Analysis Of Slope Stability Level Using Kinematic Analysis Method And Slope

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Abstract

Slope stability is a crucial factor in open-pit mining operations, as it directly affects both operational efficiency and worker safety. Slope failures can lead to significant material losses and endanger human lives. This study aims to evaluate slope stability in Area X, using the Kinematic Analysis and Slope Mass Rating (SMR) methods. The research methods include field mapping, slope geometry measurements, and discontinuity analysis using the scanline method. Rock mass parameters were evaluated using the Rock Mass Rating (RMR) classification system and subsequently modified by SMR correction factors. In addition, stereographic analysis was conducted to identify potential failure types, including planar, wedge, and toppling failures. The results show that the dominant lithology in the study area consists of igneous rocks such as diorite porphyry, with RMR values ranging from 67 to 70, indicating fair to good rock mass quality. The SMR values reflect varying degrees of slope stability, from stable to unstable, depending on the orientation of discontinuities relative to the slope face. Recommended technical reinforcements include support systems such as bolting, shotcrete application, and drainage systems (toe ditch). In conclusion, the integrated application of Kinematic Analysis and SMR provides accurate slope stability assessments and serves as a reliable reference for geotechnical risk mitigation and slope design planning in mining operations.

Keywords: Kinematic Analysis, Rock Mass Rating, Slope Mass Rating, Slope Stability

1. Introduction

1.1 Background

The mining sector is one of the important economic pillars in Indonesia, contributing significantly to state revenue and job creation. However, mining operations, especially open-pit mines, often involve the formation of high and steep slopes. These slopes have the potential for serious landslide hazards if not managed properly. Slope instability can result in large material losses, disruptions to production schedules, and even fatalities. Therefore, slope stability analysis is a crucial aspect in the planning, operation, and closure of mines to ensure occupational safety and sustainability of mining operations.

The region is known to have a varied topography with complex geological and geotechnical conditions. The lithology of rocks, geological structures such as faults and burrows, and local hydrological conditions, directly affect the characteristics of rock masses and the degree of slope stability.

Various methods have been developed to evaluate the stability of rock slopes. One of the methods that is widely used and proven to be effective in geotechnical engineering practice is the *Slope Mass Rating* (SMR) method. The SMR method is a modification and development of the *Rock Mass Rating* (RMR) rock mass classification system by Romana (1985). The advantages of the SMR method lie in its ability to integrate important parameters such as solid rock strength (UCS), *Rock Quality Designation* (RQD), discontinuity spacing, discontinuity conditions, and groundwater conditions. The resulting SMR value is then used to classify the slope stability level, ranging from very stable to very unstable, and to provide recommendations for *appropriate support* actions. The application of this method has been widely used in case studies of slope stability in various Indonesian mining sites and has been proven to be helpful in predicting potential slope collapse and underpinning mitigation planning.

Given the potential geotechnical risks in mining operations in Area X and the importance of maintaining slope stability for the smooth operation and safety of all workers, this study will focus on analyzing the level of slope stability using *the Kinematic Analysis* method and *the Slope Mass Rating* (SMR) method. This study is expected to provide a clear picture of the geotechnical conditions of the slope at the research site, identify potentially unstable zones based on SMR values, and provide relevant and applicable technical recommendations for improving slope design and geotechnical risk management in Area X.

1.2 Research Objectives

The purpose of carrying out research in Region X is:

1. Knowing the potential for landslides in area X
2. Knowing the level of slope stability in area X
3. Knowing the recommended type of slope reinforcement on X

1.3 Problem Limitations

The limitations of the problem to be studied in this study are limited to the problem of determining the weight of rock mass using *the Rock Mass Rating* method, determining the potential for mine slope landslide with kinematic analysis from *the Dips software* and determining the level of stability of the mine slope using *the Slope Mass Rating*.

2. Research Methods

The research methods used in this study are:

2.1 Data Capture

Slope stability analysis with *Slope Mass Rating* using rock mass classification and stereographic analysis requires some data used to analyze the problems in this study. The data required in this study are:

1. Slope geometry data collection is carried out by measuring slope height, slope length, slope direction and slope slope using a geological compass.
2. Lithological data collection was carried out by *sampling* fresh rocks using a geological hammer at the research site. The purpose of lithological sampling is to find out what lithology is present at the research site.
3. Rock data collection using *the scanline mapping method.* The *scanline mapping method* is one of the methods used to find the orientation of weak fields on the surface (generally on the slope wall). The data obtained in the measurement are the orientation of the burly plane including the direction and inclination of the burly plane (*strike/dip*), burly spacing, continuity of the burly plane, burly opening width, burly roughness, gap filler material and weathering rate, and groundwater condition.

