Slope Stability Analysis of Low Wall Pit 6 at PT Sarolangun Bara Prima, Mandiangin District, Sarolangun Regency, Jambi

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Abstract. PT Sarolangun Bara Prima is a company engaged in the coal mining industry located in Mandiangin sub-district, Sarolangun district, Jambi city. PT Sarolangun Bara Prima is one of the coal mining companies that uses open mining systemwith open-cut method. This research focuses on the Low Wall pit 6 slope of PT Sarolangun Bara Prima. from the results of field observations, the authors found water seepage and avalanches on the walls of the Low Wall pit 6 slope. The highrainfall at PT Sarolangun Bara Prima causes a decrease in the cohesion value and the value of the inner shear angle in the slope constituent material. The method used in analyzing the stability of the Low Wall Pit 6 slope is the Morgenstern-Price method which is run into slide 6.0 software. The analysis was carried out based on the actual slope section data in August 2023. from the results of the analysis of the stability of the Low Wall Pit 6 slope obtained a safety factor (FK) with a saturated state of 1.089 From the results of the analysis obtained, it explains that the Low Wall Pit 6 slope is in a keritis state. For this reason, the authors made modifications to the actual slope geometry to get FK ≥ 1.3 or the slope is said to be safe. The results of the modification of the geometry of the Low Wall pit 6 slope obtained FK value for saturated conditions is 1.30.

Keywords: *low wall*, *morgenstern-price*, *slope stability*

1 Introduction

PT Sarolangun Bara Prima is an industrial company engaged in the coal mining sector. PT Sarolangun Bara Prima conducts coal mining activities located in Mandi Angin District, Sarolangun Regency, Jambi Province.

PT Sarolangun Bara Prima uses an open-cut mining system as its mining method. Open-cut mining is very synonymous with slopes and can trigger landslides. This trigger is usually caused by external and internal factors, for example external factors are vibration, coal excavation and earthquakes while internal factors are geological conditions, groundwater, and so on. Therefore, it is necessary to analyze the stability of the slope to carry out mining activities safely, starting from the slope geometry plan and the method used in excavation.

Currently at PT Sarolangun Bara Prima there is no geotech study on the safety factor (FK) of slope stability. Of course this is very dangerous if a landslide occurs, if no slope stability analysis is carried out and maximum handling of landslides, it will cause losses to the company such as disrupted or stopped mining activities. It can even cause loss of life.

From field observations in July on the lowwall slope of pit 6 PT Sarolangun Bara Prima has occurred avalanches due to high rainfall. apart from that water seepage was also found on the walls of the low wall pit 6 PT Saralongun Bara Prima.

2 Research Location

Figure 1. Location of PT Sarolangun Bara Prima

PT Sarolangun Bara Prima is located in the Village of Simpang Kertopati, Mandiangin Sub-District, Sarolangun District, Jambi Province, with a Mining Business License area of 243H, the distance from Padang to the location can be travelled with a distance of 508 km with a travel time of 10 hours if traveled by car.

3 Literature Review

3.1 Slopes

A slope is a surface of land or rock that slopes and forms a certain angle to a horizontal plane and is not protected (Das 1985). Existing slopes are generally divided into two categories of land slopes, namely natural slopes and artificial slopes.

3.2 Concept of Slope Stability

According to Irwandy Arif (2015:4). The force responsible for the stability of the slope is the retaining force and the driving force. If the retaining force is greater than the driving force then the slope will be stable, otherwise if the retaining force is smaller than the driving force then the slope is unstable.

Safety Factor (FK) = $\frac{Holding\ Force}{Driving\ Force}$

Where;
FK < 1: means the slope is unstable
FK = 1: means that the slope is in a criticalstate FK> 1: means that the slope is stable

3.3 Factors Affecting Slope Stability

(According to Moshab, 1997.) Slope stability is influenced by slope geometry factors, physical and mechanical characteristics of slope formation materials, water (hydrology and hydrogeology), rock weak plane structure (location, direction, frequency and mechanical characteristics), natural stresses in the rock mass, local stress concentration, vibration (natural: earthquakes; and man-made: blasting effects and heavy equipment traffic effects), climate, mine workers' actions, and thermic influences.

3.3.1 Anchoring Force Forming Factor

3.3.1.1 Rock Type

Basically, rocks that have undergone a weathering process will provide worse slope stability than rocks that have not undergone weathering.

3.3.1.2 Rock strength

The stronger the rocks that make up a slope, the greater the slope recommendation will be.

