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Slope Stability Analysis for Mine Slope Design Optimization Planning at Pit Middle of PT Banjarsari Pribumi Open Pit Mine, Merapi Timur, Lahat, South Sumatera

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Abstract. *PT Banjarsari Pribumi is a subsidiary of PT Titan Infra Energy (Titan Group) which is engaged in coal mining. The company is located in Merapi Timur, Lahat, South* Sumatera. *PT Banjarsari Pribumi conducts mining using the Open Pit Mining method. To determine the safety factor using the morgenstren-price method. The results of the slope stability analysis for Section A-A' obtained a saturated FK of 1.092, saturated FK Section B-B' of 1.041 saturated FK Section C-C' of 1.148. From the analysis results obtained, it is explained that the slope is in critical condition. For this reason, the authors conducted a slope dewatering simulation and a resloping + dewatering simulation on the Lowwall Pit Slope. The results of the 2 m dewatering simulation for section A-A' obtained an FK value of 1.454, for dewatering 10 m section B-B' FK value of 1.301 and for dewatering 5 m C-C' FK value of 1.301. The resloping simulation results for section A-A' obtained an FK value of 1.319. The resloping + dewatering simulation results for section B-B' obtained an FK value of 1.345 and for section C-C' of 1.369.*

Keywords: *back analysis, slope stability, monte carlo, morgenstren-price*

1. Introduction

PT. Banjarsari Pribumi is a PT Titan Infra Energy (Titan Group) subsidiary in the coal mining sector. This company is located in East Merapi, Lahat, South Sumatera, which is located between 103º42'391.4" East Longitude to 130º43'4" East Longitude and 3º40'2" South Latitude to 3º40º2" South Latitude with an IUP of 519.84 ha. Currently, PT Banjarsari Pribumi has three mining pit locations: Middle Pit, ABC Pit, and South Pit. However, the only pits that carry out operations are Pit South and Pit Middle.

PT Banjarsari Pribumi carries out mining using the open-pit mining method. Mining activities using this method are carried out by stripping overburden and digging coal. Using this method, the company works to widen and deepen the excavation. The broader and more profound the excavation, the more significant the disruption and risk will occur, including slope instability.

Slope instability can cause landslides or collapses on the slopes, which will have an impact on mining activities. To avoid this can be done by analyzing the stability of the slope. Slope stability analysis can be carried out using various methods. One way is to use the Limit Equilibrium Method (LEM) or limit equilibrium method. This method is widely used to indicate the occurrence of landslides on planned slope designs.

Based on observations at PT Banjarsari Pribumi which focuses on the middle pit, where there is a slope on the eastern part of PT Banjarsari Pribumi's middle pit, a landslide has occurred, which has resulted in the cessation of mining activities in that section. Therefore, PT Banjarsari Pribumi is clearing new land in the western part of Pit Middle to achieve production targets. Then, there is a pool of water at the pit crest, which can cause the slope to become saturated so that the strength of the slope formed can

In the final design of the mining slope that has been designed, it is necessary to evaluate to avoid something similar happening to the slope in the eastern part because, on the slope of the eastern part of the middle pit, which slip, the results of the company's analysis have shown that the slope is in a stable condition or FK value > 1.3 will be but still landslides.

Based on these problems, the value of the safety factor and the probability of slope failure will be calculated; then a reverse analysis will be carried out to obtain new input material properties, followed by recommendations for optimal slopes by Minister of Energy and Mineral Resources Decree No. 1827 of 2018.