2.2 Data Analysis Stage

The data processing stage is carried out to process all field data which includes geological data, burly data, and slope geothermal data as well as laboratory data including petrographic data and rock mechanical data. The data processing carried out in this study is:

1. **Rock Mass Rating *(RMR)* Analysis**

The results of *Rock Mass Rating* data processing were then analyzed to classify the rock mass at each research location based on five parameters that must be measured and observed, namely rock compressive strength, sturdy spacing, *Rock Quality Designation* (RQD), burly conditions and groundwater conditions

2. **Kinematics Analysis**

The results of stereographic data processing were then analyzed to determine the type of avalanche that occurred on a rock slope. Based on data on the *dip direction* of the slope, the slope dip, *the burly strike / dip* and the magnitude of the depth sliding angle, it will be possible to determine the type of avalanche.

3. **Slope Mass Rating *(SMR)* Analysis**

Slope Mass Rating *analysis* is used to determine the level of slope stability at the research site with parameters that must be considered, namely the results of stereographic analysis and *Rock Mass Rating analysis* that have been carried out. In addition, other input data used are the dip *direction* of the slope surface, the *dip direction* of *the burly plane,* the trend *direction formed by the two sets of burly planes, the slope angle (*dip*),* the dip angle of the burly plane and the plunge angle) formed by both the burly set as well as the slope exploration method.

3.1 Results and Discussion

3.1.1 Geology Research Area

The geology of the research area is divided into two, which includes a discussion of the geomorphology and lithology of the research area.

3.1.2 Geomorphology of Research Areas

Geomorphology (*Geomorphology*) comes from the Greek language, which consists of three words, namely: *Geos* (*earth*), *morphos* (*shape*), *logos* (*knowledge* or science). Geomorphology is one of the branches of geological science that has many aspects of observation, therefore some geomorphologists conduct research in several existing literature. The basis for naming the morphological units of the research area is based on two aspects of the approach, namely the morphographic approach and the morphogenesis approach. The morphography approach is an approach based on the shape of the earth's surface found in the field, namely the topography of hills and mountains. This aspect of formation needs to pay attention to several parameters of each topography such as the shape of the peak, the shape of the valley, and the shape of the slope found in the field. The morphogenetic (genetic) approach is an approach based on the origin of the formation or process that forms the landscape on the earth's surface, with the formation process mainly controlled by endogenous processes. Based on the above approach, the research area is included in the morphological unit of denudational hills.

The morphological unit of this denudation hill has a difference in height of about 224 - 310 meters above sea level, so that based on its relative height, the topographic shape or relief of the unit can be classified as hills. The appearance of morphology directly in the field shows the topographic shape in the form of sloping to steep slopes with sloping - steep reliefs with the appearance of a blunt peak shape. The land use in this unit is plantations.

Figure 1 Hills with the shape of blunt peaks in the study area.

3.1.3 Lithology of Research Areas

The grouping and naming of rock units in the research area is based on informal lithostratigraphy that is linked to the physical characteristics of the rocks. The basis for naming lithology of rock units in the research area is through megascopic observation of rocks. Megascopic observations are directly determined by the physical properties and composition of observable minerals.

On the slope of the study, outcrops with a type of igneous rock were found, the megascopic appearance has a fresh blackish-white color, a blackish-brown weathered color. The texture of the rock i.e., the crystallity of the rock includes holocrystalline, the granularity of the rock which is phaneritic, the subhedral shape, the massive structure, and the mineral composition is plagioclase, hornblend. Based on Fenton's (1940) classification, this rock is named Diorite Porfiri.

Figure 2 The slope which is the place where the slope and burly geometry data are taken

3.2 Geometry Lereng

Slope geometry is the visual appearance of the slope in the field. Slope geometry measurements are carried out using a compass, *Global Positioning System* (*GPS)* and roll meters which are used to determine slope height, slope length, *strike*, *dip direction* and slope angle (*dip*). From measurements in the field, slope orientation data was obtained, namely dip/dip direction (53°/N 275° E), slope height 5M, and slope length 37M.

