} (g)	w_n (%)	w_n (%)
Clay with crushed sandstone	1	25.4	52.61	47.99	20.45	21.59
	2	22.3	45.47	41.18	22.72	
Processing waste	1	22.15	50	47.91	8.11	7.95
	2	25.15	49.09	47.36	7.79	

Shear strength was determined according to PN-B-04481 standard. The tests were performed on four samples with natural moisture and disturbed structure (two samples of clay with crushed sandstone and two others with processing waste) as well as for two samples of processing waste with higher moisture level and also with disturbed structure.

The tests were conducted in a shear strength apparatus for three load levels: 50, 100 and 150 kPa. The test results were used for estimation of the Coulomb–Mohr parameters: cohesion and internal friction angle (Table 2).

Table 2

Values of strength parameters

Soil type	Sample No.	Normal stress	Shear stress	Cohesion	Internal friction angle
		σ_n (kPa)	τ_{max} (kPa)	c (kPa)	φ (°)
Clay with crushed sandstone	1	50	46.52	31.22	18.62
		100	67.96		
		150	80.19		
	2	50	51.54	39.56	17.13
		100	77.24		
		150	82.35		
Processing waste	1	50	57.98	15.26	35.17
		100	76.48		
		150	128.44		
	2	50	66.37	22.29	36.56
		100	82.45		
		150	140.53		
Processing waste (moisture ~16%)	1	50	70.17	33.38	28.46
		100	68.21		
		150	124.36		
Processing waste (moisture ~18%)	1	50	41.54	15.59	20.74
		100	39.43		
		150	79.41		

3. THE METHODOLOGY AND ASSUMPTIONS APPLIED TO THE SLOPE STABILITY ANALYSIS

The slope stability calculations for waste dump no. 1 were conducted for six geological sections (Fig. 1). These sections were chosen considering their location as well as through factors relevant for the stability of the object including slope inclination, object geometry and distance from the Skawa River [5]. Sections A and B correspond to location of the sections presented in the Technical Documentation of the object [4]. Sections 1–4 have been made for the purpose of this study.

The values of strength parameters for processing waste and native soil deposited on the surface of the lower level are based on the results of laboratory tests, which further have been reduced by the safety index 0.8. The waste rock strength parameter values were estimated applying back analysis. The results are presented in Table 3.

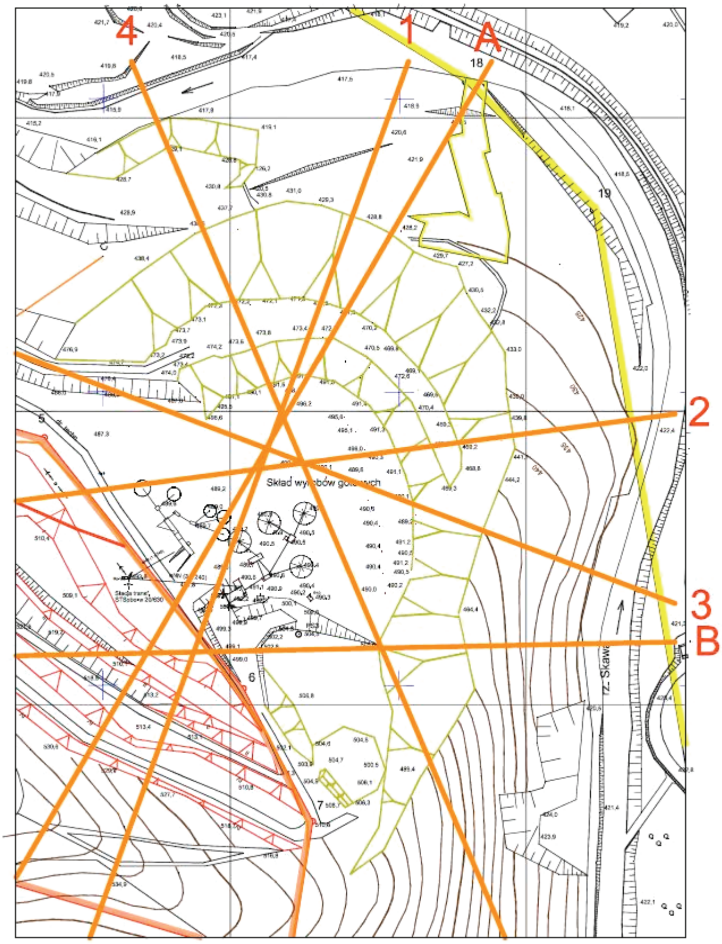

Fig. 1. Location of geological sections (scale 1: 2000)

