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Analysis Of Limestone Quarry Slope Stability, Nimbokrang District, Jayapura Regency, Papua, Indonesia

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Abstract-Slope stability analysis generally uses the concept of factor of safety (FoS) value using several whole rock parameters. The slope stability analysis method that will be used in this research is the slope stability analysis method in open pit mines based on rock mass classification with the Rock Mass Rating (RMR) system and the Geological Strength Index (GSI) system and analyses the potential for landslides that can occur on slopes at that location with kinematics and limit equilibrium methods so that the type of landslide can be determined based on the intensity of the geological structure on the slope of the CV. Inti Jaya open pit limestone mine, in Wahab Village, Nimbokrang District, Jayapura Regency. This research aims to provide information on the current condition of the slope whether it is by safety standards, make slope engineering improvements and redesign safe slopes if unstable slope conditions are found. Research on the stability of limestone slopes begins with the collection of field data and rock samples. Furthermore, sample testing was carried out to obtain physical and mechanical properties and weighting of rock masses, which were then analysed to obtain the characteristics and quality of rock masses that would be applied using the finite element method with Slide 6 from Rocscience to determine the Factor of Safety (FK) and the design of safe slope geometry. The RMR value for slope 1 is 62, slope 2 is 61, and slope 3 is 62. So it can be concluded that the rock is included in rock mass class 2 with good quality. Based on the analysis of potential avalanche types, the three slopes have non-arc avalanche types. From the analysis carried out using Rocscience Slide 6.0 software, the FoS value for slopes in original, dry, and saturated conditions is obtained, where on slope 1: FoS in original conditions is 0.935, FoS in dry conditions is 1.619, and FoS in saturated conditions is 0.671. Then slope 2: FoS in original condition is 0.896, FoS in dry condition is 1.457, and FoS in saturated condition is 0.806. Slope 3: FoS in original condition is 3.490, FoS in dry condition is 4.199, and FoS in saturated condition is 3.368. So it can be concluded that slopes 1 and 2 are unsafe or unstable in original and saturated conditions so that landslides can occur. In the analysis of the FoS value of the actual condition of the slopes in the field using the Hoek & Brown method, the FoS value of slope 1 is 0.387, the FoS value of slope 2 is 0.579, and the FoS value of slope 3 is 1.272, it can be seen that the actual condition of the slopes in the field is slopes 1 and 2 in an unsafe or unstable state. Improvements must be made to the slope geometry to maintain the stability of the slope to remain safe or stable. The recommended improvement is to create a new working level for slopes 1 and 2, with steep height and large rock porphyry.

Keywords: Slope Stability, Safety Factor, Rock Mass Rating (RMR), Kinematic Analysis, Rock Mechanics.

I. INTRODUCTION

The research area is located in Wahab Village, Nimbokrang District, Jayapura Regency. This village has a limestone quarry managed by CV. Inti Jaya, where the excavated materials are used for construction work and piles for building facilities in this village. Geographically, this location has mountains and hills of medium to rough relief with quite steep slopes. The problem that occurs in the field is the steep slopes caused by the material excavation process, which does not have good planning, resulting in the formation of hanging rocks which, if left longer, will cause fatal work accidents.

Starting from this, research was carried out on the stability of limestone slopes, starting with collecting field data and rock samples. Next, samples are tested to obtain the physical and mechanical properties and weighting of the rock mass, which are then analyzed to obtain the Figure 1 shows that gravity is the force acting on a slope, and then the driving force and resisting force are produced. To ensure that objects on the slope do not fall (failure), it is necessary to calculate the slope according to the desired safety factor (Romana, 1993). [17]. The slope is stable if the FoS value for a slope is > 1.0 (resisting force > driving force). However, if the value of F < 1.0 (resisting force < driving force), the slope is unstable, and landslides may occur on the slope.

Characteristics and quality of the rock mass, which will be applied using software to determine the Safety Factor (FoS) and a safe slope geometry design for the slope of quarry mine located at Inti Jaya, in Wahab Village, Nimbokrang District, Jayapura Regency.