3.3.1.3 Shear Strenght

The higher the shear strength value of the building material on the slope, the more stable/safe the slope is.

3.3.1.4 Cohesion and Inner Shear Angle

Cohesion (c) is the force of attraction between particles in soil or rock which is expressed in units of weight per unit area (Haris et al., 2018). The cohesion of soil or rock will be large if the shear strength is also large.

3.3.2 Driving Force Forming Factor

3.3.2.1 Groundwater

Water contained in the soil or rock forming the slope can load the slope. The presence of water in the material that makes up the slope (soil or rock) is related to the weight of the contents, the more the water content of the slope.

3.3.2.2 Content Weight

The fill weight value will affect the driving force, where the higher the fill weight value the greater the loading on the slope and the lower the shear strength value, the higher the fill weight value the higher theshear strength value.

3.3.2.3 Slope Geometry

The slope and height of the slope greatly affect its stability. The greater the slope and height of a slope, the less stability (Febriadi et al., 2020).

3.3.3 Factors Affecting Driving Force

3.3.3.1 Weak Fields

Discontinuity planes that greatly affect the stability of the slope are fault planes, layers and fractures. Theserock structures are weak areas or discontinuities and atthe same time a place where water seeps, so that rocksare more prone to landslides.

3.3.3.2 Weathering

Weathering changes the mineralogical composition of the rock and its internal structure (packing, texture, crystal system, etc.). The impact causes the mechanical and physical properties of the rock to change, and generally leads to a reduction in the strength of therock.

3.3.3.3 Climate

Rainfall, which is one of the climate components, will affect water saturation, moisture content, and weathering rates in rocks. Rain can increase the water content in the soil and in turn willcause the physical condition of the slope body to change. The increase in soil moisture content will affect the mechanical and physical properties of thesoil.

3.3.4 Factors Affecting Driving Force

3.3.4.1 Blasting Vibration

The energy liberated from the explosive is transmitted to the rock mass as strain energy, which occurs in the form of waves that destroy the rock mass around the blasthole.

3.3.4.2 Tectonic Activity

The energy liberated from the explosive is transmitted to the rock mass as *strain* energy, which occurs in the form of waves that destroy the rock mass around the blasthole.

3.3.4.3 Load Increase Hoarding

Backfilling activities in the bag section of the slope will increase the loading which will result in an increase in the driving force of the slope.

3.4 Morgenstern-Price

This method is one of the methods based on the principle of boundary equilibrium developed by Morgenstern and Price in 1965, where the analysis process is the result of the equilibrium of each normal force and moment acting on each slice of the slope's good force.

The advantages of the Morgenstern-Price method are that it is a slope analysis method suitable for all types of materials with all forms of sliding planes and produces more stable analysis values and simpler numerical calculations based on equilibrium boundary conditions.

3.5 Legal Basis of Mining Geotechnics

The legal basis for slope stability is guided by the Decree of the Minister of Energy and Mineral Resources Number 1827K/30/MEM/2018, which is as follows:

Table 1. FK of slope

Slope type	Qonsequenc es of failure	Acceptance criteria		
		Static safety factor (minimu m)	Safety Factor Dinami s Conditi on (minimum)	Probabilit y of Failure (maximu m)PoF (SF<1)
Single slope	Low-high	1.1	-	25-50%
Inter-ramp	Low	1.15-1.2	1.0	25%
	Medium	1.2-1.3	1.0	20%
	High	1.2-1.3	1.1	10%
Overa ll slope	Low	1.2-1.3	1.0	15-20%
	Medium	1.3	1.05	10%
	High	1.3-1.5	1.1	5%

4. Research Methodology

4.1 Implementation Time

Research activities were carried out from August 7 to September 7, 2023, on September 5, 2023 to September 6 the author took samples which were then used for data processing.

4.2 Research Location

Data collection was carried out in the IUP mining area of PT Sarolangun Bara Prima, this research wasthen limited and focused on the *Low Wall* pit 6 slope at the PT Sarolangun Bara Prima mine, Mandi Angin sub- district, Sarolangun Regency, Jambi.

4.3 Type of Research

The type of research that researchers do is Quantitative and applied research. This research is directed to applied research, which is a type of research that aims to apply the theory obtained in lectures to the actual field.

4.4 Literature Study

literature study aims to study or understand the theories related to the problems that will bediscussed by the author through literature references and theoretical studies.

4.5 Field Observation

Field observations aim to see firsthand the problems that occur in the object of research.