The slope stability analyses were performed using Limit Equilibrium Methods. The results are presented for the Janbu method. The calculation was conducted in Geostudio 2012 code. In order to investigate the location of the slip surface the Entry & Exit and Fully Specified applications were used.

In each model, along the floor of the object, a weak contact layer was implemented. For this layer the strength parameters of native soil were used (clay with crushed sandstone – Table 3). In the past, mining waste was stored directly on native subgrade, hence the layer which was lying at the base of the object, due to its low strength parameters values can be a potential location for slip surface [6].

In order to assess slope stability factor of safety (FS) state of the dumping ground facility the following classification was implemented [7]:

– FS ≥ 1.5 – occurrence of landslides is very unlikely,
– 1.3 ≤ FS ≤ 1.5 – occurrence of landslides is unlikely,
– 1.0 ≤ FS ≤ 1.3 – occurrence of landslides is likely,
– FS < 1.0 – occurrence of landslides is very likely.

Table 3

Values of parameters implemented in slope stability calculations

Geotechnical layer	Unit weight [kN/m^3]	Internal friction angle [°]	Cohesion [kPa]	Color used in the figures
Processing waste from upper layer *	18.00	28.46	12.21	green
Clay with crashed sandstone *	19.00	18.62	31.22	red
Rock waste from lower layer**	19.00	32.2	15.5	yellow

* Parameters obtained from laboratory tests.
** Parameters obtained from back analysis results.

4. SLOPE STABILITY ANALYSIS OF WASTE DUMP NO. 1 – CURRENT STATE (2012)

The slope stability calculations for waste dump were conducted for current state (September 2012) in six geological sections. General slope inclination for all sections analyzed is less than 38° (Table 4). General substrate inclination does not exceed 13°.

Table 4

Geometry parameters for each section

Section	Unit	A	1	2	3	4	B
General substrate inclination	[°]	13	13	10	5	7	12
General object slope inclination	[°]	29	29	33	38	25	33
Distance from the Skawa River	[m]	121	108	102	98	84	81
Inclination of lower slope	[°]	35	35	39	38	33	36
Inclination of upper slope	[°]	33	35	42	38	34	36
Shelf width on the first level	[m]	23	27	18	×	35	×
Lower level height	[m]	40	43	30	20	34	50
Upper level height	[m]	20	20	22	20	19	×

Values of the factor of safety estimated with the Janbu method for all sections are presented in Table 5.

Table 5

The FS values for sections analyzed

Section	Factor of safety values (Janbu method)		
	Upper slope	Lower slope	Entire slope
A	1.302	1.135	1.242
1	1.252	1.101	1.244
2	1.002	1.083	1.184
3**	×	×	1.0
4	1.264	1.227	1.414
B	×	×	1.055

** Section used for calibration of the rock waste strength parameters.

It can observed that moving to the east direction, the values of FS are decreasing (from 1.414 in section 4 to 1.055 in section B). This is strictly connected with rising inclination for slopes of the object as well as for substrate in eastern site of the area. The potential slip surface is located along the bottom of the object, so through the contact layer with lower values of strength parameters. The results of the analysis show that values of FS for sections located on northern part of the object are much higher and oscillate at the level of 1.184–1.414 (sections 4, 1, A, 2, respectively). In section 2, the slip surface for the entire slope was obtained for FS = 1.184 (Fig. 2), whereas for the upper one for FS = 1.002. The decreasing value of the factor of safety is caused by general slope inclination rising as well as high inclination of upper slope.