Basic Principles of Slope Stability Analysis

The stability of slopes, both natural slopes and artificial slopes (man-made), as well as embankment slopes, is influenced by several factors, which can be stated simply as resisting forces and driving forces responsible for the slope's stability. If the resisting force (against landslides) exceeds the driving force, the slope will be stable (safe). However, if the resisting force is smaller than the driving force, the slope will be unstable, and a landslide will occur. In fact, landslides are a natural process that occurs to obtain a new condition of slope stability (new balance), where the resisting force is greater than the

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driving force. The term Safety Factor is known to express the stability level of a slope. Safety factors are needed to determine the stability of a slope to prevent the danger of landslides in the future.

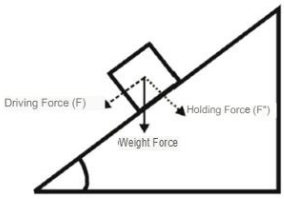

Figure 1. Simple Safety Factor (Romana, 1993)

Factors Affecting Slope Stability

Generally, whether a slope is stable depends on several factors, including aspects of slope geometry, rock structure, physical and mechanical properties of rock, bulk density of rock, and rock porosity. Slope geometry includes the shape of the slope, both slope height and slope angle. The slope and height of a slope greatly influence its stability. The greater the slope and height of a slope, the less stability it will have. Furthermore, rock structures that greatly influence slope stability are fault planes, layers, and fractures.

Discontinuous Field Measurement (Scanline Method)

The separation distance between discontinuous planes (solids) is the perpendicular distance between two consecutive discontinuous planes along an observation line called the scan line and is expressed as intact length. The minimum scan-line length for measuring discontinuity distances is approximately 50 times the average distance of the discontinuity to be measured. However, according to the International Society for Rock Mechanics (ISRM, 1981), this length is around 10 times sufficient, depending on the purpose of the scanline measurement. Kramadibrata, 1997 [14, 16].

Rock Mass Rating (RMR) Classification

Bienawski (1973) published a rock mass classification called the Rock Mass Rating (RMR). [2]. The last RMR classification system was in 1989 (RMR 89). The RMR 89 measurement parameters use the following 6 parameters: Compressive strength of intact rock (σc), Rock Quality Designation (RQD), spacing of discontinuous planes, condition of discontinuous planes, groundwater conditions in discontinuous planes, and orientation of discontinuous planes. RQD can also be calculated indirectly by measuring the orientation and distance between discontinuous planes on rock outcrops (Priest & Hudson, 1976) [15].

Rock Mechanics

Determination of the physical properties of rocks is determined for geotechnical research, including natural density, dry density, saturated density, true specific gravity, and apparent specific gravity. apparent specific gravity), natural water content, saturated water content/absorption, degree of saturation, porosity (n), and void ratio (e). Meanwhile, determining the mechanical properties of rocks can be done using the Point Load Test (Franklin Test). [5]. Where the relationship between the Franklin index (Is) and compressive strength (σc), according to Bieniawski, is $\sigma c = 23$ Is for a rock sample with a diameter of 50 mm. If Is = 1 MPa, this index no longer has meaning so it is recommended to use other tests in determining rock strength. [1]

Kinematic Analysis to Determine Landslide Potential

Kinematic analysis is an analysis using software and stereographic techniques. The stereographic technique is a graphic method used to show the strike and dip of a plane. Stereographic techniques are widely used to help identify the type of collapse that may have occurred. Simultaneous plotting of strike and slope, both slope faces and weak planes on a stereonet which will soon be known. The plotting results are very useful for choosing between areas with the potential to experience collapse and areas that are unlikely to be involved in landslides. Hoek and Bray, 1981 [10].

Calculation of FoS Values (Hoek & Brown, 1981)

The Hoek & Brown method can determine the actual safety factor (FoS) value on slopes in the research area and analyze the four types of landslides on rock slopes. In conducting analysis using the Hoek & Brown method, the slope FoS value can be calculated manually using the equation below to obtain the actual safety factor value in the field. [11].