4.6 Data Capture Stage

Data collection in the field is used to find out the existing problems so that they can be studied and provide the best solution. The data taken consists of primary data and secondary data.

4.7 Data Processing

Data processing is carried out after primary data and secondary data have been taken in the field. The data processing carried out in this study is data on physical properties and mechanical properties.

4.8 Conclusion

After correlating the results of field observations, data processing, data analysis, and evaluation, the results provide alternatives to the critical and unstable with a safe safety factor and a stable slope geometry design.

5. Result and Discussion

5.1 Research data

5.1.1 Research Location

The research site is located on the slope of Low Wall pit 6 PT Saralongun Bara Prima in Mandi Angin sub-district Sarolangun district Jambi city.

5.1.2 Physical Properties Data

5.1.2.1 Water Content Test Data

Table 2. Test data for moisture content of sample 1

	Testing	W1 (grams)	W2 (grams)	W3 (grams)
Sample 1	1	5,82	10,87	9,54
	2	4,73	9,72	8,41
	3	5,37	10,44	9,14

Table 3. Water content test data of sample 2

	Testing	W1 (grams)	W2 (grams)	W3 (grams)
Sample 2	1	5,29	10,28	8,86
	2	5,21	10,26	8,9
	3	5,56	10,56	9,18

Table 4. Test data for moisture content of sample 3

	Testing	W1 (grams)	W2 (grams)	W3 (grams)
Sample 3	1	4,94	9,98	8,93
	2	5,73	10,75	9,7
	3	4,94	9,97	8,95

Description:

W1 = Weight of cup (g)
W2 = Weight of cup + Original Soil
W3 = Weight of Cup + DrySoil

Table 5. Upper H coal moisture content test data

Lithology	Wn	Wo
H *Upper*	37,35	32,2

Table 6: Lower coal moisture content test data

Lithology	Wn	Wo
H Lower	**138,64**	**116,12**

Description:

Wn = Original Rock Weight(g)
Wo = Dry Rock Weight (g)

5.1.2.2 Content Weight Test Data

Table 7. Test data of soil material content weight

Lithology	W1 (grams)	W2 (grams)	W3 (grams)	A (cm^3)
Sample 1	61,01	173,54	152,8	55,8
Sample 2	68,9	172,65	151,7	55,8
Sample 3	62,13	175,17	158,04	55,8

Description:

W1 = Ring weight (g)
W2 = Ring weight + OriginalSoil
W3 = Ring weight + DrySoil

Table 8. Test data of coal material content weight

Lithology	Wn	Ws	Ww	Wo
H *Upper*	93,85	32,12	102,3	82,2
H *Lower*	115,37	39,8	123,1	99,6

Description:

Wn = Original coal weight (g)
Ws = Weight of coal floating in water
Ww = Weight of coal in saturated state
Wo = Weight of coal in dry state

5.1.3 Mechanical Properties Data

Table 9. Soil shear strength test data

Code Sample	Load Normal	Load Slide	D	A
Sample 1	3	4,7	6,15	29,7
	6	5,6	6,15	29,7
	9	6,5	6,15	29,7
Sample 2	3	6,1	6,15	29,7
	6	7	6,15	29,7
	9	8,4	6,15	29,7
Sample 3	3	8,4	6,15	29,7
	6	9,8	6,15	29,7
	9	11,2	6,15	29,7

5.1.3.1 Cohesion and Shear Angle Values In Coal To

To get the cohesion value and inner shear angle of coal material can be obtained from processing in roclab software. To do the processing in roclab, we first look for the PLI (Point Load Index) value which will later be converted to the UCS value, which is the ucs value that we will later input into the roclab software. The following is the PLI value of the coal sample.value of the coal sample.

Table 10. PLI (Point Load Index) Test Data

Lithology	Sample Code	W1 (mm)	W2 (mm)	D (mm)	F (Mpa)
H *Upper*	1	44	36,5	27,9	660
	2	45,8	39,5	29,1	640
H *Lower*	1	52,9	44,9	26,6	742
	2	42	42	26	860

To get the cohesion value and the inner shear angle value we have to process it with Rocsience Roclab software where there are some data needed to be inputted into the tab on the left side available such as, UCS value, *Geological Strength Index* (*GSI*), *Intact Rock Parameter* (Mi), fill weight and slope height.

