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Original scientific paper

ANALYSIS AND EVALUATION OF THE SECURITY FACTOR (Fs) BY CHANGING THE VALUES OF THE WATER COEFFICIENT (r_u)

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Abstract

In this paper, we will define the basic procedures of the concept of slope stability of the working front, the stability of the working slope ending up as a result of the presence of surface water, and how the increase in the level of suboxide water affects the values of geomechanical parameters, wherein the structure of that mass of coal cover are several types of layers or different substrates of soils (clays), which it proves that there are heterogeneous lithologies in the locality of the surface coal mine "Oslomej-West" Kicevo.
The following two methods have been used to analyze the general slope stability: Methods for boundary equilibrium and Numerical methods.
The main components used for slope stability analysis are:
- Presence of surface water and level of non-toxic waters.
- Physico-mechanical characteristics of the soil researched in the field, in the laboratory and the safety factor (Fs).
- The slope stability reduction is done with the following software packages: GGU Stability, SLIDE and PLAXIS.

The paper presents the assessment of slope stability with a special focus based on the different values of the porous water coefficient (r_u) and the change of possible and expected values of geomechanical parameters (angle of internal friction and cohesion) that affect the value (size) of the security factor.

Keywords: r_u coefficient, methods, stability, safety factor, geomechanical parameters, r_u sensitivity analysis

1. Introduction

Based on previous geo-mechanical researches and examinations, we can conclude that it is about heterogeneous soil environments with multiple soil layers. From the data of geo-mechanical properties of the treated area, we can divide the soil materials into three groups, as following: *roof sediments, productive coal mass,* and *underlying sediments*. By analyzing the data and results from the previous researches, it can be freely stated that the hydro-geological condition has a great impact on geo-mechanical properties of the presented soil materials.

In general, from a geo-mechanical aspect, it can be concluded that in the following period it is necessary to conduct detailed engineering-geological and hydro-geological researches and examinations for those areas that lack sufficient data.
Because of the above mentioned, the thesis shall obtain the following analyses:

- Geo-mechanical analysis and statistical processing;
- Application of various numeric and graphical methods;
- Geostatic analysis.

2. General knowledge about locality, "Oslomej"

The surface mine "Oslomej" from the design phase lies in two parts:

- "Oslomej-East";
- "Oslomej-West".

The Oslomej coal mine is located in the Neogene basin of Kicevo, about 10 km north of Kicevo.
It covers an area of about 200 [ha], including the northern part of the mine, which has been exploited or excavated for coal.
At the beginning in 2008, during the period when the excavated fronts of the II and I ETP systems (Excavator-conveyor-belt conveyor) were in the position between the transverse profiles XV, XIV, XIII, XII and XI, they gradually shifted to parallel development up until the end of the exploitation period, until the end of the exploitation of "Oslomej - West". [56]

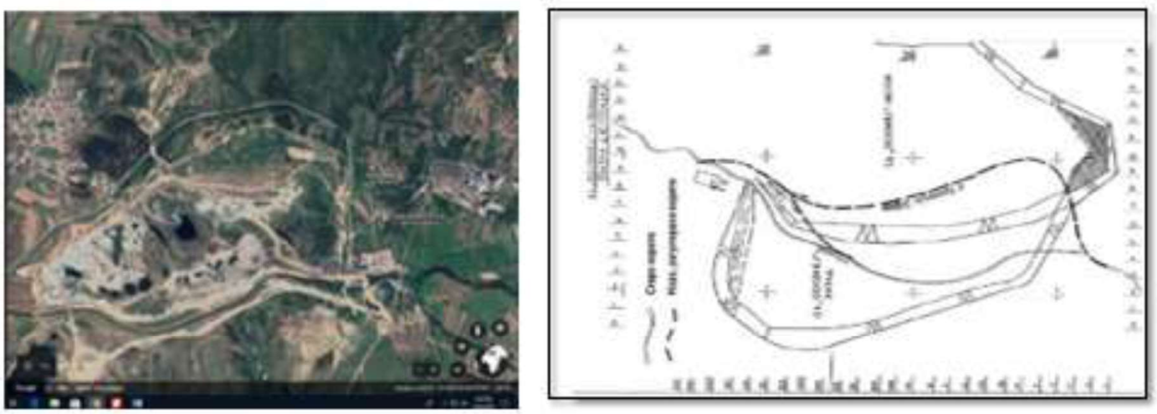


Figure 1. View of the Oslomej Mine and the relocation of the Temnica River bed through phases

3. Hydrogeological characteristics

3.1. Overview of hydrogeological research

The description of hydrogeological research in this locality began in 1952. The next research phases were developed in 1969 by the Institute of Mining in Belgrade, where 3 wells and 18 piezometers were realized in order to determine the filtering characteristics of lithological members in the coal layer.
In the period 1970-71, for the needs of the main project of water drainage in the surface mine in Oslomej, detailed hydrogeological researches were carried out and the following data were extracted:

Table 1. Overview of Geological, Hydrogeological and Geomechanical Research conducted in 1991

Drillings num.	Depth (m)	Purpose
A-1	54.00	Geological-hydrogeological structure
A - 2	64.00	Geological structure
A - 3	61.00	Geological-hydrogeological structure
A - 4	94.00	Geological structure
A - 5	22.00	Geological structure
A - 6	96.00	Geological-hydrogeological structure
A - 7	59.00	Geological structure
A - 8	80.00	Geological-hydrogeological structure
A - 9	78.00	Geological-hydrogeological structure
A - 10	51.00	Geological-hydrogeological structure
A - 11	40.00	Geological structure