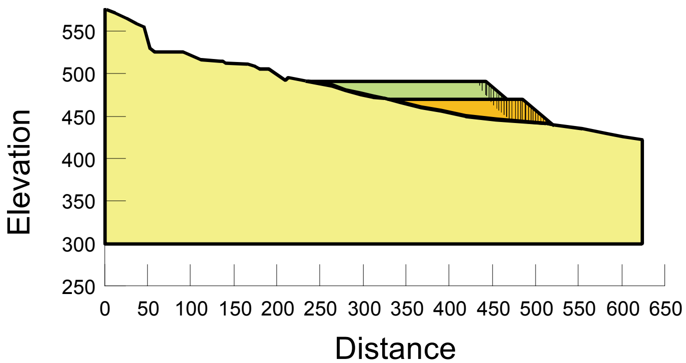

Fig. 2. Slope stability results for section 2 – current state (2012) (entire slope, FS = 1.184)

The results of the slope stability analysis for the current state as well as study visit showed that in eastern part of the waste dump there is a landslide hazard. Section B, for which the lowest value of FS was obtained, like section 3, is located in that part of the object where there is no shelf crossing the slope. In addition, the general inclination of the substrate in this area is 12°, and the slope inclination reaches the value of 33°. In this location there is only the storage of processing waste. Considering the results of laboratory tests (φ = 35.17° and c = 15.26 kPa – Table 2) for section B FS = 1.055 (Fig. 3) was obtained. This result indicates that the object in this area is in limit equilibrium state. In this location, there is a high probability of landslide occurring.

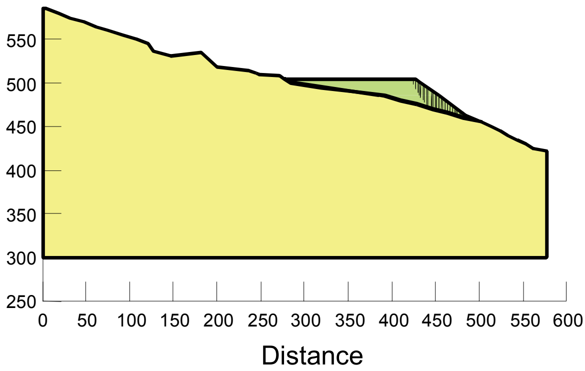

Fig. 3. Slope stability results for section 4 – current state (2012)
(entire slope, FS = 1.055)

The results of the analysis indicate that in sections 2, 3 and B landslide hazard is quite high. The major reason for the high risk of slide occurring is the lack of a shelf cutting the slope as well as high inclination of the slope and substrate in the east part of the object.

5. SLOPE STABILITY ANALYSIS FOR FINAL GEOMETRY OF THE WASTE DUMP NO. 1

The final geometry design of waste dump assumed that the safe distance to the Skawa River will be at least 30 meters. In addition, in the area where there is a plan for further waste storing, there is a need to remove the top native layer from the surface (clay with crushed sandstone). In order to avoid slip surface developing in this area in the future, the current inclination of the substrate requires that a leveling platform be designed. The platform will have a height of 10 m and inclination of 45° and will be made of thick rock waste which minimizes the impact of substrate inclination on the slope stability. The platform was designed with a shelf of 20 m in width at the end of which the waste dump slope will be formed. In the course of calculations four options were analyzed:

option I: inclination of the lower slope is 45°; inclination of the upper slope is 30°,
option II: inclination of the lower slope is 30°; inclination of the upper slope is 30°,
option III: inclination of the lower slope is 30°; inclination of the upper slope is 30° + additional buttress
option IV: inclination of the lower slope (height 20 m) is 30°, inclination of the middle slope (height 20 m) is 25°, and inclination of the upper slope is 25°.

The adopted shelf width between levels was: 20 m (for options 1–3) and 15 m (for option 4). Table 6 shows the values of strength parameters used for additional materials.