3.3 Rock Mass Rating (RMR)

The weighting of the rock mass for each slope is carried out by weighting and calculation of the *Rock Mass Rating* value using five parameters developed by Bieniawski (1989), namely *uniaxial compressive strength, Rock Quality Designation (RQD),* spacing of discontinuities, *discontinuity conditions, which include persistence,* the distance between the discontinuity surfaces or gaps *(separation/aperture), roughness,* filler material *(infillinf/gouge)* and weathering level*,* and *groundwater conditions* to be weighted according to the *Rock Mass Rating* classificationwhich is then accumulated to obtain the mass class of the rocks at the research site.

Table 1 *Rock Mass Rating* System or RMR (Bieniawski, 1989)

<table>
<tr><th colspan="3">PARAMETER</th><th colspan="7">Range of values // ratings</th></tr>
<tr><td rowspan="3">1</td><td rowspan="2">Strength of intact rock material</td><td>Point-load strength index</td><td>> 10 MPa</td><td>4 - 10 MPa</td><td>2 - 4 MPa</td><td>1 - 2 MPa</td><td colspan="3">For this low range uniaxial compr. strength is preferred</td></tr>
<tr><td>Uniaxial com-pressive strength</td><td>> 250 MPa</td><td>100 - 250 MPa</td><td>50 - 100 MPa</td><td>25 - 50 MPa</td><td>5 - 25 MPa</td><td>1 - 5 MPa</td><td>< 1 MPa</td></tr>
<tr><td colspan="2">RATING</td><td>15</td><td>12</td><td>7</td><td>4</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Drill core quality RQD</td><td>90 - 100%</td><td>75 - 90%</td><td>50 - 75%</td><td>25 - 50%</td><td colspan="3">< 25%</td></tr>
<tr><td colspan="2">RATING</td><td>20</td><td>17</td><td>13</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Spacing of discontinuities</td><td>> 2 m</td><td>0.6 - 2 m</td><td>200 - 600 mm</td><td>60 - 200 mm</td><td colspan="3">< 60 mm</td></tr>
<tr><td colspan="2">RATING</td><td>20</td><td>15</td><td>10</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="11">4</td><td rowspan="11">Condition of discon-tinuities</td><td>Length, persistence</td><td>< 1 m</td><td>1 - 3 m</td><td>3 - 10 m</td><td>10 - 20 m</td><td colspan="3">> 20 m</td></tr>
<tr><td>Rating</td><td>6</td><td>4</td><td>2</td><td>1</td><td colspan="3">0</td></tr>
<tr><td>Separation</td><td>none</td><td>< 0.1 mm</td><td>0.1 - 1 mm</td><td>1 - 5 mm</td><td colspan="3">> 5 mm</td></tr>
<tr><td>Rating</td><td>6</td><td>5</td><td>4</td><td>1</td><td colspan="3">0</td></tr>
<tr><td>Roughness</td><td>very rough</td><td>rough</td><td>slightly rough</td><td>smooth</td><td colspan="3">slickensided</td></tr>
<tr><td>Rating</td><td>6</td><td>5</td><td>3</td><td>1</td><td colspan="3">0</td></tr>
<tr><td rowspan="2">Infilling (gouge)</td><td>none</td><td colspan="2">Hard filling</td><td colspan="4">Soft filling</td></tr>
<tr><td>-</td><td>< 5 mm</td><td>> 5 mm</td><td>< 5 mm</td><td colspan="3">> 5 mm</td></tr>
<tr><td>Rating</td><td>6</td><td>4</td><td>2</td><td>2</td><td colspan="3">0</td></tr>
<tr><td>Weathering</td><td>unweathered</td><td>slightly w.</td><td>moderately w.</td><td>highly w.</td><td colspan="3">decomposed</td></tr>
<tr><td>Rating</td><td>6</td><td>5</td><td>3</td><td>1</td><td colspan="3">0</td></tr>
<tr><td rowspan="4">5</td><td rowspan="3">Ground water</td><td>Inflow per 10 m tunnel length</td><td>none</td><td>< 10 litres/min</td><td>10 - 25 litres/min</td><td>25 - 125 litres/min</td><td colspan="3">> 125 litres /min</td></tr>
<tr><td>$p_w / \sigma 1$</td><td>0</td><td>0 - 0.1</td><td>0.1 - 0.2</td><td>0.2 - 0.5</td><td colspan="3">> 0.5</td></tr>
<tr><td>General conditions</td><td>completely dry</td><td>damp</td><td>wet</td><td>dripping</td><td colspan="3">flowing</td></tr>
<tr><td colspan="2">RATING</td><td>15</td><td>10</td><td>7</td><td>4</td><td colspan="3">0</td></tr>
</table>