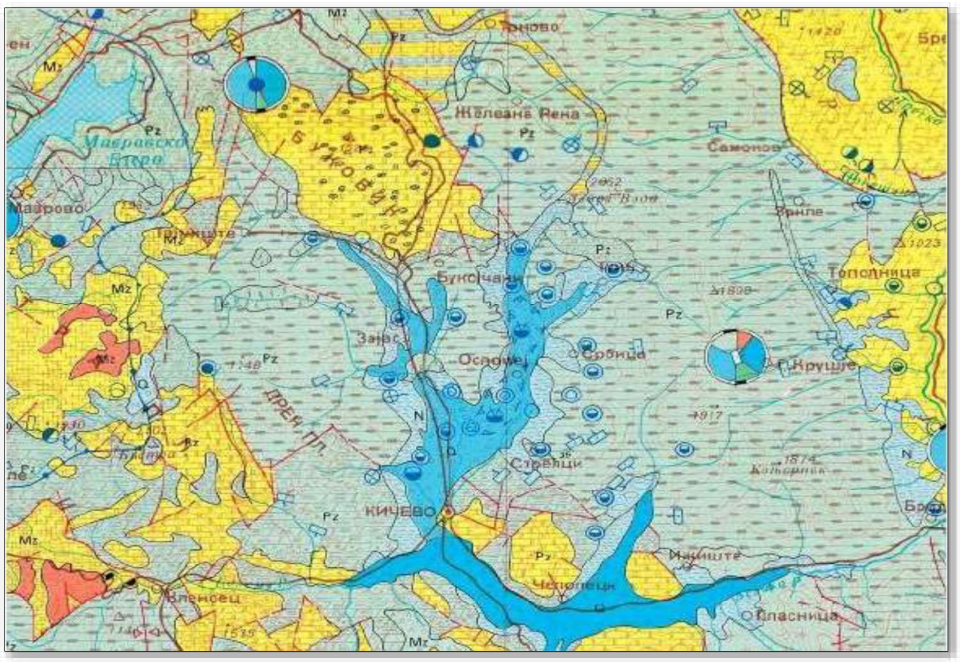


Figure 2. Hydrogeological Map of Valley of Kërçovë

4. Hydrogeological

From the hydrogeological phenomena, as an indicator of the presence of groundwater, the presence of water is evident, from the following phenomena:

- Wet areas on terrain surfaces
- Presence of subarterial and arterial water in wells.

In terms of hydrography, within the explored terrain and in its wider environment, the river network has developed poorly. The main watercourse of this area is the river Temnica, with its tributaries the rivers Tuhejni and Popojan. The Temnica River flows through the central part of the Oslomej-West coal mine. Characteristic of the Temnica River is that during its exploitation, its river bed has been relocated several times.

Table 2. The annual amount of precipitation in the two countries of the measuring stations: Oslomej and Crvic.

Amounts of annual rainfall (mm)																	
measuring stations	min	2010	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	Average
Osllomej.	683	688	1037	507	823	893	948	921	552	809	708	760	725	646	532	563	504	726
Crvic	760	527	735	645	808	872	746	633	488	572	474	572	656	561	365	545	381	646

4.1. Surface and groundwater protection

Groundwater that occasionally springs from the surface mine, as well as, water from rain and snow, accumulates in the catchment area (fig.3), in places where mine work is not hampered, and then leaves with pump systems up to the bed of the Temnica River.

Figure 3. Catchment

Table 3. Groundwater level measurements

Drilling	Field quota	Level quota	Level of depth
A-1	674,70	669,20	5,5
A-2	666,50	-	there is not
A-3	681,20	664,20	17,0
A-4	670,52	-	there is not
A-5	667,60	-	there is not
A-6	679,63	664,63	15,0
A-7	662,30	657,30	5,0
A-8	664,50	656,00	8,5
A-9	663,36	652,36	11,0
A-10	647,10	640,90	6,2

4.2. Hydrogeological research in the field

Research work in the field that has been done:

- Detailed engineering hydrogeological research and field classification
- Hydrogeological drilling
- Inclusion of piezometric construction
- Classification of nuclei by hydro-geological drilling

Based on the data obtained from the geological, hydrogeological and engineering-geological maps and the essence of the nuclei and the terrain map, have been constructed hydrogeological engineering-geological profiles and transverse profiles.

Table 4. Filtration coefficient

Drilling	Interval	Filtration coefficient (m/s)	r_u
Sh-2/XV	8,60-12,00	5.73 x 10-8	13,30
	19,10-38,60	2.67 x 10-7	39,00
Sh-1/XII	18,09-22,00	2.38 x 10-8	3,50
	23,50-25,00	8.04 x 10-8	4,40
Sh-2/XIII	8,00-21,00	2.58 x 10-8	4,60
	22,00-25,00	2.67 x 10-7	9,10
	31,60-37,00	9.66 x 10-7	19,70
	52,00-57,00	9.04 x 10-7	5,20
Sh-3/XI	3,60-14,10	5.41 x 10-8	13,30
	15,00-20,40	3.06 x 10-7	9,10
	43,40-47,70	2.79 x 10-8	5,70
Sh-3/XIV	2,50-7,00	2.69 x 10-8	20,00
	8,00-9,50	1.84 x 10-8	8,40
	12,00-26,50	5.40 x 10-8	3,80
	27,70-37,40	5.26 x 10-8	46,10
	54,00-54,30	3.36 x 10-8	5,70

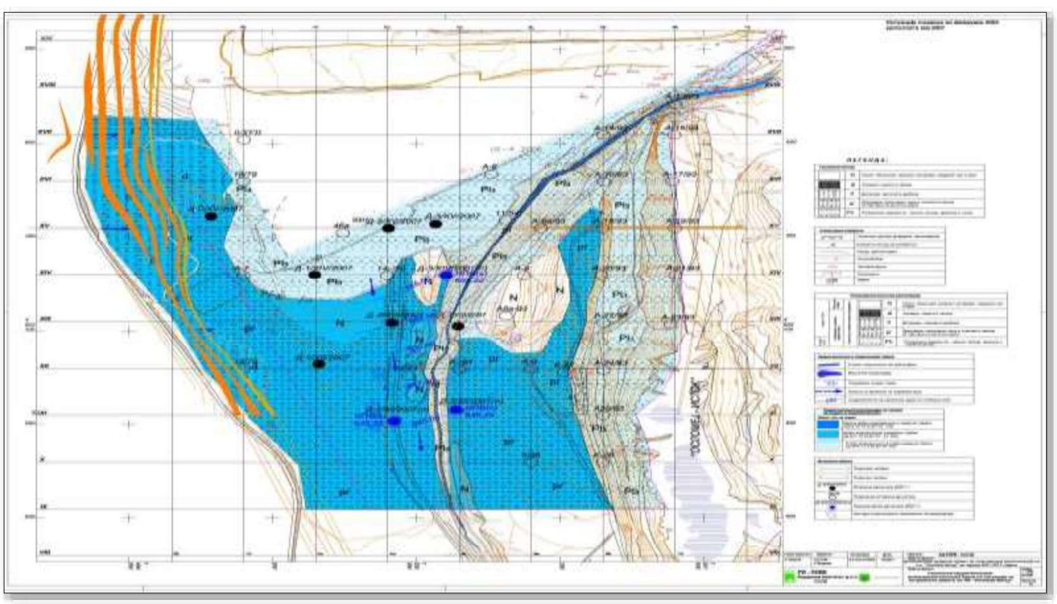


Figure 4. Engineering map, hydro-geological

5. Analysis of state stability

Acquisition of geomechanical parameters that have been statistically processed in the previous section. They should be reduced depending on the current conditions of the pit field. The design of the slopes shows a large number of cracks of different directions and dimensions, and often these cracks are in the normal direction or with small angles and lengths of cracks. However, it has been confirmed that the length of the cracks varies from 1 to 15 m.

