PROGRAM BOOK

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Implementation of Study Rockfall Hazard Rating System (Rhrs) Method for Slope Stability Analysis at Samarinda Seberang District, East Kalimantan, Indonesia

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Abstract

Conditions of the observation area is an area of the openings to the residential area, so that the population will increase along with the housing. Because originally there is a forestry area, many hills engineered with "cut and fill" to make the road not too uphill or steep. Leaving so many slopes on the edge of the road with an average height of 10 meters. Such conditions increase the risk of casualties due to exposure to material debris from the slope, because the frequency of vehicles will increase in the area.

The study analyzes the slope stability by using RHRS (Rockfall Hazard Rating System) to determine the slope stability in order to prevent rock falls, in analyzing the rock fall that would cause harm either materially or casualties, the rate of fall-rock performed on the slope along the 40 m that spanned the Kurnia makmur street East Kalimantan province. The data that will be analyzed are slope high, the ditch of the effectiveness, the average risk of the vehicle, the percentage of visibility for decision sight distance, roadway width including paved shoulders, geological characteristics, the rock's sliding surface, block size, climate and presence of water on slope, and records of rock falls have occurred in the location.

Results of analysis provided an risk assessment of rock falls, the total weight of RHRS, then the priority to handling that slope is more high. From the total amount on each parameter in RHRS slope, the slope is categorized as slopes which have priority "*very low priority for remedial action"* for handling action, with the total number is 195.

Keywords: Rock Falls, Wedge Failure, Slope Stability, RHRS's Weighting System

1. Preface

In this study, measurements were taken at the opening area for a residential purpose, so that the population will increase along with the housing. Because originally there are forestry area, many hills which are cut to make the road not too uphill or steep. It made so many hills in the edge of road with an average height of 10 meters. Such conditions increase the risk of casualties due to exposure to material debris from the slope, because the frequency of vehicles will increase in the area. RHRS analysis performed on a 40-meter segment. And geographically located at an elevation of 24 meters above sea level, 117 ° 09'00 "E and 00 ° 59'00" latitude.

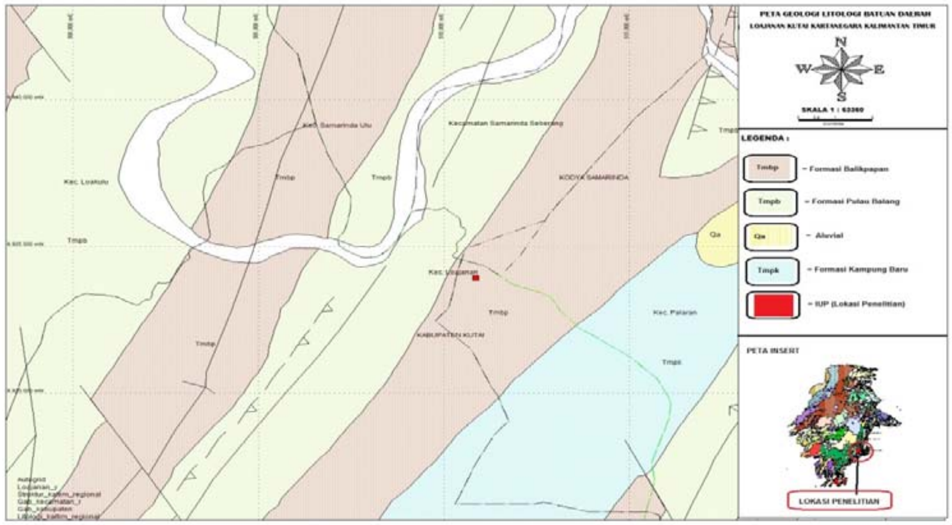

Fig. 1. Study Location

Based on the information from regional geological map Hidayat and Umar (1994) in zulfiadi Zakaria et al (2012), the Balikpapan Formation was middle Miocene to end Miocene on the top consisting of alternated sandstone quartz, claystone silty and shales with marl insertions, limestone, and coal.

Slope instability and rock falls can generally occur because of climate change, weather and biological events that lead to change the forces on the rock. Some examples that might be the cause of which is the pore water tension enhancement because rain inflation, erosion, freezing pore water, changes in the chemical composition of rocks, rocks corrosion, plant's roots that grow on rocks, discontinuous joint, and mechanical processes such as excavation and blasting. At the time of slope construction activities, slope instability and falling rocks can occur because of a mechanical process and have a greater influence than other causes such as those mentioned above.