3.3.1 Weighting of Rock Mass Rating Parameters on Slopes

3.3.1.1 Rock Compressive Strength (R1)

The strength of whole rocks can be determined through direct field testing and laboratory tests. Samples taken in the field are then cut and smoothed using *the Norton Clipper Archives* tool. After cutting and smoothing the surface, the sample will be made into 10 boxes with the same distance, which is per 2.5 cm, then the sample is ready to be tested for compressive strength using *the Schmidt Hammer* tool as many as 10 tests on each sample according to the predetermined distance. The values obtained from the *hammer test* are then processed to obtain the strength of the rock. Then after knowing the value of the mass strength of the rock, we enter it into the classification parameters published by (Bieniawski, 1984) to find out what is the weighting value of the compressive strength of the rock.

Based on the results of the calculation of the compressive strength value using *the Schmidt Hammer*, the compressive strength value of the sample on the slope is 64 MPa, so the value weight of 7 is obtained.

Figure 3 Sample preparation process

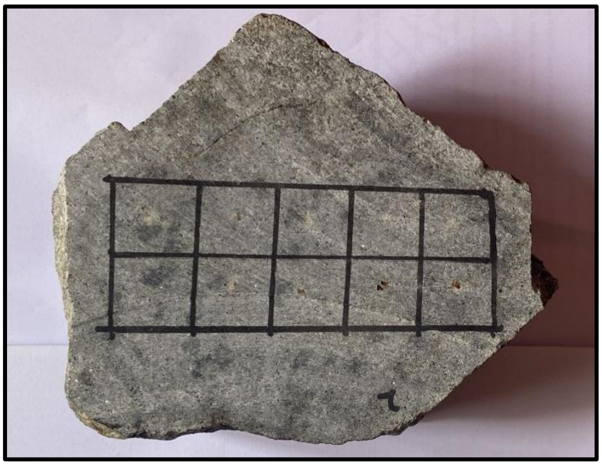

Figure 4 Sample of preparation results before the compressive strength test process of rock with *Schmidt Hammer tool*

Figure 5 Rock sample testing process using *Schmidt Hammer test equipment*

3.3.1.2 RQD (*Rock Quality Designation*) (R2)

Rock Quality Designation (RQD) is a rough measure of the degree of cracking in rock mass. The calculation of RQD values has two methods used, namely direct methods and indirect methods. Calculations by indirect method are carried out if drill data or core logs are available. This calculation was carried out by calculating burly data that had a burly distance of more than 10 cm (Deere, 1964). Meanwhile, the direct method is used if the core logs are not available. The method was directly developed by (Priest & Hudson, 1976). In this study, RQD calculation was carried out by direct method because core log data is not available. RQD has a weight based on the percentage obtained with the following formula:

$$RQD = 100\ (1 + 0{,}1\lambda)\ e^{-0{,}1.\lambda}$$

Known:

RQD = *Rock Quality Designation*

λ= total number of burly per length of scanline.

RQD data collection was carried out directly in the field using the scanline method. Based on the length of the scanline on the slope for the calculation of RMR 1 which is 15.73 meters with 31 burly measured and for the calculation of RMR 2 which is 19.27 meters with 26 burly measured burrows. Using the equation above, the RQD value obtained is as follows:

First RMR:

$$\lambda = \frac{jumlah\ kekar}{panjang\ scanline}$$

$$= \frac{31}{15.73\ meter} = 1.97 \text{ kekar / meter}$$

$$RQD = 100e^{-0{,}1\lambda}.\ (0{,}1\lambda + 1)$$

$RQD = 100e^{-0,1(1.97)} \text{ x } (0,1(1.97) + 1)$

$RQD = 82.16 \text{ x } 1.197$

$RQD = 98.34\%$

Second RMR:

$$\lambda = \frac{jumlah\ kekar}{panjang\ scanline}$$

$$= \frac{26}{19.27\ meter} = 1.34 \text{ kekar / meter}$$

$RQD = 100e^{-0,1\lambda}. (0,1\lambda + 1)$

$RQD = 100e^{-0,1(1.34)} \text{ x } (0,1(1.34) + 1)$

$RQD = 87.49 \text{ x } 1.134$

$RQD = 99.21\%$

Based on the results of the calculation of the RQD value on the slope, the values were obtained of 98.34% and 99.21%. From the RQD value on the Slope of 97.25% and 99.21%, a value weight of 20 was obtained based on (Table 2).