Based on this, it is necessary to reduce the parameters based on the Fisenko formula, which is applied in open germination openings, based on the map data on the sloping terrain. This reduction of the parameters is based on the length of the height and the size of the blocks that are divided H / l (m), as well as the value of the laboratory cohesion obtained.

The formula used to do statistical processing according to Fisenko is:

$$C_r = \frac{C}{1 + a \cdot \ln \frac{H}{l}} \left[KN/_{m^2} \right]$$

Slope stability analysis is done (logarithmically) with different software packing methods: GGU Stability, SLIDE and PLAXIS. Stability analysis is done for the profile; 3-3 ', (angle β = 19°).

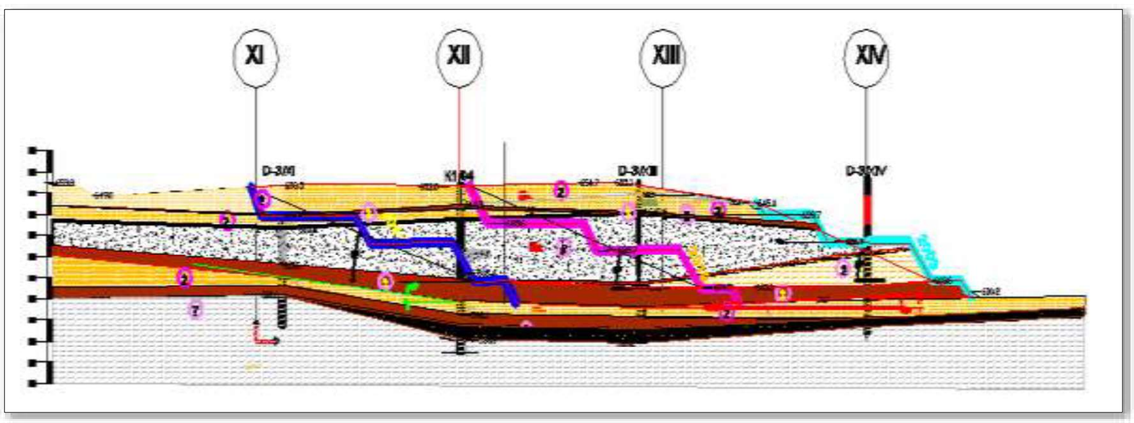


Figure 5. Profile 3-3 ',(β =19°)

Table 5. Acquisition of geomechanical parameters for the profile.3-3

Nr.	Physico-mechanical characteristics	Geomechanical designation	c	φ	γ	
			(kPa)	(°)	(kN/m3)	r_u
2	Organic medium to high plastic clay	OH/OI	10.00	16.40	17.00	0.00
						0.20
						0.30
3	Coal	L	50	25	13.5	0.00
5	Clay sands	SFc	20.37	21.71	21.41	0.00
						0.20
						0.30
7	Medium plastic clay	CI	18.00	18.00	19.90	0.00
8	Coal with carbon clay	L/OH	20.00	17.80	17.90	0.00

By analyzing the data and the results of previous research, we can conclude that the geomechanical characteristics have an impact on the hydrogeological condition, i.e. the simulation of the values (r_u) of the polar coefficient of water, which significantly affects the stability of the slope.

Table 6. Drilling coordinates. profile 3-3 '

Prof. 3-3’	
Drilling	Coordinates
3/XV	X= 4602386,00
	Y= 7500084,00
	Z= 654,10
3/XIV	X= 4602249,08
	Y= 7500101,58
	Z= 660,02
K1/94	X= 4602000,00
	Y= 7500120,00
	Z= 653,35
3/XIII	**X= 4602112,64**
	Y= 7500122,22
	Z= 651,97
3/XI	X= 4601890,36
	Y= 7500118,50
	Z= 653,64

Table 7. Lithology of profile 3-3’,(β =19°)

Cutting	**Symbol**	**Layer thickness (m)**	
XI	(2) OH/OI	19,08	Organic medium x=35,99 (m)
	(5) SFc	16,91	
	(3) L	4,62	Coal x=4,62 (m)
	(2) OH/OI	4,88	high plastic clay x=4,88(m)
	(3) L	5,00	Coal x=5,00 (m)
XII	(2) OH/OI	15,69	Organic medium x=44,99 (m)
	(5) SFc	29,30	
	(3) L	8,89	Coal x=8,89 (м)
	(2) OH/OI	6,73	high plastic clay x=6,73 (m)
	(3) L	6,10	Coal x=6,10 (m)
	(8) L/OH	6,44	Coal, carbon clay x=6,44 (m)
XIII	(2) OH/OI	12,27	Organic medium x=45,72 (m)
	(5) SFc	33,45	
	(3) L	9,90	Coal x=9,90 (m)
	(2) OH/OI	4,88	high plastic clay x=4,88 (m)
	(3) L	5,60	Coal x=5,60 (m)
	(8) L/OH	5,70	Coal with carbon clay

a) Direct cutting

$$\Delta = \mathrm{n}\sum_{(i=1)}^{n}(\sigma_i)^2 - \sum_{n-1}^{n}(\sigma_i)^2$$

$$\mathrm{C} = \frac{1}{\Delta}\left[\sum_{(i=1)}^{n}\tau_i\sum_{(i=1)}^{n}\sigma_i^2 - \sum_{(i=1)}^{n}\sigma_i\sum_{(i=1)}^{n}\sigma_i\tau_i\right]$$

$$\mathrm{tg}\varphi = \frac{1}{\Delta}\left[n\sum_{i=1}^{n}\tau_i\sigma_i - \sum_{i=1}^{n}\tau_i\sum_{i=1}^{n}\sigma_i\right]$$

b) Statistical processing

$$tg\varphi = \frac{a-1}{2\sqrt{a}},\left[{}^0\right]$$

$$C = \frac{b}{2\sqrt{a}},\left[\frac{kN}{m^2}\right]$$

$$a = \frac{1}{\Delta}\left(n\sum\sigma_1\sigma_3 - \sum\sigma_1\sum\sigma_3\right)$$

$$b = \frac{1}{\Delta}\left(\sum\sigma_3^2\sum\sigma_1 - \sum\sigma_3\sum\sigma_1\sigma_3\right)$$

$$\Delta = n\sum(\sigma_3)^2 - (\sum\sigma_3)^2$$

$$C_r = \frac{C}{1 + a\cdot\ln\frac{H}{l}}\left[KN/m^2\right]$$

Where:

C – cohesion values obtained in the laboratory [KN/m^2]

a-the coefficient which depends on the type of material and is taken from the table
H- slope height [m]

***l*-** the length of the detached blocks[m]

6. APPLIED (IMPLEMENTED) METHODS

6.1. Bishop's method

6.2. Jambo's method

6.3. Spencer's method

6.4. Finite element method.

Bishop's method

$$R_v = W + W' + R_y + p \cdot b + k_y \cdot (W + W_z)$$

$$M_x = R_x \cdot y_r / R + k_x \cdot y_z \cdot (W + W_z) / R$$

Spence's method

$$m = \frac{\sum_{i=1}^{n} [c_i \cdot l_i + (P_i - u_i \cdot l_i) \cdot tg\varphi']}{\sum_{i=1}^{n} Wi \cdot sin\alpha_i}$$

F

$$\sum_{i=1}^{n} (E_i - E_{i-1}) = 0$$

$$\sum_{i=1}^{n} (X_i - X_{i-1}) = 0$$

$$= \frac{\sum_{i=1}^{n} [c_i \cdot l_i + (P_i - u_i \cdot l_i) \cdot tg\varphi'] \cdot cos\alpha_i}{\sum_{i=1}^{n} P_i \cdot sin\alpha_i}$$

F_f

Jambo's method

$$Fs = f_0 \cdot \frac{\sum_{i=1}^{n} [c_i \cdot l_i + (P_i - u_i \cdot l_i) \cdot tg\varphi_i] \sec\alpha_i}{\sum_{i=1}^{n} W_i \cdot tg\alpha_i}$$

$$Fs = \frac{\sum_{i=1}^{n} [c_i \cdot b_i + [W_i - u_i \cdot b_i] \cdot tg\varphi_i] \cdot n_{ai}}{\sum_{i=1}^{n} W_i \cdot tg\alpha_i}$$

Where:

$$n_{ai} = \frac{1/\cos^2\alpha}{1 + tg\alpha_i \; tg\varphi_i'/Fs}$$

7. Stability assessment, β=19°

7.1. GGU stability software analysis

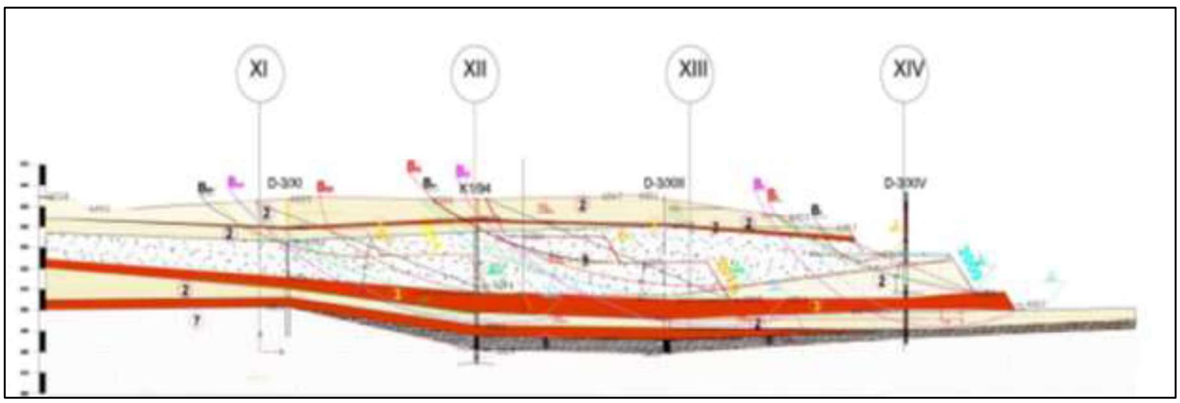


Figure 6. Geomechanical profile with excavation scales 2019-2025 in profile 3-3 'and sliding surfaces with Bishop and Janbu methods for β = 19°

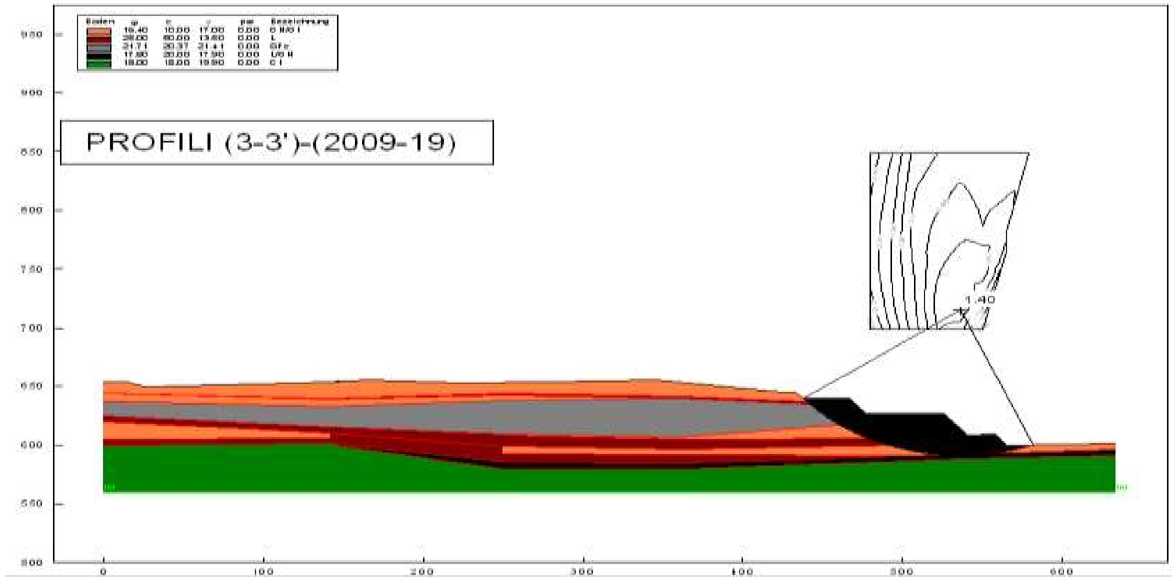


Figure 7. Bishop, sliding surface (area) 3, Fs=1.40. for r_u=0.00

Table 8. Reached Fs difference for sliding surfaces by different methods, (Bishop, Jambo) depending on the r_u, on the profile 3-3',(β =19°).