2. Research Sites

2.1Map of PT. Banjarsari Pribumi WIUP

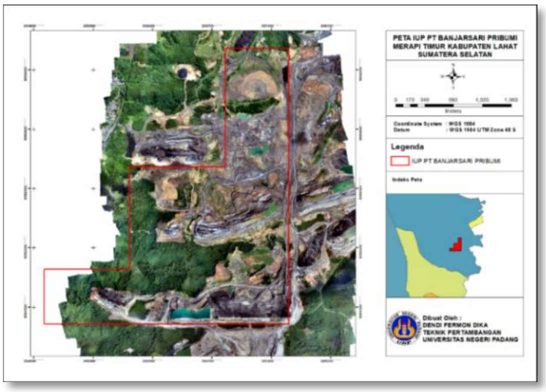

Fig 1 Map of WIUP location PT. Banjarsari Pribumi

PT. Banjarsari Pribumi is an industrial company operating in the coal mining sector. This company, which carries out coal mining activities, is located in East Merapi District, Lahat Regency, South Sumatera Province. PT Banjarsari Pribumi is located between 103º 42' 391.4" East Longitude to 130º 43' 4" East Longitude and 3º 40' 2" South Latitude to 3º 40' 2" South Latitude with an area of 519.84 Ha.

Table 1. Coordinates of WIUP PT Banjarsari Pribumi

X	Y
357603.775	9591304.974
354734.381	9591300.792
354733.419	9591954.959
355730.003	9591956.418
355728.235	9593169.54
356842.074	9593171.155
356840.082	9594553.187
357599.105	9594554.276

Source : PT Banjarsari Pribumi

2.2 Regional Geological Conditions

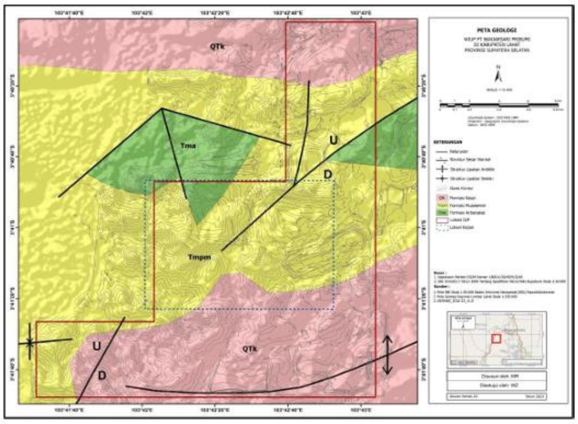

Fig 2 Geological Regional Map of PT Banjarsari Pribumi

PT Banjarsari Pribumi is regionally geologically included in the South Sumatera basin. On the regional geological map above, the PT Banjarsari Pribumi area is located in the Muara Enim Formation with claystone, siltstone, and tuffaceous sandstone with coal inserts, and the Air Mindatat Formation, which has a competing lithology of claystone, with siltstone and shale generally calcareous and carbonaceous.

3. Theoritical Review

3.1 Slope

Natural land surfaces that appear more prominent due to elevation differences are called slopes. Apart from that, a slope can also be interpreted as an earth's surface that forms a certain inclination angle with a horizontal plane—the process of slope formation due to erosion, weathering, and soil movement.

3.2 Slope Stability

Slope stability can be influenced by the structural conditions of weak areas of rock, slope geometry, constituent materials, water, climate, vibration, the results of mine workers' actions, and internal thermal influences (Moshab, 1997) (Irwandy Arif, 2016). The stability of slopes, both natural slopes and artificial slopes (manufactured), as well as embankment slopes, is influenced by several factors, which can be expressed simply as resisting forces and driving forces related to the stability of the slope.

A safety factor can express slope stability. The safety factor compares the forces that resist movement and the driving forces that can cause landslides (Irwandy Arif, 2016). The following equation can express the safety factor:

$$\text{Factor of Safety } (F) = \frac{\text{Restraining style}}{\text{mover style}} \quad (1)$$

As for the basic concepts of mechanics, stability can be determined using the Mohr-Coulomb equation. This equation can express the shear strength of materials in slope stability analysis. The material's shear strength is in the form of Cohesion and Internal shear angle. The Mohr-Coulomb equation can be formulated as follows:

$$\tau = c + \sigma' \tan \phi \quad (2)$$

3.3 Factors Affecting slope stability

Factors affecting slope stability are as follows:

a. Slope geometry
b. Rock Spread
c. Regional and Local Geological Structure
d. Water Presence
e. Surface relief
f. Physical and mechanical properties of materials

3.4 Landslide Classification

A landslide is the collapse of a land mass located on a slope, resulting in downward and outward movement of the land mass. Avalanches can occur in various ways, slowly or suddenly. The instability of the mine slope will cause landslides until the slope finds a new balance and becomes stable.