Tabel 2 Parameter *rock quality designation* (RQD) (Bieniawski, 1989)

RQD (%)	Rock Quality	*Rating*
90-100	*Excellent*	20
75-90	*Good*	17
50-75	*Fair*	13
25-50	*Poor*	8
<25	*Very Poor*	3

3.3.1.3 Joint Spaces (R3)

The spacing between burly planes is obtained from measurements in the field. Based on the results of the calculation of the average burly space on the Slope, it was found that the value of the burly space for the calculation of RMR 1 was 50.54 cm and for the calculation of RMR 2 was 74.11 cm, so the average space distance of the burly plane on the Slope was 50.54 and 74.11 cm or 505.4 mm and 741.1 mm. From the average spacing distance of the burly plane on the slope of 505.4 mm and 741.1 mm, the weights of values of 10 and 15 were obtained based on (Table 3).

Table 3 Distances between discontinuities (Bieniawski, 1989)

Description	Discontinuity Spacing (m)	*Rating*
very wide	>2	20
wide	0,6-2	15
moderate	0,2-0,6	10
close	0,06-0,2	8
very close	<0,06	3

3.3.1.4 Joint Conditions(R4)

The burly condition was obtained from the results of observations at the research site. The parameters observed were *persistence, aperture* width, roughness, gouge and *weathering*. Measurements and observations are made on each burial and layer plane in a single layer of rock to obtain accurate burly condition data.

Based on the results of observation of burly conditions on the slope for the calculation of RMR 1, it was found that the average burly continuity is 1-3 m, the average burly opening is >5 mm, the average burly roughness is *very rough*, the average filling material is also *hard filling* with an opening of >5 mm and the weathering rate is moderately weathered. From the results of observation of burly conditions on the slope for the calculation of RMR 1, a value weight of 15 was obtained based on (Table 5).

Meanwhile, the results of the observation of burly conditions on the slope for the calculation of RMR 2, it was found that the average burly continuity is 3-10 m, the average burly opening is >5 mm, the average burly roughness is *very rough*, the average filler material is also *hard filling* with an opening of >5 mm and the weathering rate is moderately weathered. From the results of observation of burly conditions on the slope for the calculation of RMR 2, a value weight of 13 was obtained based on (Table 5).

Table 4 Classification of weathering levels (ISRM, 1981)

Class	Type	Description
I	Fresh	No signs of weathering, no changing color, fresh rocks, bright crystal colors
II	Slight Weathering	There is a discoloration of the rock grains and discontinuous surfaces. The rock decomposed into soil. Fresh rocks and/or that have only undergone discoloration still remain
III	Moderate Weathering	Less than half of the rock grains decompose into soil. Fresh rocks and/or that have only undergone discoloration still remain
IV	High Weathering	Rocks that are still fresh or that have changed the color of the rock texture are still visible
V	Very High Weathering	All rock materials are decomposed into soil. The original rock mass structure still exists
VI	Soil	All rock material turns into soil. There is a change in volume but the soil is not transported

Table 5 Total weight of discontinuity conditions (Bieniawski, 1989)

Parameters	*Rating*				
Persistence	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
Value	6	4	2	1	0
Aperture	None	< 0,1 mm	0,1 - 1 mm	1 - 5 mm	> 5mm
Value	6	5	4	1	0
Roughness	Very Rough	Rough	Slightly Rough	Smooth	*Slickensided*
Value	6	5	3	1	0
Filling Material	None	Hard < 5 mm	Hard > 5 mm	Smooth < 5 mm	Smooth > 5 mm
Value	6	4	2	2	0
Weathering	Not Weathered	Slightly Weathered	Moderate Weathered	Very Weathered	Crushed
Value	6	5	3	1	0

3.3.1.5 Groundwater Conditions (R5)

The groundwater condition found in the discontinuity measurement was identified as one of the conditions such as dry, damp, wet, *dripping*, or *flowing*. In the calculation of RMR values, *groundwater conditions parameters* are weighted based on the weighting parameter table of Bieniawski, 1984 classification. The observation results of groundwater conditions on the slope are dry. From the condition of groundwater on the slope is dry, a value weight of 15 is obtained based on (Table 6).