Modeling Using Rocscience Slide 6.0

Rocsience Slide 6.0 is a geotechnical software that specializes in slope stability calculation software. Rocscience Slide is one of the programs in the Rocscience geotechnical calculation package, consisting of Swedge, Roclab, Phase2, RocPlane, Unwedge, and RocData. One of them can be done using the Limit Equilibrium Method. The calculation is carried out by dividing the soil/rock in the landslide area into slices, which is also called the slice method.

The objective of this research is to determine the level of stability of the mine slope based on the Safety Factor (SF) value on the actual slope in the CV. Inti Jaya quarry mining area, by analysing the slope geometry using the limit equilibrium, kinematical method and rock strength based on the Rock Mass Rating (RMR) method with the help of Rocsience Slide 6.0 software and making safe slope modelling engineering in quarry mining in Wahab Village, Nimbokrang District, Jayapura Regency.

II. METHODOLOGY

Primary data in this research are actual slope geometry data in the field, data from measurements of discontinuity areas in the field (scanline), and data from testing physical properties and mechanical properties in the laboratory. Meanwhile, secondary data is data used to support primary

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data. Secondary data used in this research are topographic maps and rainfall data.

Scanline measurement materials and equipment include a scanline data table, slope geometry table, geological compass, geological hammer, pocket meter, plastic rope, concrete nails, data board, 30 cm ruler, and writing tools. The software used to process scanline data is Microsoft Excel 2010 and Dips V7. Then for laboratory testing materials and equipment in the form of limestone samples from the research location, water, O'hauss balance, vernier calliper, desiccator, oven and PLI compressive strength equipment. The software used to process laboratory test data is Microsoft Excel 2010 and RocLab 1.0. This research's quantitative data collection technique results from measuring discontinuity areas on the mine slope (scanline). Several pictures of the research location are also needed as supplementary material for research data

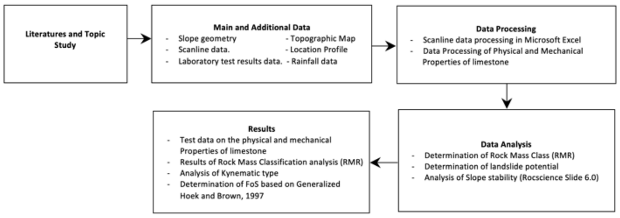

Figure 2. Research Flow Diagram

III. RESULTS AND DISCUSSION

RESULT

CV. Inti Jaya is administratively located in Wahab Village, Nimbokrang District, Jayapura Regency, Papua Province. Excavated materials from this location are used as fill material for constructing facilities in the Nimbokrang District. Astronomically, the research location is at coordinates 02^{o} 32' 43.26” South Latitude and 140 ^{o} 11' 55.35” East Longitude, with an area of 774.8 km^2. As a result of the material extraction process, a mass of weak rock is exposed on the slope's surface, which is feared to cause landslides.

Figure 3. Top view and general location of the research

Discontinuous Field Mapping

1. Scanline Slope 1, where there are only fractures, with a total of 15 joints data with the orientation of 2 joint families located at a distance of 30 cm up and 30 cm down from the measuring tape line, so that for plotting the discontinuity set only fracture data is used.
2. Scanline Slope 2, where there are only fractures, with a total of 18 joints data with the orientation of 2 joint families located at a distance of 30 cm up and 30 cm down from the measuring tape line, so that for plotting the discontinuity set, only fracture data is used.
3. Scanline Slope 3 only contains fractures, with a total of 9 joints data with the orientation of 2 joint families located at a distance of 30 cm up and 30 cm down from the measuring tape line so that for plotting the discontinuity set, only fracture data is used.