Road construction in hilly areas will always be faced with slope stability problem and the rock fall hazard. Because of the problem's seriousness, a classification system can be done by visual inspection and a simple calculation has been developed. The purpose of this classification is to identify slopes hazards that will have rock falls. In estimating the danger of rock falls, a system most widely accepted is the *Hazard Rating System* (RHRS), which was developed by Oregon State Highway Division (Hoek, 2000).

There are ten categories for weight rating on RHRS, including the slope height, the effectiveness of the ditch, the average risk for the vehicle, the percentage of visibility for decision making, road's width, geological characteristics, the surface of the rock slide, block size, climate and the presence of water, and records of rock falls that have occurred at the site. The summation of the weights of each category will determine the priority of implementation time for slope handling action. The higher number for value of all the weight, then the slope handling priority becomes higher. (high priority for remedial action).

From the results of field observations, the rock slope composition are mostly sandstone with discontinuous joints intersecting each other. Around the location also contributed to their joint structure with the intensity is high enough.

Measurement of joint structure carried on the slopes. The slopes have a 10 m height, and the angle is about 33^{o}. From the measurement results obtained joint closeness spacing between 2.27 to 0.33 cm, with the average joint spacing is 1.07 cm. Joint intensity on the bottom. In the fair condition, the water flow is only a minor seepage, but when it rains the flow is large enough.

Fig. 2. Study Site

2. Theory

2.1 Slope stability analysis

Slope stability analysis done by using the limit equilibrium method. Purpose of this analysis is to provide a sense of the slope sliding mechanism which is the basic evaluation of the geological characteristics from the RHRS classification system.

In the slope stability analysis, slopes sliding can occur if both of the kinematic and kinetic factors of the slopes are fulfilled. Slope's kinematics factor can qualified to cause instability if there are spaces on the slope rock masses block segment to move on the slip surface towards the space. While the kinetic factor is the ratio between retaining force and stimulant force in the slip surface. If the retaining force is exceeded by stimulant force, then the avalanches will occur (Hoek and Bray, 1981).

Sliding slopes are affected by geological structures such as joints or discontinuities, orientation and shear strength of discontinuous joint determine the slope. Based on the presence of the geological structure, the form of failure that may occur is wedge failure. Beside the geological structure, the presence of water and physical-mechanical characteristics of the rock mass also affects the stability of the slope.

Safety factors analysis using the balance limit, when the slopes have a safety factor higher than 1.5 (minimum FK road slope according to the national standardization association) then the slope is expressed in a safe condition. Within the limit equilibrium method (Arief S 2008) using the following formula :

$$F = \frac{c}{\gamma . h . \sin\beta . \cos\beta} + \frac{\tan\phi}{\tan\beta} \qquad (1)$$

2.2. Rock Fall Analysis with RHRS

Table 1 is a weighted system for various categories (parameters) in
Volume (x) = Volume (cu,ft.)/3

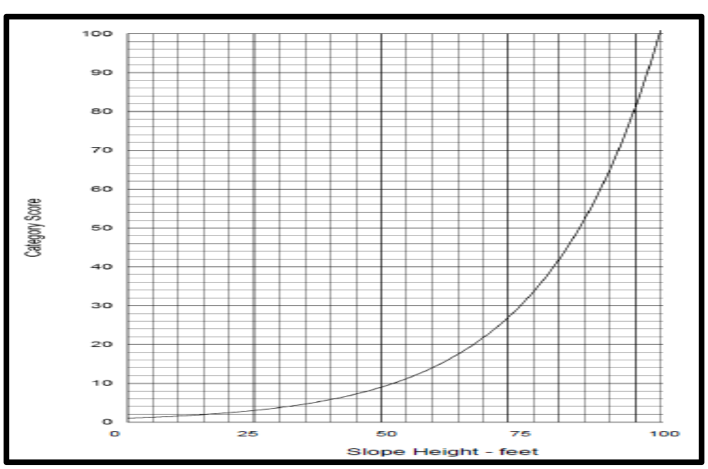

Fig. 3. Weighting graphic for slope height parameter (Hock, E, Practical Rock Engineering, page 151)