Landslides can be differentiated based on the landslide process. The following landslides are differentiated based on the landslide process, namely:

3.4.1 Circular failure

This type of landslide is often encountered in nature. In hard rocks, this type of landslide can only occur in rocks that have experienced weathering, and there are discontinuous (weak) areas that are densely jointed or continuous along part of the slope, causing sliding landslides on the surface. What occurs more frequently is a combination of plane landslides and arc landslides, especially on artificial slopes.

3.4.2 Plane Failure

A *plane Failure* is a rock slide along a flat sliding plane. These sliding areas can be faults, joints, or areas of rock layers. Apart from that, what can trigger this landslide is if the slope angle is greater than the angle of the sliding plane and the angle of internal sliding is smaller than the angle of the sliding plane.

3.4.3 Wedge Failure

This landslide model can only occur in rocks with more than one weak or free discontinuous plane, with the angle between the two planes forming an angle more significant than the internal shear angle. The most frequent occurrence is that the line of intersection of two joint planes slopes towards the slope.

3.4.4 Toppling Failure

Toppling Failure occur on steep slopes and on hard rocks, where the weak plane structure is in the form of columns. This landslide occurs when the weak planes on the slope have a slope opposite to the slope where the structure of the weak plane is in the form of a column.

3.5Limit Equilibirum Method

The limit equilibrium method is relatively general and practical in stability analysis, where the stability condition is expressed as a safety factor, especially by calculating weighting forces, equal or equilibrium moments, or both, depending on the calculation method used. In this method, slope stability analysis is calculated using only static equilibrium conditions and ignoring the stress-strain relationship on the slope. Another assumption is that the geometry of the failure plane must be known and determined first.

3.6 Probability Of Failure Method

According to Ministerial Decree 1827, 2018, Probability of Failure is the level of possibility that a slope has the potential for landslides due to the value of one or more geotechnical parameters that deviate from the calculation of the slope safety factor (FK≤1). The possibility of landslides can be analyzed using the landslide probability method, where the landslide probability method is an alternative approach method used to calculate slope stability, which produces the possibility that a slope will experience a landslide apart from the safety factor (FK) value of the slope itself. The probability of landslides (PoF) also answers the possibility of a slope experiencing a landslide due to one or several geotechnical parameters experiencing deviations.

4. Research Methods

4.1 Types of Research

This research uses a quantitative type of research. This is because, in future research, data will be used as numbers. In carrying out this research, secondary and primary data were used, which were then developed per the research objectives. Primary data is data obtained directly from the party whose data is needed; secondary data is not obtained directly from the party whose data is needed.

4.2 Data Collection Technique

4.2.1 Study of Literature

Bringing together various reading sources for research as a reference when carrying out research activities, whether in the form of books, previous research, company data, or other sources that refer to supporting factors for research activities.

4.2.2 Field Observation

Field activities are carried out through careful visual observations to reveal the problems to be discussed. This activity takes the form of a field orientation with company employees to see the situation, conditions, and activities at the search location and the initial stages of the search process, identifying research objects and collecting primary data.

4.2.3 Data Collection

The data taken in this research are primary data and secondary data. Primary data includes slope geometry and secondary data, topographic maps, regional geological maps, material properties, rainfall data, and drilling location maps.

4.2.4 Data Processing Stages

The data processing and analysis steps used in this research are related to the data results obtained from field measurements. First, I modeled the slope geometry using Minecraft 5.7 software. Second, an analysis of slope stability and landslide probability using the Limit Equilibrium Method, namely the Bishop method, was performed with the help of rock science software. In analyzing slope stability, we will refer to KEPMEN ESDM NO 1827 OF 2018, namely FK ≥ 1.3 on the overall slope and the probability of landslides (PK) not exceeding 5%. Meanwhile, to analyze probability using the Monte Carlo method with a sample size of up to 1000.