$J_{0,2}-J_{0,3}$	$J_0-J_{0,3}$	$J_0-J_{0,2}$
0.19	0.58	0.39
0.20	0.59	0.39
0.11	0.33	0.33

Table 9. The table shows that Fs values for sliding surfaces by methods (Bishop and Jambo) depend on the profile 3-3.

$B_{0,2}-B_{0,3}$	$B_0-B_{0,3}$	$B_0-B_{0,2}$
0,20	0.60	0.40
0.15	0.45	0.30
0.11	0.32	0.21
$B_{0,3}/B_{0,2}$	**$B_{0,3}/B_0$**	**$B_{0,2}/B_0$**
0,91	0,77	0,84
0,92	0,79	0,86
0,92	0,80	0,87
$J_{0,3}/J_{0,2}$	**$J_{0,3}/J_0$**	**$J_{0,2}/J_0$**
0.91	0.76	0.91
0.90	0.75	0.90
0.92	0.80	0.92

From table 5.-1 it can be seen that in all the analyzed conditions there is a noticeable difference in the results according to the two methods. Expectedly, it is found that with the increase in the values of the porous water coefficient (r_u), the values of the safety factor (Fs) will decrease regardless of which method will be applied (Bishop or Jambo) also, the values according to the Jambos method will are distinguished in comparison with the values of the Bishop method for about ±10%, which difference is more pronounced for sliding surfaces with medium depth even for larger values of the porous coefficient (r_u). What is useful from a consistent and practical point of view is that the coefficients achieved are higher than the minimum. From the table 8 and table .9, β = 19 for analysis of various sliding surfaces (1,2,3) that are characterized by the difference between them based on depth, there is a marked decrease in the intensity of the safety factor (Fs).

Respectively for the sliding surface 1, and the increase of the r_u from 0.0 to 0.2, the absolute difference in Fs is observed, in the value for 0.4 and by increasing the porous coefficient by 50%, in an absolute value from 0.2 to 0.3, one reduction of 0.2 Fs is observed to the same sliding surface of 0.2.

his is a linear decrease in the safety coefficient and this downward trend can be observed in other sliding surfaces analyzed, but with altered intensity. Thus, on the sliding surface 2, with an increase of the polar pressure coefficient from 0 to 0.2, the safety coefficient decreases by 0.3, and in case of a further increase of (r_u) from 0.2 to 0.3, the Safety Factor (Fs) would also fall by 0.15. On the slip surface 3, again with an increase of (r_u) of 0.1, Fs falls (decreases) by an average of about 0.1.

7.2. Analysis with slide software

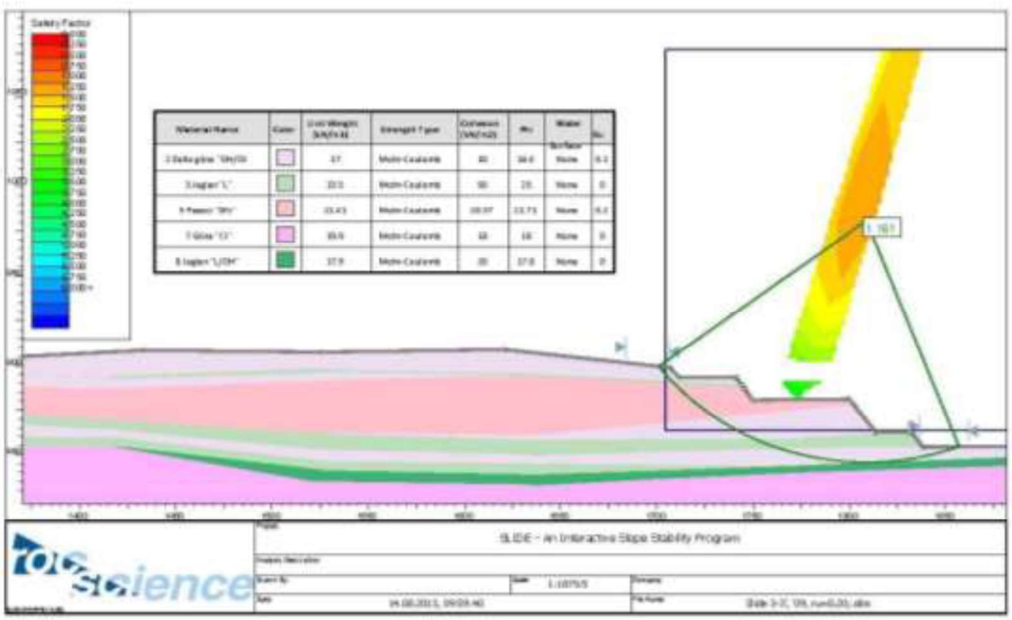


Figure 8. Sliding area (surface) 3, Bishop, r_u = 0.20. Fs = 1.161

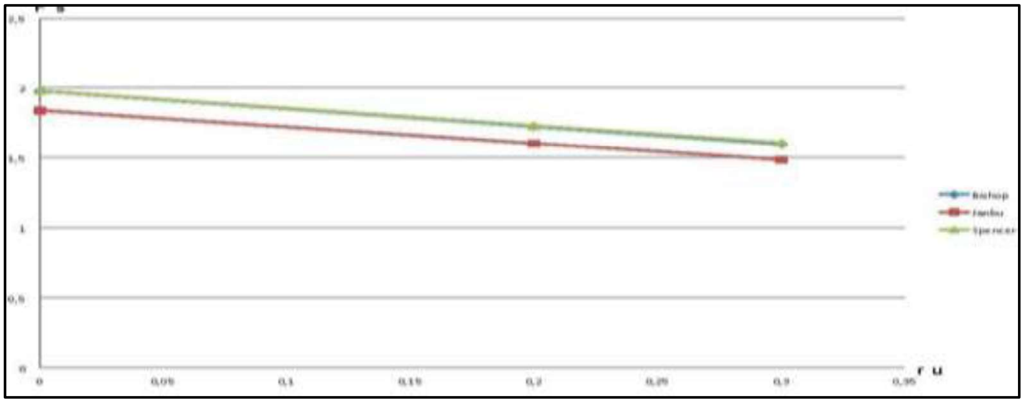


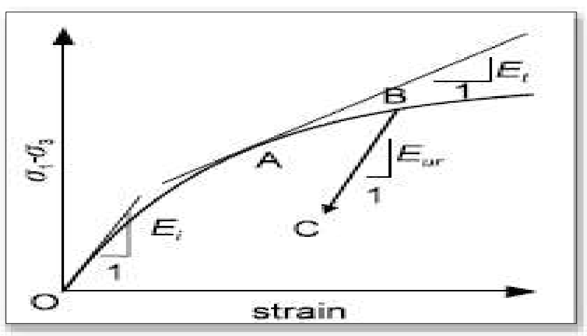
Figure 9. Sliding zone (area) 2, (Bishop, Jambo and Spencer) Fs for r_u.