Table 6 Weighting of groundwater conditions (Bieniawski, 1989)

Groundwater Conditions	Dry	Damp	Wet	Dripping	Flowing
Rating	15	10	7	4	0

All *the Rock Mass Rating* parameters that have been weighted are then accumulated to obtain the basic RMR value at the research site. From the results of the *calculation of Rock Mass Rating,* it was obtained that the *Rock Mass Rating* on the Slope for the calculation of RMRbasic 1 was 62 and the value of *the Rock Mass Rating* for the calculation of RMRbasic 2 was 65.

Table 7 Results of the calculation *of the Rock Mass Rating* on the Slope for the calculation of RMR 1

Parameter	**Value/Conditions**	**Rating**
Rock Compressive Strength	64 MPa	7
RQD	98.34 %	20
Spacing of Discontinuities	505.4 mm	10
Condition of Discontinuities	The average burly continuity is 1-3 m, the average burly opening is >5 mm, the average burly roughness is very rough, the average filler material is also hard filling with an opening of >5 mm and the weathering rate is moderate weathering	15
Ground Water	Dry	15
Value of RMR_{basic}		67

Table 8 Results of *Rock Mass Rating* calculation on Slope for RMR 2 calculation

Parameter	Value/Conditions	Rating
Rock Compressive Strength	64 MPa	7
RQD	99.21 %	20
Spacing of Discontinuities	741.1 mm	15
Condition of Discontinuities	The average burly continuity is 3-10 m, the average burly opening is >5 mm, the average burly roughness is very rough, the average filler material is also hard filling with an opening of >5 mm and the weathering rate is moderately weathered	13
Ground Water	Dry	15
Value of RMR$_{basic}$		70

3.4 Kinematics Analysis

The kinematic analysis aims to determine the type of avalanche that will occur on the research slope based on discontinuity data in the field with the help of *a stereonet*. The analysis was carried out on *the Dips software* with the required data in the form of *strike/dip*, *dip direction* of discontinuity field, slope slope.

3.4.1 Kinematics Analysis on Slopes

From observations and measurements in the field on the slope, slope data were obtained with the dip direction *of the* slope N 306° E, slope dip of 62°, slope height ±15 meters and slope length ±37 meters. Discontinuity data on the slope is in the form of 57 burly data with a *scanline* distance of 35 meters.

Figure 6 The slope which is the place where the geometry data of slopes and burly is taken. Photographed towards N 231°E

From the process of grouping burly using *the rocscience Dips software* , two sets of burly dips were obtained on the slope, namely JS1 and JS2. The general position of JS1 is 29°/N 175°E, and the general position of JS2 is 68°/N 236°E.

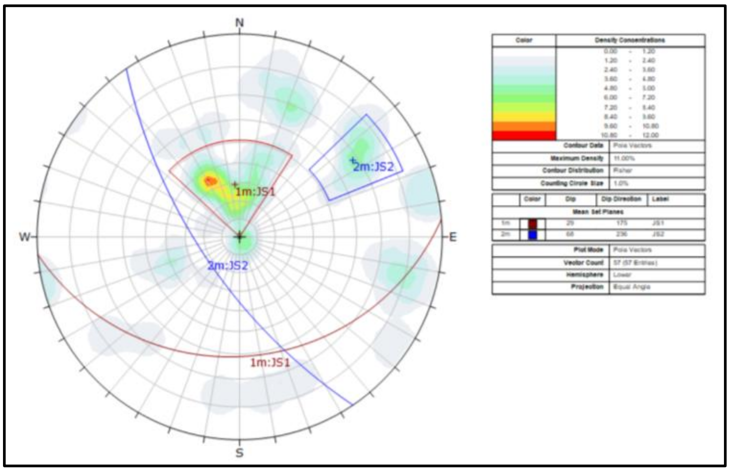

Figure 7 Interpretation of the burly set on the Slope using *the software rocscience Dips*

3.4.2 Avalanche Analysis (*Direct Toppling)* on Slopes

Based on the results of stereographic analysis using *the rocscience Dips software* , it shows that there is a type of avalanche *direct toppling*. This is shown by the fact that the JS1 burly set has an orientation that is opposite to the slope orientation.