Table 6

Values of strength parameters used for additional materials implemented in the analysis

Material	Unit weight [kN/m^3]	Internal friction angle [°]	Cohesion [kPa]	Color used in the figure
Leveling platform, buttress	19.00	35.00	15.70	
Additional retaining construction	25.00	35.00	800	

Table 7

FS values for options I–III

	Factor of safety values, FS (Janbu method)							
	Option I			Option II			Option III	
	Lower slope inclination 45°			Lower slope inclination 30°			Additional buttress	
Slip surface contour	Upper slope	Lower slope	Entire slope	Upper slope	Lower slope	Entire slope	Lower slope	Entire slope
Section A	1.384	0.927	1.205	1.38	1.411	1.565	1.482	1.616
Section 1	1.380	0.926	1.179	1.38	1.410	1.565	1.480	1.612
Section 2	1.367	0.973	1.266	1.369	1.455	1.461	1.570	1.505
Section 4	1.380	0.913	1.178	1.432	1.443	1.553	1.522	1.611

Table 7 contains a summary of the FS values for options I–III. In the first option, the entire sections analyzed showed instability for the lower slope. This result is caused by too high an inclination of the lower slope. This conclusion is confirmed by the analysis of the second option. A decrease of the inclination for the lower slope from 45° to 30° results in the FS values within 1.410–1.455 indicating slope stability.

The slope stability improvement can be observed also for the entire slope. In the analysis of option I a slip surface which runs through the full height of the slope occurs for FS = 1.178 (section 4) whereas in the analysis of option II such a slip surface is created for FS = 1.461 (section 2). The analysis of option III shows that implementation of additional supporting element caused an increase in the safety of the object (Fig. 4).

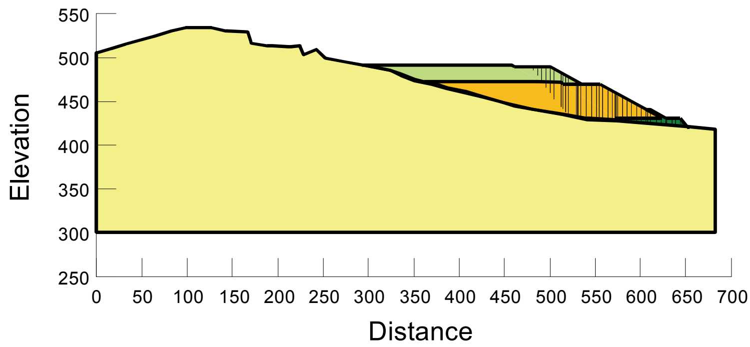

Fig. 4. Slope stability analysis results for section 1 (additional buttress), FS = 1.612 – entire slope

Slope stability analysis conducted for sections 3 and B assumed FS calculation for this part of the object where the sections are cut with a shelf of width 5 m and 10 m in both cases (Table 8).

Table 8

FS values for sections 3 and B

	Width of the shelf	FS for upper slope	FS for entire slope
Section 3	5 m	1.386	1.226
	10 m	1.386	1.309
Section B	5 m	1.396	1.064
	10 m	1.387	1.127

The analysis of section 3 for shelves of 5 m and 10 m in width shows that the upper slope is stable with FS = 1.386, and in the case of the entire slope stability FS = 1.226 and FS = 1.309 (Fig. 5), respectively. The analysis shows that larger shelf width causes an increase in the stability of the object in section 3.

The results of slope stability analysis for section B show that in each case analyzed the upper slope is stable (FS within 1.387–1.396), whereas for the entire slope the factor of safety amounts to FS = 1.064 and FS = 1.127 (Fig. 6) for shelf width 5 m and 10 m, respectively. These values of FS indicate very little margin of safety, which causes an considerable landslide hazard.

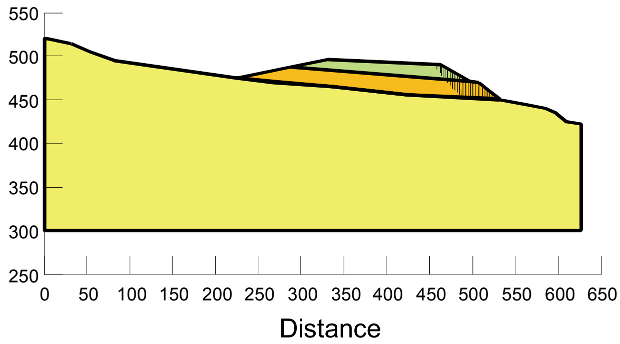

Fig. 5. Slope stability analysis results for section 3, FS = 1.309 – entire slope