Table 11. Data input to Roclab software

No.	Input	Coal H Upper	*Lower* H coal
1	UCS (MPa)	6,4	8,45
2	GSI	14	14
3	MI	6	6
4	Content weight (Mn/m^3)	0,0131	0,0135
5	Slope height (m)	35	35

5.2 Data Analysis

5.2.1 Test Result for Physical Properties

5.2.1.1 Moisture Content Testing Result

After testing the water content of the three samples, the water content value of each sample and coal can be seen inTable 12.

Table 12: Water content test results

Lithology	Test 1,2,3 (%)	Average (%)
Sample 1	35,75	35,27
	35,59	
	34,48	
Sample 2	39,77	38,25
	36,85	
	38,12	
Sample 3	26,31	26
	26,44	
	25,43	
H *Upper*	15,9	15,9
H Lower	19,4	19,4

5.2.1.2 Weight of Contents Testing Result

After testing the Weight Content of the three samples, the Weight Content value of each sample and coal canbe seen in Table 13.

Table 13. Test result of Fill Weight

Sample code	γnat		γdry		γsat	
	gr/cm^3	kN/m^3	gr/cm^3	kN/m^3	gr/cm^3	kN/m^3
Sample 1	2	19,6	1,64	16	2,22	21,75
Sample 2	1,85	18,13	1,48	14,5	2,05	20
Sample 3	2,	19,6	1,71	16,75	2,16	21,2
Coal H *Upper*	1,34	13,1	1,17	11,5	1,45	14,21
Coal H *Lower*	1,38	13,5	1,19	11,6	1,47	14,4

5.2.2 Mechanical Properties Testing Result

5.2.2.1 Result of Conversion Of PLI

Table 14. UCS Values of Coal Samples

Lithology	Sample Code	UCS	Average
H *Upper*	1	6,912993	6,4
	2	5,927378	
H *Lower*	1	6,94398	8,45
	2	10,0972	

5.2.2.2 Cohesion Value and Inner Shear

Angle After testing the inner shear strength processing of UCS Values to Obtain Cohesion and Deep Shear Angle values, the cohesion and deep shearangle values of each sample and coal can be seen in Table 15.

Table 15. Cohesion value and inner shear angle

Sample Code	Cohesion (C)	Inner shear angle (∅)
	(MPa)	o
Sample 1	12,54	16,7
Sample 2	15,5	21,8
Sample 3	22,96	25,4
Coal H *Upper*	40	25,44
Lower H coal	45	26,98

5.3 Actual Slope Stability Analysis

Based on the data section of the *Low Wall* Pit 6 slope of PT Sarolangun Bara Prima in August, it is known that the geometry of the *Low Wall* slope has a height of 35m and a slope angle of 35°.

This stability analysis will assume the possibility of a groundwater table (MAT) on the slope from the high-water table of the sump. Pit 4 of PT Sarolangun Bara Prima from the bottom of the Pit 6 surface.

5.3.1 Slope Stability Analysis under Natural Conditions

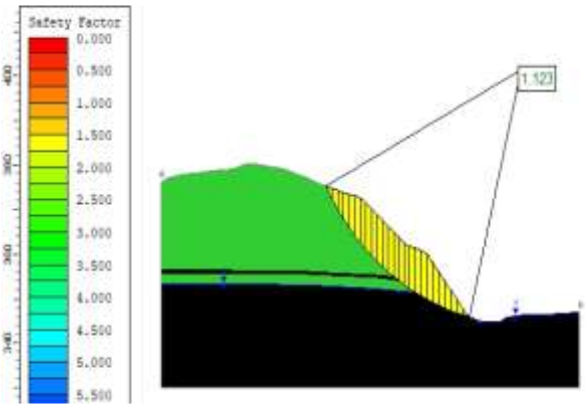

Figure 2. FK slope with Natural Conditions

The value of the safety factor (FK) of the slope is obtained. with Natural conditions of 1.123. which is also unstable and has the potential for landslides. The slope safetyfactor can be seen in Figure 2.