Table 10. Safety Factor Values (Fs), Profile 3-3 '2019, Slide

3/3	ru=0			ru=0,20			ru=0,30		
	Bishop	Janbu	Spencer	Bishop	Janbu	Spencer	Bishop	Janbu	Spencer
1	2,022	1,878	2,025	1,765	1,539	1,758	1,574	1,37	1,367
2	1,553	1,504	1,543	1,273	1,231	1,266	1,133	1,094	1,127
3	1,386	1,297	1,38	1,161	1,082	1,157	1,047	0,974	1,043

ru=0			ru=0,20			ru=0,30		
J/B	S/B	J/S	J/B	S/B	J/S	J/B	S/B	J/S
0,928783	1,001484	0,927407	0,871935	0,996034	0,875427	0,870394	0,995553	0,874282
0,968443	0,994849	0,973463	0,967007	0,994301	0,972354	0,965378	0,994704	0,970719
0,935786	0,995671	0,939855	0,931955	0,996555	0,935177	0,930277	0,99809	0,932057

7.3. Plaxis analysis



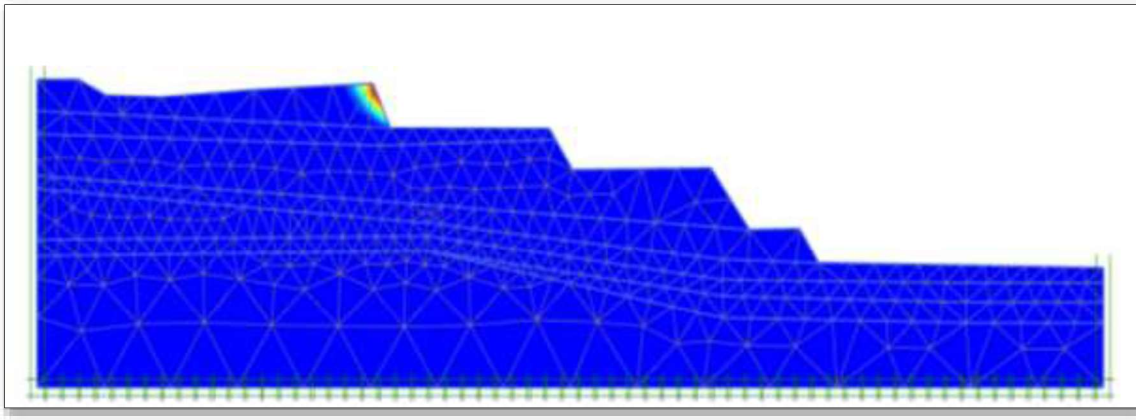


Figure 10. Production of stability analysis in the Plaxis 2D software package

8. Influence of coefficient (r_u) on stability

In the analysis of stability for the working degree scale a safety coefficient Fs = 1.15 is entered, with variations of r_u for the different presence of groundwater levels whereas the barometer is obtained $r_u = 0.00$ which value should be achieved by removing the water by various methods (measures to be taken for water removal). The simulated values (r_u) of $r_u = 0.2$ and $r_u = 0.3$ show the negative impact of the increased presence of water, but with the application of methods for water removal, it should be avoided. The slope has been verified for years; in which case the entire representative lithological description has been included in the physical-mechanical characteristics.

Table 11. Influence of β on (Fs) for slip surface B003, 2019

3-3	ru=0			ru=0,20			ru=0,30		
	Bishop	Janbu	Spencer	Bishop	Janbu	Spencer	Bishop	Janbu	Spencer
1	2,304	2,265	2,307	1,942	1,91	1,947	1,761	1,732	1,766
2	1,979	1,841	1,981	1,725	1,604	1,731	1,598	1,485	1,609
3	1,524	1,478	1,519	1,305	1,264	1,302	1,194	1,155	1,192

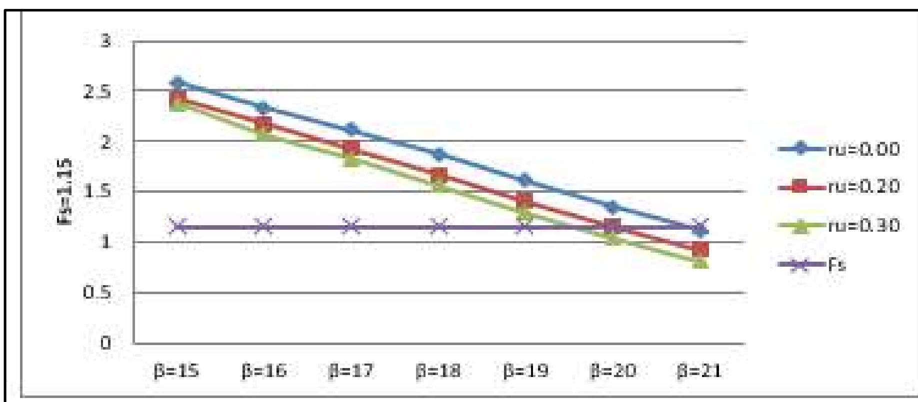


Figure 11. Diagram of Fs sensitivity from β and r_u in profile 3-3 ′ B003

Table 12. Impact of r_u in Fs

B3	r_u=0.00	r_u=0.20	r_u=0.30
β=19°	1.4	1.22	1.1
β=15°	2.12	1.84	1.71
Fs	1.15	1.15	1.15

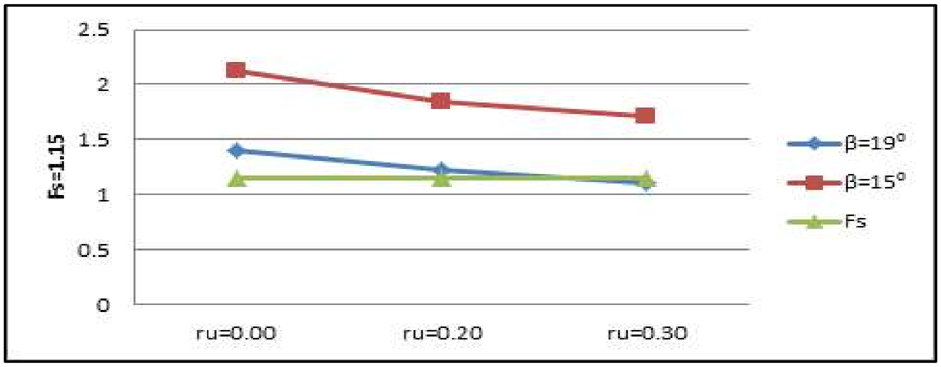


Figure 12. Influence diagram of r_u and β in Fs (Bishop)