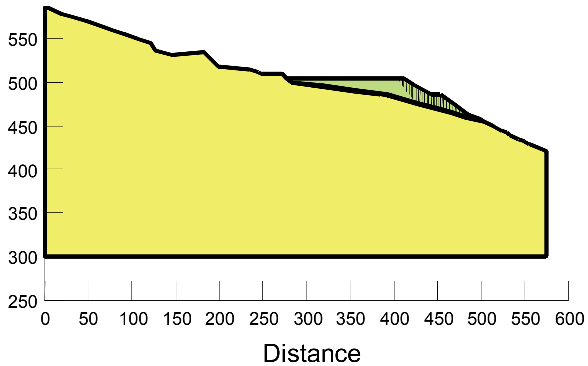

Fig. 6. Slope stability analysis results for section B, *FS* = 1.127 – entire slope

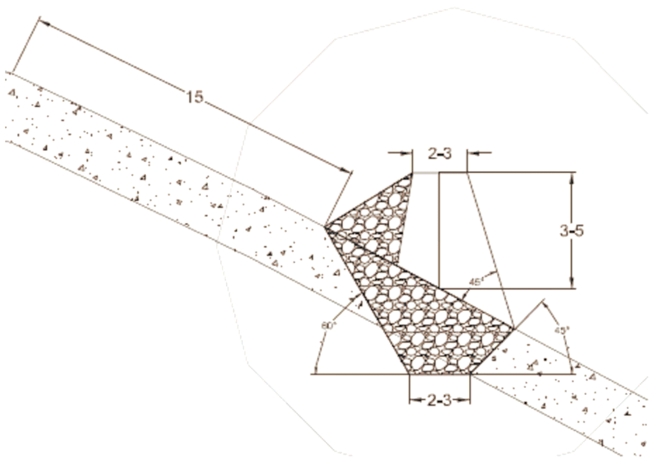

Fig. 7. Retaining structure conception

Application of additional retaining construction in sections 3 and B allows safe FS values. The design of retaining structure requires prior investigations to be conducted in the area analyzed. Figure 7 shows the concept of a retaining structure.

Parameters of the final geometry design for each section with option IV are presented in Table 9.

Table 9

Parameters of the final geometry of the waste dump

Section	Unit	A	1	2	3*	4	B*
General substrate inclination	[°]	11	11	10	5	8	12
General object slope inclination	[°]	21	22	21	30	22	27
Distance from Skawa River	[m]	30	30	30	98	30	76
Leveling platform inclination	[°]	45	45	45	×	45	×
Inclination of lower slope	[°]	30	30	25	38	30	18
Inclination of middle slope	[°]	25	25	30	×	33	×
Inclination of upper slope	[°]	25	25	25	30	21	25
Shelf width between levels	[m]	15	15	10;16	10	15	10
Lower level height	[m]	20	20	20	22	20	34
Middle level height	[m]	20	21	12	×	18	×
Upper level height	[m]	20	18	22	21	18	19

* Sections for which there is a need for retaining structure application.

In option IV, FS gains the highest values. Table 10 contains FS values for each section of the object. These values of both the single slopes and the entire slope are greater than 1.5, which according to the criteria indicates a very low probability of landslide occurring for the final geometry of waste dump presented.

Table 10

FS values obtained in option IV

Slip surface contour	Upper slope	Middle slope	Lower slope	Entire slope
Section A	1.639	1.638	1.616	1.577
Section 1	1.668	1.615	1.616	1.542
Section 2	1.603	1.573	1.664	1.571
Section 4	1.964	1.517	1.625	1.554

Figure 8 shows the final geometry of the object for section 2. In order to obtain adequate stability of the slope the inclination of the upper slope has been alleviated to

25°. FS for the final geometry presented reaches the value of FS = 1.571 for entire slope, whereas for single slopes, FS = 1.573–1.664, so the landslide occurrence for this section is highly unlikely.