5.3.2 Slope Stability Analysis under Dry Conditions

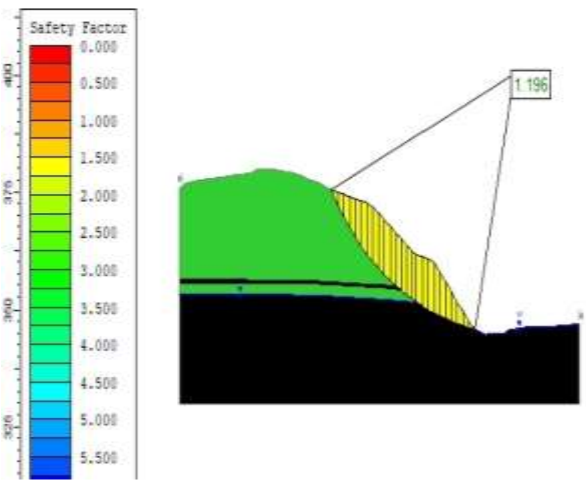

Figure 3. FK Slope with Dry Condition

5.3.3 Slope Stability Analysis under Saturated Conditions

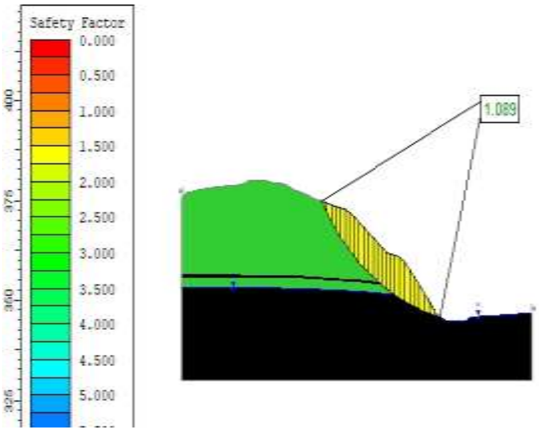

Figure 4. FK Slope with Dry Condition

Based on slope stability analysis with Using rocksience slide 6.0 software, the factor of safety (FK) value of the slope with saturated conditions is 1.089. which means that this slope is unstable and hasthe potential for landslides. The slope safety factor canbe seen in Figure 4.

Table 16. Actual slope FK recap

Conditions Slope	Analysis Slope	High (m)	Slope (°)	FK
Saturated	Single	35	35	1.089
Natural	Single	35	35	1.123
Dry	Single	35	35	1.196

5.4 Modeling of actual slope recommendations after modification

5.4.1 Double slope recommendation

The author conducted the first experiment by modifying the slope modeling of the double slope model type, where the experiment was carried out by calculating the safety factor starting from Slope 1 having a slope of 42° and Slope 2 having a slope of 53° with a banch width of 4 m until at what banch width the slope has a safety factor ≥ 1.3.

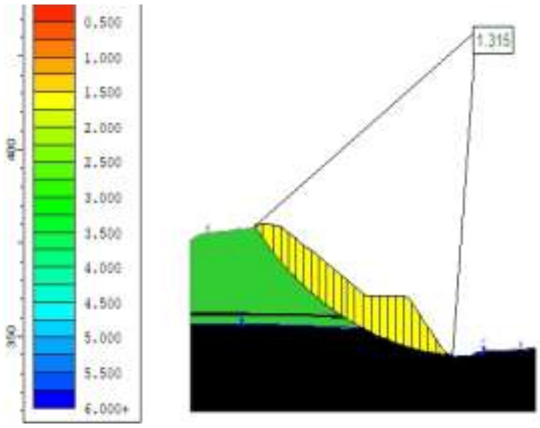

Figure 5. FK for Double Slope

Table 17. FK for double slope slope

Slope analysis	Slope (degree)	Banch width	Height (m)	Safety Factor (FK)	Total area (m²)
Overall doble slope	33	12	35	1,315	181,61
Slope 1	35		19	1,336	
Slope 2	53		16	1,317	

Based on analysis using Rocscience slide six point zero software, the factor value is obtained slope safety with groundwater level conditions is 1.315, meaning the slope is in a safe condition.

5.4.2 Triple Slope Recommendation

The author conducted a second experiment by modifying the modeling of slopes of the *triple slope* model type, where the experiment was carried out by calculating the safety factor starting from each having a *slope* of 35^{o} for the *overall slope* and 42°, 42°, for *slope* 1, 2 and 53° for *slope* 3 with the width of the *banch.* 4m until at what banch width the slope has a factor of safety ≥ 1.3.

5.3.2 Triple slope recommendation

Based on analysis using software rocscience slide 6.0, then obtained the value of the safetyfactor of the slope with the condition of the groundwater table is 1.30. Meaning that the slope is in safe condition.