Table 13. Impact of r_u in Fs

J004	r_u=0.00	r_u=0.20	r_u=0.30
β=19°	1.46	1.33	1.26
β=15°	1.78	1.66	1.58
Fs	1.15	1.15	1.15

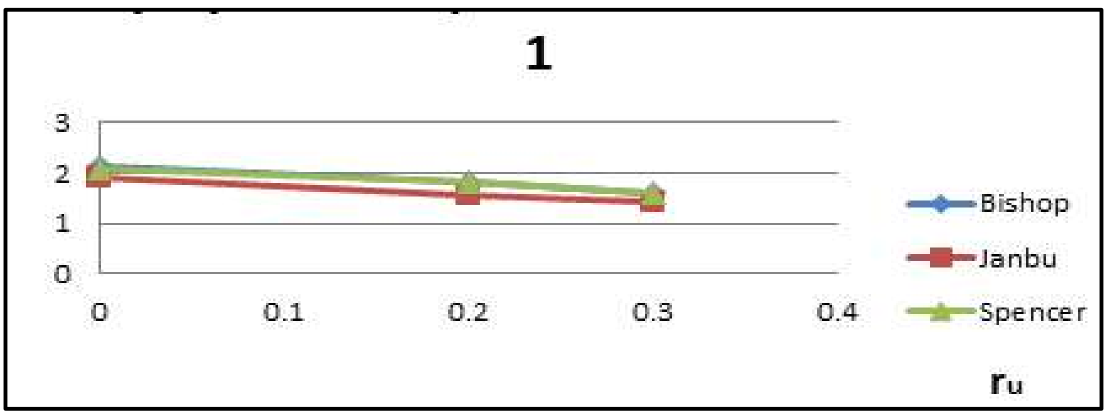


Figure 13. Influence of r_u and β diagram on Fs (Jambo)

Table 14. Changing the stability from (r_u) (profile 3-3 ') to β = 19°

3-3'-B003	β=15°	β=16°	β=17°	β=18°	β=19°	β=20°	β=21°
r_u =0.00	2.58	2.33	2.12	1.88	1.61	1.35	1.12
r_u =0.20	2.43	2.17	1.93	1.67	1.4	1.15	0.92
r_u =0.30	2.38	2.07	1.83	1.57	1.29	1.04	0.81
Fs	1.15	1.15	1.15	1.15	1.15	1.15	1.15

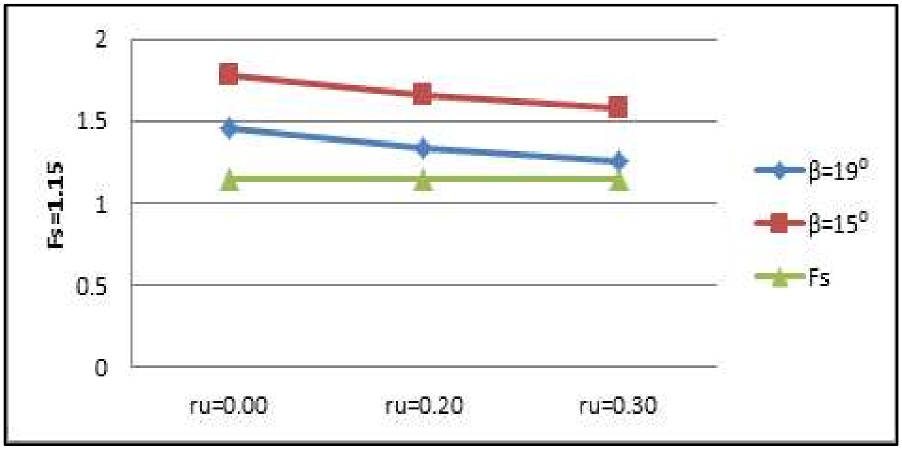


Figure 14. Fs dependency diagram of water coefficient (r_u)

Table 15. Influence of β on (Fs) on the B003, 2019 feed surface

β=19°	r_u=0			r_u=0,20			r_u=0,30		
	Bishop	Jambo	Spencer	Bishop	Jambo	Spencer	Bishop	Jambo	Spencer
1	2.304	2.265	2.307	1.942	1.91	1.947	1.761	1.732	1.766
2	1.979	1.841	1.981	1.725	1.604	1.731	1.598	1.485	1.609
3	1.524	1.478	1.519	1.305	1.264	1.302	1.194	1.155	1.192
Fs	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15

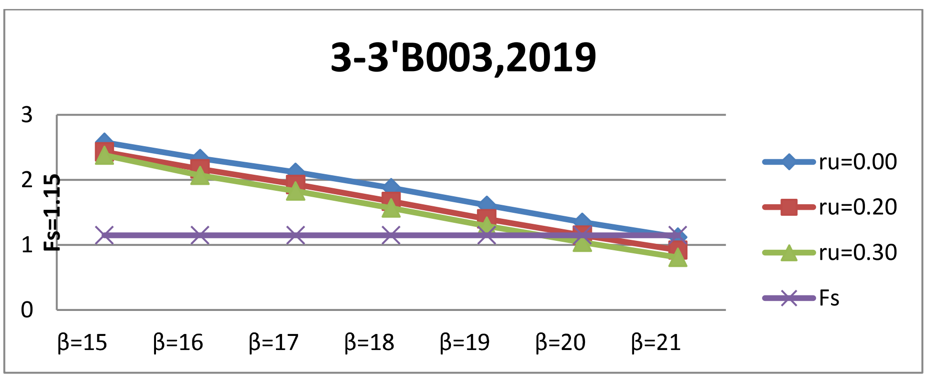


Figure 15. Sensitivity diagram in Fs from β and r_u in profile 3-3 ′, BOO3

Table 16. Influence of β on (Fs) on the J003 feed surface

3-3'-J003	β=15°	β=16°	β=17°	β=18°	β=19°	β=20°	β=21°
r_u=0.00	2.62	2.39	2.13	1.87	1.58	1.31	1.04
r_u=0.20	2.26	2.05	1.84	1.6	1.36	1.1	0.84
r_u=0.30	1.9	1.74	1.55	1.39	1.25	1.02	0.8
Fs	1.15	1.15	1.15	1.15	1.15	1.15	1.15