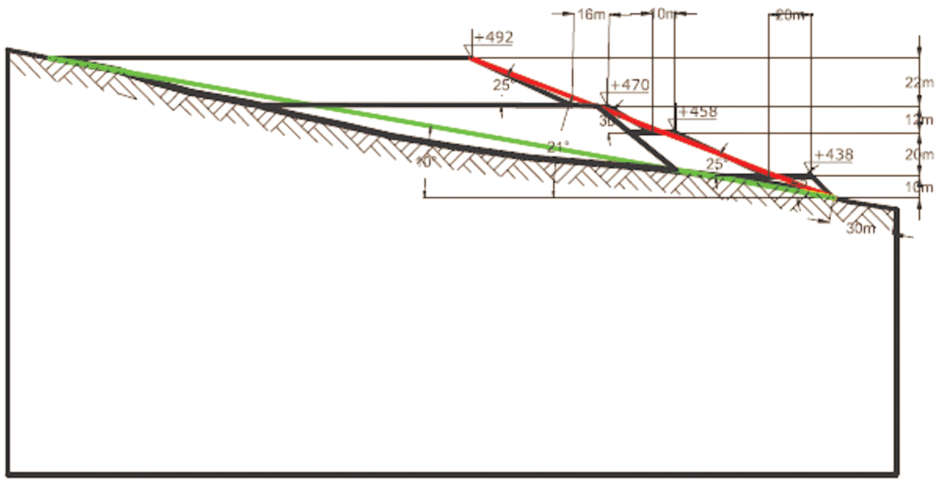

Fig. 8. Final geometry design of the waste dump for section 2

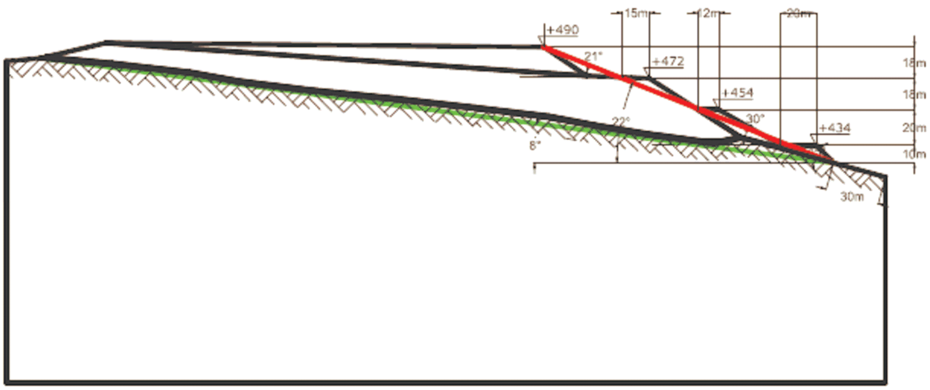

Fig. 9. Final geometry design of the waste dump for section 4

In order to obtain sufficient slope stability of the object in section 4 analyzed in option 4 the inclination of the slope ought to be alleviated to 21°. FS for the final geometry of the facility equals FS = 1.554 for entire slope. For this FS value landslide occurrence is very unlikely. Figure 9 shows the final geometry of the object for section 4.

6. SLOPE STABILITY ANALYSIS OF THE WASTE DUMP WHEN THE MIXTURE OF ROCK AND PROCESSING WASTE IS STORED ON THE LOWER LEVEL

Slope stability analysis for mixture stored on the lower level was carried out for participation of processing waste in the range 10–100%. For the analysis, the sections of final geometry design were used. The proportion of components in the mixture ought to be chosen in such a way as to ensure stability of the slope as well as safety of the entire object. For the mining object like waste dump the minimal FS = 1.3. However, considering the fact that the waste dump is situated nearby the Skawa River, landslide occurrence could have very serious consequences. Therefore, it was assumed that FS for the mixture stored on the lower level of the object need to be FS ≥ 1.5. Establishing FS = 1.5 as the minimal safe value is also justified by the fact that the analysis was carried out for processing waste with 8% moisture content. In the case of an increased water content in the material stored, FS would get a lower value, which can lead to landslide risk. The calculation for varying proportion of the mixture components indicates that for the safe disposal on the dumping ground facility the mixture ought to contain up to 40% of the processing waste. Table 11 contains FS values for each section.