5. Result and Discussion

5.1Result

5.1.1 Conditions and Research Location

The research was conducted at PT Banjarsari Pribumi, which is a subsidiary of PT Titan Infra Energy (Titan Group). PT Banjarsari Pribumi is located in East Merapi District, Lahat Regency, South Sumatera, located between 103º 42' 391.4” East Longitude to 130º 43' 4” East Longitude and 3º 40' 2” South Latitude to 3º 40º 2” South Latitude with limited IUP coordinates as wide as 519.84 ha. This research starts from 24 July 2023 to 21 August 2023. This research focuses on the Middle Pit of PT Banjarsari Pribumi, as seen in the picture below.

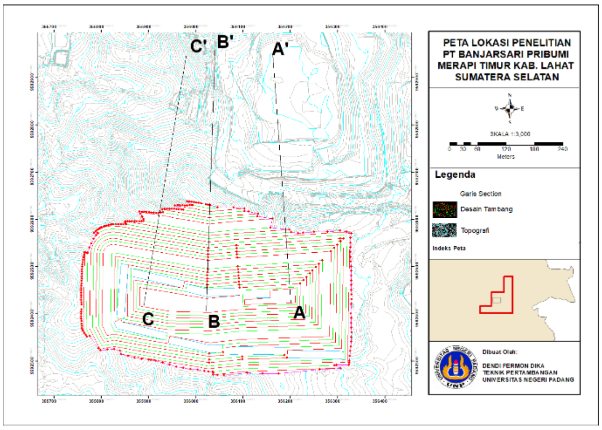

Fig 3 Research Location

5.1.2 LaboratoryTest Result

Laboratory tests were carried out to determine the characteristics of the constituent rocks, which consisted of topsoil, mudstone, siltstone, sandstone, carbonaceous mudstone, and coal. Tests were carried out at the Bandung Islamic University Laboratory (UNISBA) in the mining laboratory to determine rocks' physical and mechanical properties. The following are the values of physical and mechanical rock test results used in analyzing slope safety factors.

Table 2. LaboratoryTest Result

Material	Property	Mean	Std. Dev	Rel. Min	Rel. Max
Sandstone	*Cohesion*	181.64	60	136.34	**244.25**
Sandstone	*Unit weight*	20.07	1.38	18.62	**22.59**
Sandstone	*Phi*	18.28	2.26	15.04	**22.16**
Claystone	*Unit weight*	22.23	1.67	20.56	**24.90**
Claystone	*Cohesion*	187.77	50	168.64	**197.34**
Claystone	*Phi*	21.84	1.47	20.53	**23.90**
Siltstone	*Cohesion*	182.73	30	132.76	**242.19**
Siltstone	*Phi*	19.31	3.87	13.12	**24.24**
Siltstone	*Unit weight*	23.20	0.31	22.89	**23.52**
Carbonecous	*Phi*	19.08	0	19.08	**19.08**
Carbonecous	*Unit weight*	20.40	1.38	18.62	**22.59**
Carbonecous	*Cohesion*	159.67	30	159.67	**159.67**
Coal	*Phi*	19.04	0.47	18.57	**19.52**
Coal	*Cohesion*	191.06	40	179.40	**202.72**
Coal	***Unit weight***	**13.92**	**0.78**	**13.73**	**21.19**

Source : PT Banjarsari Pribumi

5.2 Discussion

5.2.1 Analysis of Slope Safety Factors Section A-A'

Safety factor analysis is carried out to obtain safety factor values. In this research, analysis was carried out using the limit equilibrium method, namely the Morgenstren-Price method, using material properties from laboratory test results. The material properties used can be seen in Table 3 below.