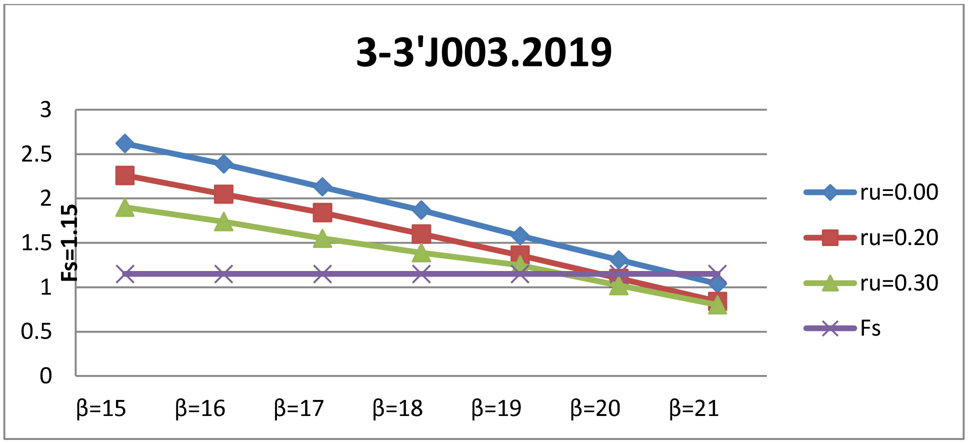


Figure 16. Sensitivity diagram in Fs from β and r_u in profile 3-3 ' ' J003

Table 17. Influence of (r_u) on stability (profile 3-3 ') for β = 19°

β=19^0	r_u =0			r_u =0,20			r_u =0,30		
	Bishop	Janbu	Spencer	Bishop	Janbu	Spencer	Bishop	Janbu	Spencer
1	2.304	2.265	2.307	1.942	1.91	1.947	1.761	1.732	1.766
2	1.979	1.841	1.981	1.725	1.604	1.731	1.598	1.485	1.609
3	1.524	1.478	1.519	1.305	1.264	1.302	1.194	1.155	1.192
Fs	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15

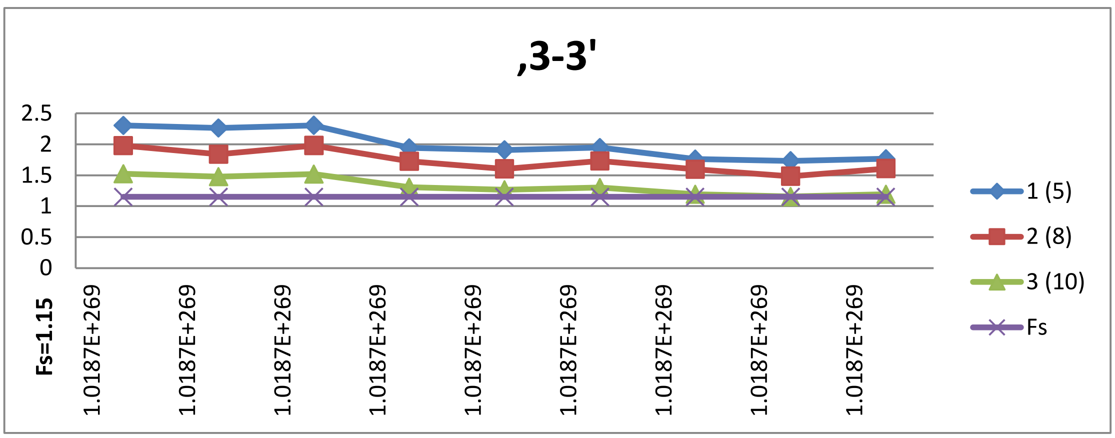


Figure 17. Diagram with variations of coefficient of water (r_u)Slide

Table 18. Influence of (r_u) on stability (3-3 'profile) for β=15°

	r_u=0.0		r_u=0.2		r_u=0.3	
β=15^0	Bishop	Janbu	Bishop	Janbu	Bishop	Janbu
1	1.64	1.54	1.37	1.3	1.26	1.12
2	2.24	2.19	1.88	1.73	1.53	1.45
3	2.58	2.62	2.43	2.26	2.24	1.9
Fs	1.15	1.15	1.15	1.15	1.15	1.15

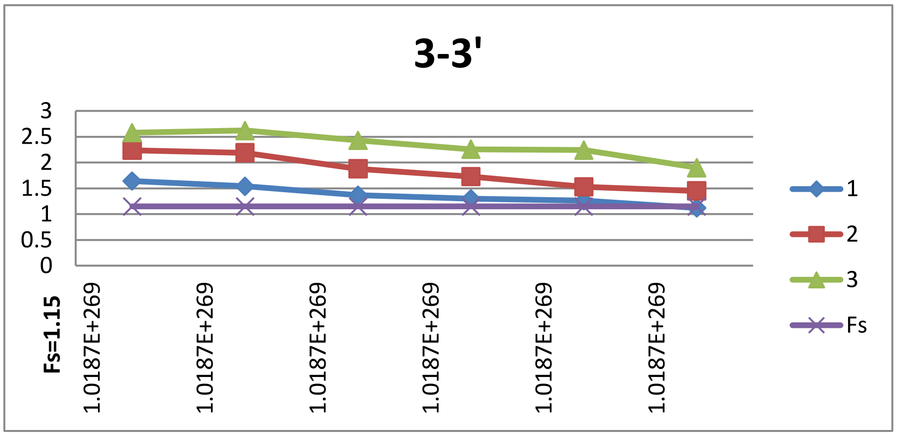


Figure 18. Diagram with value variations (r_u). GGU

9. Conclusion

The values according to the Jambos method are distinguished in comparison with the values of the Bishop method for about% 10%, which difference is more pronounced for sliding surfaces with medium thicknesses even for larger values of the polar coefficient (r_u). What is e useful from a consistent and practical point of view is that the achieved coefficients are higher than the minimum.

Instability analysis for the working degree scale introduced with safety coefficient Fs = 1.15, with r_u variations for the different presence of groundwater levels whereas the barometer is obtained $r_u = 0.00$ which value should be achieved by removing the water by various methods (measures to be taken to remove water).

The simulated values (r_u) $r_u = 0.2$ and $r_u = 0.3$ show the negative impact of the increased presence of water, but with the application of methods for water removal, it should be avoided.

Verification of slope has been done for years, in which case the entire representative lithological description has been included in the physico-mechanical characteristics.

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