The following are the results of stereographic analysis using *the rocscience Dips Software* as follows:

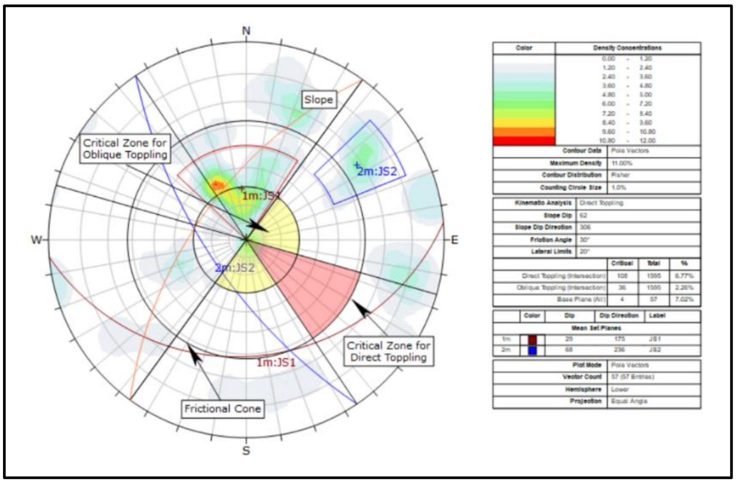

Figure 27 Results of stereographic analysis on the slope using *rocscience Dip Software* which shows the presence of *a direct toppling avalanche*

3.5 Slope Mass Rating (SMR)

The analysis of the characterization of the rock slope used is the Slope Mass Rating (SMR) method. SMR analysis requires 4 parameters in its analysis. To find out the parameters, there are several factors that must be considered, namely the *dip direction* of the slope surface, *the dip* direction of *the burly plane,* the trend *formed by the two sets of burly, the slope angle* (dip*),* the burly *dip angle and* the plunge angle) formed by both the burly set as well as the slope exploration method. In addition, the results of stereographic analysis and *Rock Mass Rating* calculations that have been carried out are used as an input parameter in determining the level of slope stability using the *slope mass rating method.* Slope Mass Rating *analysis* was carried out on 3 slopes of *the scanline mapping research area.*

3.5.1 Slope Weighting and *Slope Mass Rating* (SMR) Weighting

Slopes have one type of avalanche that may occur, namely avalanches (*direct toppling*).

3.5.1.1 Weighting of *Slope Mass Rating* on Slope Avalanche Type (*Direct Toppling*) Slope

Table 9 Weighting of SMR levels (Romana, 1985 in Singh, B and Goel, R.K., 2011)

Adjustment Factor Values for Different Burly Orientations					
Case of Slope Failure		Very Favourable	Favourable	Fair	Unfavourable
P	$\lvert\alpha j - \alpha s\rvert$	> 30°	30° - 20°	20° - 10°	10° - 5°
T	$\lvert\alpha_j - \alpha_s - 180°\rvert$				
W	$\lvert\alpha_i - \alpha_s\rvert$				
P/T/W	**F1**	**0,15**	**0,40**	**0,70**	**0,85**
P	$\lvert\beta_j\rvert$	< 20°	20 - 30°	30 -35°	35 - 45°
W	$\lvert\beta_i\rvert$	< 20°	20 - 30°	30 -35°	35 - 45°
P/W	**F2**	**0,15**	**0,40**	**0,70**	**0,85**
T	**F2**	**1**	**1**	**1**	**1**
P	$\beta_j - \beta_s$	> 10°	10° - 0°	0°	0° - (-10°)
T	$\beta_j + \beta_s$	< 110°	110° - 120°	> 120°	-
W	$\beta_i - \beta_s$	> 10°	10° - 0°	0°	0° - (-10°)
P/T/W	**F3**	**0**	**-6**	**-25**	**-50**
P = Planar Failure; T = Toppling Failure; W = *Wedge Failure* ; αs = Slope Strike; αj = Joint Strike; αi = Plunge Direction of Line of Intersection; βs = slope dip; βj = joint dip ; βi = Plunge of Line of intersection.					