Table 1 Slope geometry measurement results

Quarry	Slope Orientation			Height (m)	Length (m)	Slope (..°)
	Strike (N °E)	Dip (°)	Dip Direction (N °E)			
Slope 1	39	70	129	39	15	77
Slope 2	151	87	241	23	10	78
Slope 3	39	86	129	15	12	64

Next, the physical and mechanical properties of the rock were tested. Testing the physical properties of rocks is testing a sample without destroying the sample, or what is usually called non-destructive testing. Rock properties obtained from the results of testing the physical properties of rocks are natural density, dry density, saturated density, true specific gravity, and apparent specific gravity. gravity), natural water content, saturated water content/absorption, degree of saturation, porosity (n), and void ratio (e) (Rai, 2013). [16].

Table 2 Data on Testing Physical Properties of Rocks

NO.	SAMPLE	NATURAL WEIGHT (Wn)	SATURATED WEIGHT (Ww)	WEIGHT ON WATER (Ws)	DRY WEIGHT (Wo)
		grams	grams	grams	grams
1	GP_1	161.2	167	81.3	159.8
2	GP_2	180.6	190.7	90.2	178.2
3	GP_3	191.1	196.9	106.7	190
4	GP_4	181.5	194.7	95.9	178.3
5	GP_5	188.5	198.4	99	185.4

After the rock has been cored and tested with Point Load Index, PLI (diametrical testing), the test result data is obtained in table 3 below.

Based on the data processing that has been carried out, it can be concluded that the compressive strength value, σ_c of the rocks forming slope 1 is 21.6 MPa, slope 2 is 22.7 MPa, and slope 3 is 25.3 MPa.

DISCUSSION

Analysis of the characterization and strength of the rock mass and the RMR and GSI weighting values were obtained, and the intact rock value and disturbance factor were determined, so all parameters were met, and an analysis of the strength of the rock mass was carried out to obtain the cohesion and friction angle values using Roclab

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Figure 4. Compressive Strength Testing Using Point Load Machine (Geotechnical Laboratory, Universitas Cenderawasih)

Table 3 Data processing results for point load index compressive strength test

SAMPLE	L (mm)	D (mm)	De (mm)	INITIAL CONUS (mm)	END CONUS (mm)	CONUS CHANGES (mm)	P (kN)	Is (MPa)	Is 23 (Mpa)
GP_1	91.50	51.33	47.33	42	38	4	1.04	0.464	10,676
GP_2	97.97	47.80	43.80	47	43	4	2.25	1,173	26,975
GP_3	92.50	48.07	43.07	46	41	5	2.12	1,143	26,289
GP_4	97.20	47.97	42.97	47	42	5	1.14	0.618	14,203
GP_5	97.33	48.13	41.13	45	38	7	2.18	1,288	29,634
AVERAGE								**0.937**	**21.6**
GP_6	93.17	47.77	41.77	45	39	6	2.38	1,364	31,379
GP_7	96.90	48.00	45.00	46	43	3	2.78	1,373	31,575
GP_8	94.73	47.83	45.83	46	44	2	0.19	0.090	2,080
GP_9	99.40	48.43	43.43	45	40	5	2.23	1,182	27,189
GP_10	97.17	48.00	44.00	46	42	4	1.8	0.930	21,384
AVERAGE								**0.988**	**22.7**
GP_11	90.13	47.97	39.97	36	28	8	0.92	0.576	13,247
GP_12	91.90	47.97	43.97	46	42	4	2.13	1,102	25,343
GP_13	87.63	48.03	43.03	47	42	5	2.07	1,118	25,709
GP_14	93.27	47.90	45.90	46	44	2	3.42	1,623	37,336
GP_15	97.93	48.13	44.13	46	42	4	2.12	1,088	25,034
AVERAGE								**1,101**	**25.3**

.

Table 4. Results of Rock Mass Strength Analysis Using Roclab

No	Quarry	Lithology	GSI	σ_i (MPa)	D	m_i	C (MPa)	θ (°)	Em (MPa)
1.	Slope 1	Limestone	57	21.6	0.7	10	0.341	38.62	4,520.02
2.	Slope 2	Limestone	56	22.7	0.7	10	0.341	38.46	4,374.48
3.	Slope 3	Limestone	57	25.3	0.7	10	0.337	41.16	4,891.86

Kinematic Analysis to Find Out Landslide Types. Dips 7.0 software was used to determine the type of landslide that might occur on the body of the slope. This analysis is used as supporting data for Rocscience Slide 6.0 software modeling.