Table 3. Material Properties

Material Name	Color	Unit Weight (kN/m3)	Strength Type	Cohesion (kPa)	Phi (deg)	Water Surface	Ru
sandsatone		20.07	Mohr-Coulomb	181.64	18.28	None	0
Claystone		22.23	Mohr-Coulomb	187.77	21.84	None	0
Siltstone		23.2	Mohr-Coulomb	182.73	23.2	None	0
Carbonecous		20.4	Mohr-Coulomb	159.67	19.08	None	0
Coal		13.92	Mohr-Coulomb	191.06	19.04	None	0
Waste		17.57	Mohr-Coulomb	44.782	13.979	None	0

After obtaining the material properties of the slope, a slope stability analysis in a natural condition

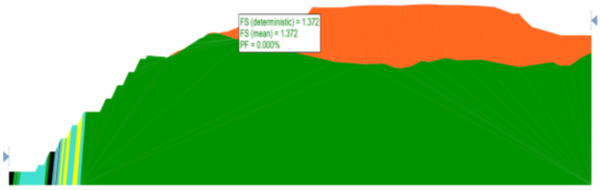

Fig 4 Result of slop analysis in Natural conditions

From the safety factor analysis results and the probability of failure of the overall slope in natural conditions, the safety factor value was 1.372 with a probability of 0%.

Then, is then carried out, assuming that the slope is in a saturated condition due to the presence of standing water in the mining area. Apart from that, the slope is assumed to be in saturated condition, and the worst condition/simulation is used to determine the value of the safety factor for a slope.

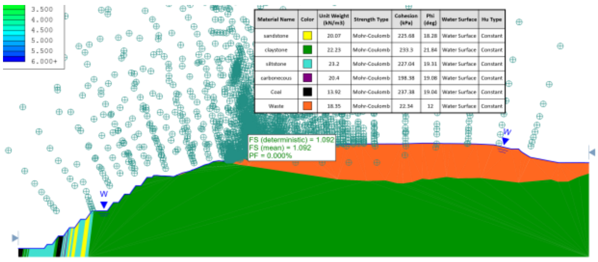

Fig 5 Result of slop analysis in saturated conditions

From the safety factor analysis results and the probability of failure of the overall slope in saturated conditions, the safety factor value was 1.092, with a probability of 0%.

5.2.2 Analysis of Slope Safety Factors Section B-B'

Safety factor analysis is carried out to obtain safety factor values. In this research, analysis was carried out using the limit equilibrium method, namely the Morgenstren-Price method, using material properties from laboratory test results. The material properties used can be seen in Table 3 below.

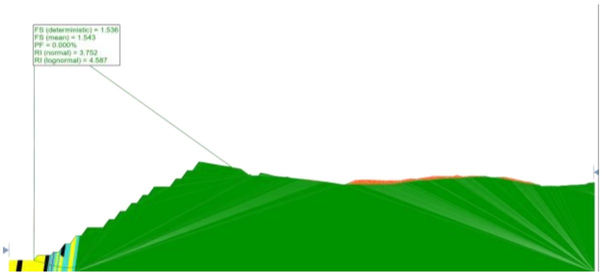

Fig 6 Result of slop analysis in natural conditions

From the safety factor analysis results and the probability of failure of the overall slope in natural conditions, the safety factor value was 1.543 with a probability of 0%.

Then, is then carried out, assuming that the slope is in a saturated condition due to the presence of standing water in the mining area. Apart from that, the slope is assumed to be in saturated condition, and the worst condition/simulation is used to determine the value of the safety factor for a slope.

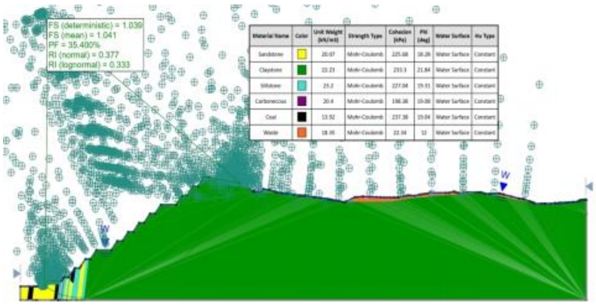

Fig 7 Result of slop analysis in saturated conditions

From the safety factor analysis results and the probability of failure of the overall slope in saturated conditions, the safety factor value was 1.041 , with a probability of 35.4%.