Table 10 Weighting Values for Slope Excavation Methods (Romana, 1985)

Method	*Nature Slope*	*Pre-splitting Blasting*	*Smooth Blasting*	*Mechanical Excavation*	*Poor Blasting*
F4	**15**	**10**	**8**	**0**	-8

A. F1 Value

In calculating the value of F1 can be used a formula developed by Romana (1993):

$$F1 = \lvert AJ - AS - 180° \rvert$$

Where:

αj = average dip direction discontinuity

αs= dip direction lereng

Using the equation above, the F1 value for the slope in the avalanche type (*direct toppling*) is:

F1 = | AJ - AS - 180° |

F1 = | 175 - 306 - 180 |

F1 = | 311 |

F1 = 311

So the weighting of F1 is 0.15.

B. F2 Value

In calculating the value of F2 using a formula developed by Romana (1993):

$$F2 = 1.0$$

Using the equation above, the value of F2 for the slope in the avalanche type (*direct toppling*) is:

F2 = 1.0

So the weighting of F2 is 1.

C. F3 Value

In calculating the value of F3 using a formula developed by Romana (1993):

$$F3 = \beta j + \beta s$$

Where:

βj= average dip of discontinuity

βs= lereng dip

Using the equation above, the value of F3 for the slope in the type of avalanche (*direct toppling*) is:

F3 = βj + βs

F3 = 29 + 62

F3 = 91

So the weighting of F3 is 0.

D. F4 Value

The research area is a slope with *mechanical excavation* so that the F4 factor is categorized as a *mechanical excavation slope* with a weight of 0 (Table 10).

Furthermore, the calculation and analysis of the mass weighting of the level developed by Romana, 1985 in Singh, B and Goel, R.K., 2011 (Table 11) was carried out. The first RMRbasic value of the research slope is 67 with the formula:

$$SMR\ 1 = RMR_{basic} + (F1 \times F2 \times F3) + F4$$

$$= 67 + (0.15 \times 1 \times 0) + 0 = 67$$

Meanwhile, the second RMRbasic value from the research slope is 70 with the formula:

$$SMR\ 2 = RMR_{basic} + (F1 \times F2 \times F3) + F4$$
$$= 70 + (0.15 \times 1 \times 0) + 0$$
$$= 70$$

So that the results of SMR weighting on the slope with the type of avalanche roll (*direct toppling*) are 67 for the first SMR and the second SMR is 70. The study slopes are included in class II (61 - 80) with good description, stable slope stability, and avalanches in the form of rock blocks.

Table 11 Slope characterization based on *slope mass rating* (Romana, 1985, in Singh, B and Goel, R.K., 2011) on slopes with avalanche type (*direct toppling*)

Class	SMR	Description	Slope Stability	Possible Avalanche Forms	Possible Avalanches
II	61 - 80	Good	Stable	In the form of rock blocks	0.2

Meanwhile, for the type of reinforcement on the slope with the type of avalanche (*direct toppling*) is included in class IIb, namely by making toe ditch or fence, nets, spot or systematic bolting (Table 12).

Table 12 Recommended reinforcement types for each SMR class (Romana, 1985)

Class	*SMR*	*Support*
Ia	91-100	*None*
Ib	81-90	*None Or Scaling*
IIa	71-80	*(None, Toe Ditch Or Fence), Spot Bolting*
IIb	61-70	*Toe Ditch Or Fence, Nets, Spot Or Systematic Bolting*
IIIa	51-60	*Toe Ditch And/Or Nets, Spot Or Systematic Bolting, Spot Shotcrete*
IIIb	41-50	*(Toe Ditch And/Or Nets), Systematic Bolting, Anchor, Systematic Shotcrete, Toe Wall And/Or Dental Concrete*
IVa	31-40	*Anchor, Systematic Shotcrete, Toe Wall And/Or Concrete, (Reexcavation) Drainage*
IVb	21-30	*Systematic Reinforced Shotcrete, Toe Wall And/Or Concrete, Reexcavation, Deep Drainage*
Va	11-20	*Gravity Or Anchored Wall Or Reexcavation*

4. Conclusion

Based on the results of the research on the analysis of slope stability level using the *Slope Mass Rating* method in Area X, conclusions can be drawn as follows:

1. Based on kinematic analysis, the type of avalanche that has the potential to occur on the slope is the type of avalanche (*direct toppling*) in the JS1 burly set.
2. Based on the results of the Slope Mass Rating calculation, the level of stability on the slope is included in class II with stable slope stability conditions.
3. Based on the results of the calculation of Slope Mass Rating, the recommendation for the type of slope reinforcement in the research area is recommended to make trenches or fences, nets, spot or systematic spray concrete.

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