Table 11

Collection of FS values for waste rock and processing waste mixture

Processing waste participation in the mixture	*c*	*φ*	Factor of safety values									
			section A		section 1		section 2		section 3		section 4	
			Lower slope	Entire slope	Lower slope	Entire slope	Lower slope	Entire slope	Lower slope	Entire slope	Lower slope	Entire slope
10%	15.17	31.83	1.576	1.596	1.592	1.543	1.665	1.570	×	×	1.554	1.619
20%	14.84	31.45	1.568	1.575	1.569	1.542	1.648	1.569	×	×	1.554	1.613
30%	14.51	31.08	1.545	1.573	1.544	1.540	1.639	1.568	×	×	1.553	1.605
40%	14.18	30.70	1.523	1.571	1.520	1.539	1.631	1.566	×	×	1.553	1.598
50%	13.86	30.33	1.497	1.570	1.497	1.538	1.623	1.566	×	×	1.552	1.594

Figure 10 shows the result of slope stability analysis for section A with 30% participation of the processing waste in the mixture stored on the lower level.

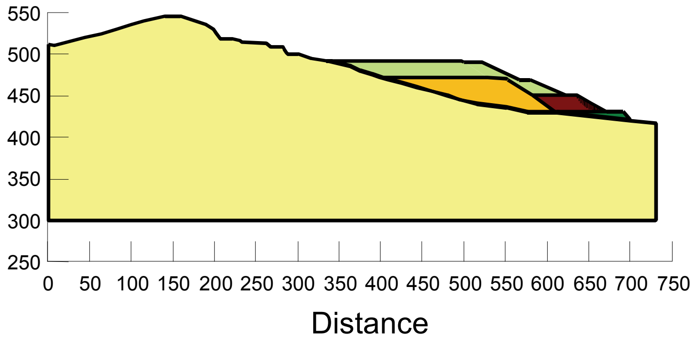

Fig. 10. Slope stability analysis results for section A
(processing waste participation – 30%), FS = 1.545

7. CONCLUSIONS

The analysis of slope stability of the dumping ground facility No. 1 leads to the following conclusions:

The best solution for the final geometry of the object is that analyzed in option IV. This geometry consists of: a lower slope with height of 20 m and inclination 30°, made from rock waste; middle and upper slopes with height of about 20 m each and inclination 25°, made from processing waste. Slopes are separated by shelves with 15 m in width. In section 2 in order to obtain inclination of 25° the upper slope needs to be alleviated (currently, the inclination for the upper slope is 42°, which causes limit equilibrium state occurring in that section).

In the eastern part of the waste dump in sections 3 and B a shelf cutting the slope (with minimal width of 10 m) as well as additional retaining structure need to be applied. Proper design of retaining structure requires prior geotechnical studies of soil to be conducted in the area analyzed.

In addition, in order to improve slope stability of the object it was recommended to establish a safe distance from the Skawa River with the width of 30 m and make leveling platforms with the height of 10 m and slope of 45° in order to reduce influence of substrate inclination on the object stability.

Slope stability analysis was carried out based on laboratory test results for processing waste with 8% moisture content. It should be noted that increasing moisture can result in lower FS values, which means that the risk of landslide occurring would increase. Therefore, continued monitoring of moisture content is also recommended and in the case of moisture increase, there will be a need to repeat laboratory tests and slope stability analysis.

Slope stability analysis for the final object geometry design, in the case of storing a mixture of rock waste and processing waste in the lower slope indicates that for safe disposal the proportion of processing waste in the mixture amounts up to 40%.

A very important issue which has considerable influence on stability conditions is proper dewatering of the object body dump. Water penetrating the body dump may have influence on decreasing strength parameters values of the stored material. In addition, water flowing on the slope surface can cause erosion. Therefore, on the upper level of the object as well as on the shelves between the levels, draining pipes ought to be installed.

Meaning of colors for figures 2–6, 9

Processing waste	Clay with crushed Sandstone	Rock waste
Leveling platform, buttress	Retaining wall	Mixture of rock and processing wastes
Bedrock		

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