5.2.3 Analysis of Slope Safety Factors Section C-C'

Safety factor analysis is carried out to obtain safety factor values. In this research, analysis was carried out using the limit equilibrium method, namely the Morgenstren-Price method, using material properties from laboratory test results. The material properties used can be seen in Table 3 below.

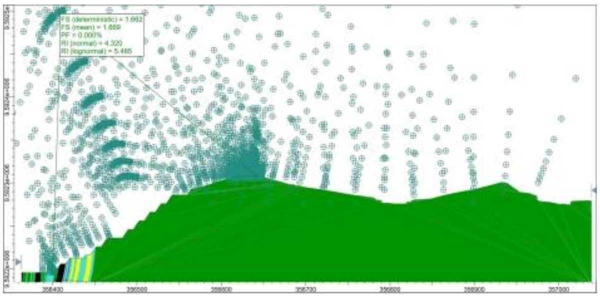

Fig 8 Result of slop analysis in natural conditions

From the safety factor analysis results and the probability of failure of the overall slope in natural conditions, the safety factor value was 1.669 with a probability of 0%.

Then, is then carried out, assuming that the slope is in a saturated condition due to the presence of standing water in the mining area. Apart from that, the slope is assumed to be in saturated condition, and the worst condition/simulation is used to determine the value of the safety factor for a slope.

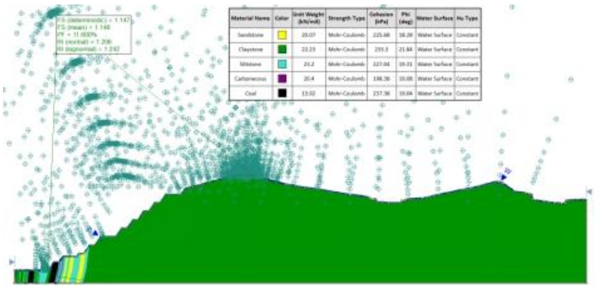

Fig 9 Result of slop analysis in saturated conditions

From the safety factor analysis results and the probability of failure of the overall slope in saturated conditions, the safety factor value was 1.148, with a probability of 11.6%.

5.2.4 Dewatering Simulation

a. Dewatering Simulation Section A-A'

This simulation aims to increase the value of the slope safety factor by dewatering low-wall slopes. This dewatering aims to reduce the slope load by lowering the groundwater level. In section A-A' is done by lowering the groundwater level to a depth of 2 meters.

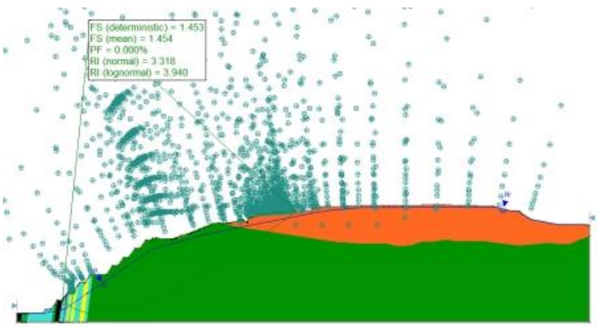

Fig 10 Dewatering Simulation Section A-A'

After the simulation was carried out with a decrease in groundwater level by 2 meters, a Safety Factor value of 1.454 and a Probability of 0%

b. Dewatering Simulation Section B-B'

This simulation aims to increase the value of the slope safety factor by dewatering low-wall slopes. This dewatering aims to reduce the slope load by lowering the groundwater level. In section B-B' is done by lowering the groundwater level to a depth of 5-10 meters

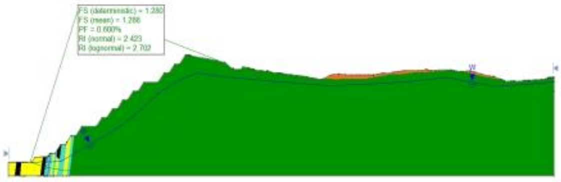

Fig 11 Dewatering Simulation 5 m Section B-B'