Slope Quarry Kinematic Analysis 1

After carrying out observations and measurements in the field, namely at quarry slope 1, data was obtained, including that the slope dip was 70°, the slope direction of the slope (dip direction) was N160^0 E, the slope height was 39 meters, and the length of the ladder was 15 meters, with discontinuity plane data of 15 joint planes and a scanline length of 10 meters.

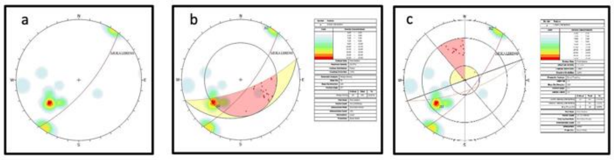

Figure 5. a- Scheme of a landslide at quarry slope 1. b,c - Analysis of wedge landslide potential slope 1

Slope Quarry Kinematic Analysis 2

After carrying out observations and measurements in the field, namely at quarry slope 1, data was obtained, including that the slope dip was 87^0, the slope direction of the slope (dip direction) was N 177^0 E, and the slope height was 23 meters. The ladder length was 10 meters, with 18 discontinuity plane data and a scanline length of 10 meters.

Slope Quarry Kinematic Analysis 3.

After carrying out observations and measurements in the field, namely at quarry slope 1, data was obtained, including that the slope dip was 86^0, the slope direction of the slope (dip direction) was N176^0 E, and the slope height was 15 meters. The ladder length was 12 meters, with discontinuity plane data consisting of 9 joint planes and a scanline length of 10 meters. From the results of the kinematic analysis of the three slopes, the potential form of a landslide that might occur on the body of the slope is obtained in the form of a non-arc landslide. So for modeling using the help of Rocscience Slide 6.0 software, the type of landslide entered is non-circular.

Research Slope Stability Analysis.

In simple terms, it can be said that if the resisting force is greater than the driving force, then the slope will be stable, whereas if the resisting force is smaller than the driving force, then the slope will become unstable and will trigger an avalanche. Calculation of the actual slope safety factor in the field uses the Hoek & Brown (1991) method. Slope Safety Factor Analysis with Rocscience Slide 6.0

Analysis of Slope 1

From the analysis of the level of slope stability, which was carried out using slide 6.0 software, the slope safety factor value for the research area in original conditions was 0.935, dry conditions were 1.619, and saturated conditions were 0.671. So it can be concluded that the slopes of the research area, when original and saturated, are unsafe or unstable. In contrast, the slopes in dry conditions are safe or stable. The FoS value indicates that the slope conditions at the research location have the potential for landslides in original and dry conditions.

Analysis of Slope 2.

Based on the analysis of the FoS value of the research slope using the Hoek & Brown method, which was carried out on slope 1, the FoS value of the research slope in actual conditions in the field was 0.387, so it can be concluded

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that the research slope is in an unstable/unsafe condition. Analysis of Slope Safety Factors Using the Hoek & Brown Method Manual analysis using the Hoek & Bray method was carried out to determine the value of the safety factor for the research slope under actual conditions in the field, the results of which can be visually observed in the following image.

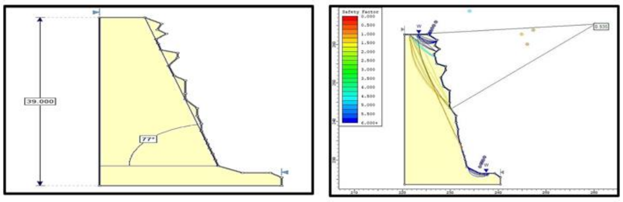

Figure 6. Slope geometry 1 (left), Slope FoS value in original condition (right)