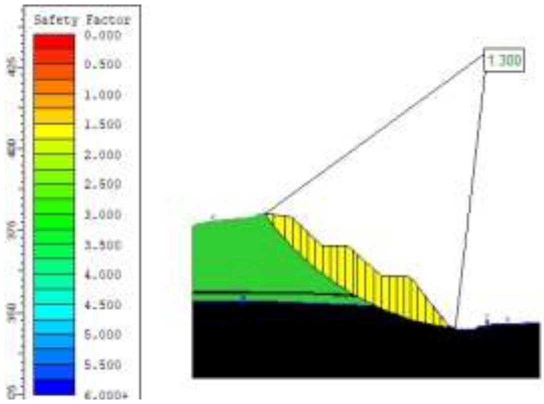

Figure 6. FK of triple slope

Table 18. FK for triple Slope

Slope analys is	Slope (degree)	Banch width	Height (m)	Safety Factor (FK)	Total area (m²)
Overall Triple Slope	33	8	35	1,30	122,81
Slope 1	42		9.5	1,416	
Slope 2	42		9.5	1,684	
Slope 3	53		16	1,371	

Through analysis using Rocscience slide software, a slope geometry recommendation was obtained using the Morgenstern price method with a safety factor (FK) of 1.315 and 1.3 for double slope and triple slope. Therefore, t h e author suggestsusing a triple slope with a bench width of 8 meters and a slope for the first and second slopes of 42^{o} andand the slope of the third slope of 53°. the area to bepeeled is 122.81 m².

6. Conclusions and Suggestions

6.1 Conclusion

1. The physical properties data obtained from laboratory testing are, for Sample 1, the content weight is 19.6 kN/m^{3} for natural content weight, 16 kN/m^{3} for dry content weight and 21.75 kN/m^{3} for saturated content weight and has a moisture content of 35.2%. For material Sample2, the content weight is 18.13 kN/m^{3} for natural content weight, 14.5 kN/m^{3} for dry content weight and 20 kN/m^{3} for saturated content weight and has a moisture content of 38.3%, formaterial Sample 3, the content weight is 19.6 kN/m^{3} for natural content weight, 16.75 kN/m^{3} for dry content weight and 21.2 kN/m^{3} for saturated content weight and has a moisture content of 26%,.

As for the coal material, the natural content weight for H *Upper Coal is* 13.1kN/m^3 for natural content weight, 11.5 kN/m^3 for dry content weight and 14.21 kN/m^3 for saturated content weight and has a water content of 15.9%. for H *Lower* Coal 13.5 kN/m^3 for natural content weight, 11.6 kN/m^3 for dry content weight and 14.4 kN/m^3 for saturatedcontent weight and has a water content of 19.4%.

2. The mechanical properties data obtained from laboratory testing and processing from the rocsience roclab 6.0 software obtained the mechanical properties test for material Sample 1 has a cohesion value of 12.54 MPa and ashear angle inside 16.7°. for material Sample 2 has a cohesion value of 15.5 MPa and an inner shear angle of 21.8°. for material Sample 3 has a cohesion value22.96 MPa and inner shear angle 25.4°. H *Upper* coal material has a cohesion value of 40 MPa and an inner shear angle of 25.44°. for *Upper* H coal material has a cohesion value of 45 MPa and an inner shear angle of 26.98°.
3. Based on the results of the actual slope analysis using the Rocsience Slide software program 6.0 with *Morgenstern price* method obtained a saturation Factor of Safety (FK) of 1.089 and for FK natural and dry have FK 1.123and 1.196. from the above data we can knowFK for low wall slopes no one has entered into the category of stable slopes because FK slopes are still < 1.3. therefore it is necessary to modifythe slope geometry modeling so that the slope has FK ≥ 1.3.
4. Slope recommendations obtained from the results analysis using rocsience slide 6.0 software, namely by modifying the slope with a *tripleslope* type where the overall slope is modeled with a slope angle of 33°, the first and second slopes 42^o and the third slope 53^o with a banch width of 8m. for overall slope heighthas a height of 35m, for the height o f t h efirst and second slopes 9.5m and the height of slope 3 is 16m, the FK for the low wall slope in a saturated state is 1.30.

6.2 Advice

1. Modifying the actual *slope* with a *triple slope* type makes the Bench in accordance with the recommendations with a banch width of 8m, the height of the single slope 1 and 2 is 9.5m and 16m respectively for the slope height of the 3rd slope with the slope of the single slope 1 and 2 is 42^o and 53^o for the slope slope of the 3rd slope and theoverall slope angle is 33°.
2. Geotechnical studies are needed to determine the FK of the slope in order to provide a sense of security in the mining process.
3. Monitoring wells are needed to determine the height of the water table.
4. Periodic observations of the slope are necessary, to identify any movement on the slope.

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