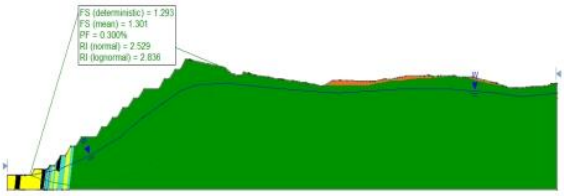

Fig 12 Dewatering Simulation 10 m Section B-B'

After the simulation was carried out with a decrease in groundwater level by 5 meters, a Safety Factor value of 1.288 and a Probability of 0.6% And by 10 meter , a Safety Factor value of 1.301 and a Probability of 0.2%

c. Dewatering Simulation Section C-C'

This simulation aims to increase the value of the slope safety factor by dewatering low-wall slopes. This dewatering aims to reduce the slope load by lowering the groundwater level. In section C-C' is done by lowering the groundwater level to a depth of 5 meters.

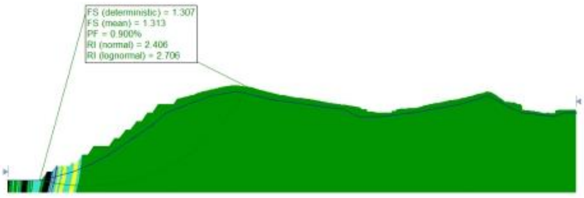

Fig 13 Dewatering Simulation Section C-C'

After the simulation was carried out with a decrease in groundwater level by 5 meters, a Safety Factor value of 1.313 and a Probability of 0.9 %

5.4.5 Resloping Simulation

a. Resloping Section A-A'

In the simulation of changing the geometry of this slope, a decrease in the angle of the single slope from 55^0 to 50^0 at elevation 70-30 was carried out, resulting in the calculation of FK 1.319 and probability of 0%

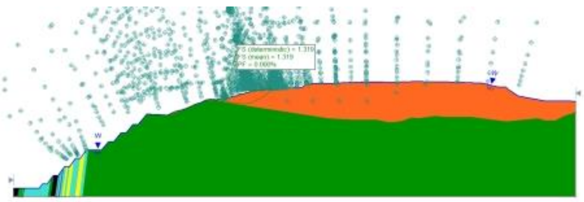

Fig 14 Resloping Section A-A'

b. Resloping Lereng section B-B'

In the simulation of changing the geometry of this slope, a decrease in the angle of the single slope from 55^0 to 50^0 at elevation 110-30 was carried out, resulting in the calculation of FK 1.105 and probability of 18.4%

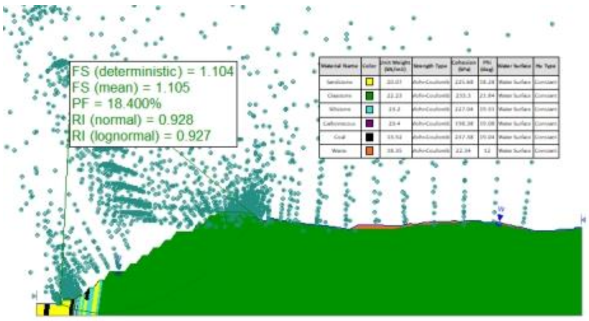

Fig 15 Resloping Section B-B'

c. Resloping Lereng section C-C'

In the simulation of changing the geometry of this slope, a decrease in the angle of the single slope from 55^0 to 50^0 at elevation 90-30 was carried out, resulting in the calculation of FK 1.162 and probability of 9.7%

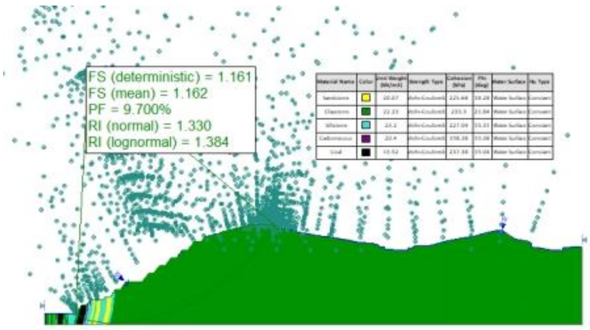

Fig 16 Resloping Section C-C'