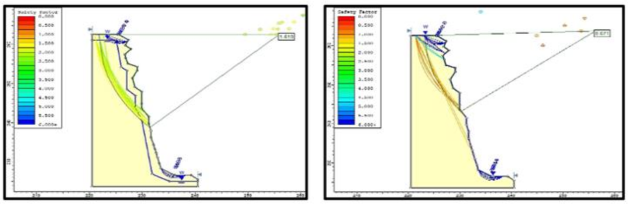

Figure 7. Slope FoS value in dry conditions (left), Slope FoS value in saturated conditions (right)

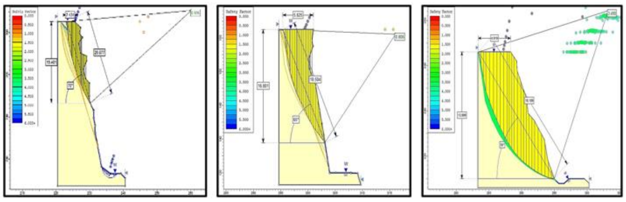

Figure 8. Analysis of Slope 1 (left), Slope 2 (middle), slope 3 (right)

Based on the analysis of the FoS value of the research slope using the Hoek & Brown method, which was carried out on Slope 2, the FoS value of the research slope in actual conditions in the field was 0.579, so it can be concluded that the research slope is in an unstable/unsafe condition. Based on the analysis of the FoS value of the research slope using the Hoek & Brown method, which was carried out on Slope 3, the FoS value of the research slope in actual conditions in the field was 1.272, so it can be concluded that the research slope is in a safe condition.

Safe Slope Recommendations.

Table 6. Recommended Values for Slope Design

No.	Quarry	Level Height (m)	The width of the road (m)	Over All Slopes (degree)	Single Slope (degree)	FoS
1.	Slope 1					
	Original	9	6	48	70	2,257
	Saturated	9	6	48	70	2,179
2.	Slope 2					
	Original	9	6	54	75	2,884
	Saturated	9	6	54	75	2,703

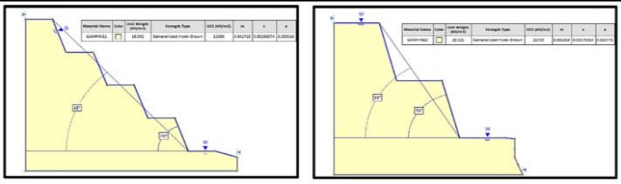

Figure 9. Overall Slope and Single Slope Slope 1 (left) and Overall Slope and Single Slope 2 (right)

IV. CONCLUSION

From the rock mass classification results using the RMR system, the RMR value for slope 1 was 62, slope 2 was 61, and slope 3 was 62. So it can be concluded that the rock is included in rock mass class 2 with good quality. Based on the analysis of potential landslide types, the three slopes have non-arc landslide types. From the analysis carried out using Rocscience Slide 6.0 software, the FoS values for slopes in original, dry and saturated conditions were obtained, where on slope 1: FoS in original conditions was 0.935, FoS in dry conditions was 1.619, and FoS in saturated conditions was 0.671. Then slope 2: FoS in original conditions is 0.896, FoS in dry conditions is 1.457, and FoS in saturated conditions is 0.806. Slope 3: FoS in original conditions is 3,490, FoS in dry conditions is 4,199, and FoS in saturated conditions is 3,368. So it can be concluded that slopes 1 and 2 are unsafe or unstable in original and saturated conditions so that landslides can occur.

In analyzing the FoS value of the actual conditions of the slopes in the field using the Hoek & Brown method, obtained the FoS value of slope 1 at 0.387, the FoS value of slope 2 at 0.579, and the FoS value of slope 3 at 1.272, it can be seen that the actual condition of the slopes in the field is that slopes 1 and 2 is in an unsafe or unstable condition. Improvements must be made to the slope geometry to maintain slope stability and remain safe or stable. The recommended improvement is creating new working levels for slopes 1 and 2, with steep heights and large rock porosity. So you get the latest slope FoS value.

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