5.4.6 Simulasi Resloping dan Dewatering

a. Resloping dan Dewatering Section B-B'

In this slope geometry change simulation, an overall decrease in slope from 32^0 to 31^0 and slope height from 120 to 119 and a 5-meter decrease in groundwater level was carried out which resulted in an FK calculation of 1.345 and a probability of 0.2%.

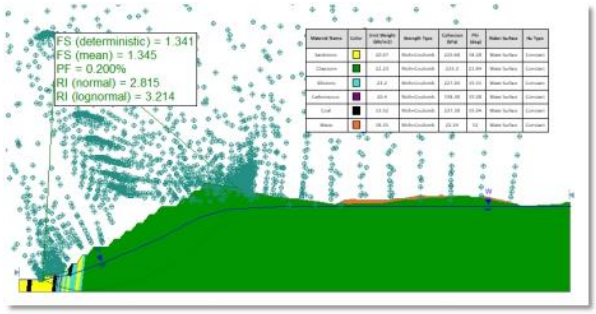

Fig 17 Resloping and Dewatering Section B-B'

b. Resloping Lereng Section C-C'

In this slope geometry change simulation, an overall decrease in slope from 33^0 to 31^0 and slope height from 90 to 88 and a 5-meter decrease in groundwater level was carried out which resulted in an FK calculation of 1.369 and a probability of 0.1%.

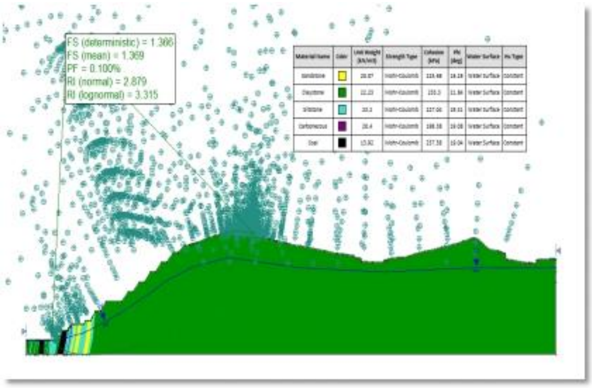

Fig 18 Resloping and Dewatering Section C-C'

8. Conclusions and Recommendations

8.1 Conclusions

a. The Result slope stability analysis for Section A-A' obtained a saturated FK of 1.092, saturated FK Section B-B' of 1.041 and saturated FK Section C-C' of 1.148.
b. Probability of Failure on slopes Saturated Condition for Section A-A' slope 0%, for Section B-B' slope 35.4% and for section C-C' slope 11.6%
c. The results of the 2 m dewatering simulation for section A-A' obtained an FK value of 1.454, for dewatering 10 m section B-B' FK value of 1.301 and for dewatering 5 m C-C' FK value of 1.301. The resloping simulation results for section A-A' obtained an FK value of 1.319. The resloping + dewatering simulation results for section B-B' obtained an FK value of 1.345 and for section C-C' of 1.369.

6.2 Recommendations

a. It is necessary to monitor these slopes to avoid landslides. Slope observations are carried out periodically and intensively, to determine the movement of the slope body using a slope monitoring tool (extensometer). For installation plans.
b. Carry out surface water control to prevent standing water in the crest Pit or Disposal area. For plans for making water channels.
c. Avoid slope conditions that are fully saturated by lowering the ground water level by installing a drain hole on the lowwall pit middle slope or using the pumping well method. The pumping well method is usually installed along a slope by operating the pump for a certain period of time. Meanwhile, the drain hole drills both horizontally and vertically by utilizing the force of gravity to drain. For the location plan for geoelectric measurements.

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