In Figure 4 above is an example graphic used for weighting that more accurate than the slope height parameter. This curve is calculated by the equation $y = 3^x$. The curves can also be made with the same count from the exponent x the following:

CATEGORY			RATING CRITERIA AND SCORE			
			POINTS 3	POINTS 9	POINTS 27	POINTS 81
SLOPE HEIGHT			25 FT	50 FT	75 FT	100 FT
DITCH EFFECTIVENESS			Good catchment	Moderate catchment	Limited catchment	No catchment
AVERAGE VEHICLE RISK			25% of the time	50% of the time	75% of the time	100% of the time
PERCENT OF DECISION SIGHT DISTANCE			Adequate site distance, 100% of low design value	Moderate sight distance, 80% of low design value	Limited site distance, 60% of low design value	Very limited sight distance, 40% of low design value
ROADWAY WIDTH INCLUDING PAVED SHOULDERS			44 feet	36 feet	28 feet	20 feet
GEOLOGIC CHARACTER	CASE 1	STRUCTURAL CONDITION	Discontinuous joints, favorable orientation	Discontinuous joints, random orientation	Discontinuous joints, adverse orientation	Continuous joints, adverse orientation
		ROCK FRICTION	Rough, irregular	Undulating	Planar	Clay infilling or slickensided
	CASE 2	STRUCTURAL CONDITION	Few differential erosion features	Occasional erosion features	Many erosion features	Major erosion features
		DIFFERENCE IN EROSION RATES	Small difference	Moderate difference	Large difference	Extreme difference
BLOCK SIZE / QUANTITY OF ROCKFALL/EVENT			1 FT / 3 cubic yards	2 FT / 6 cubic yards	3 FT / 9 cubic yards	4 FT / 12 cubic yards
CLIMATE AND PRESENCE OF WATER ON SLOPE			Low to moderate precipitation; no freezing periods, no water on slope	Moderate precipitation or short freezing periods or intermittent water on slope	High precipitation or long freezing periods or continual water on slope	High precipitation and long freezing periods or continual water on slope and long freezing periods
ROCKFALL HISTORY			Few falls	Occasional falls	Many falls	Constant falls

Fig. 4. The Criteria and weight from each categories on Rockfall Hazard Rating System Classification (Hock, E, Practical Rock Engineering, page 152)

Slope Height

This item represents the vertical height of the slope not the slope distance. Rocks on high slopes have more potential energy than rocks on lower slopes, thus they present a greater hazard and receive a higher rating. Measurement is to the highest point from which rockfall is expected. If rocks are coming from the natural slope above the cut, use the cut height.

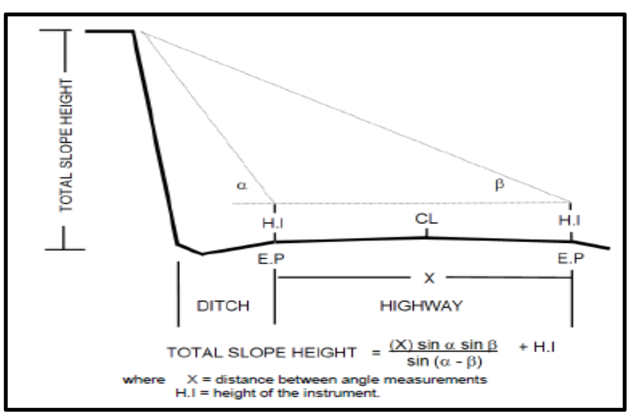

Fig. 5. Measurement of slope height. (Hock, E, Practical Rock Engineering, page 153)

Average Vehicle Risk (AVR)

This category measures the percentage of time that a vehicle will be present in the rockfall hazard zone. The percentage is obtained by using a formula (shown below) based on slope length, average daily traffic (ADT), and the posted speed limit at the site. A rating of 100% means that on average a car can be expected to be within the hazard section 100% of the time. Care should be taken to measure only the length of a slope where rockfall is a problem. Over estimated lengths will strongly skew the formula results. Where high ADT's or longer slope lengths exist values greater than 100% will result. When this occurs it means that at any particular time more than one car is present within the measured section. The formula used is:

$$\text{AVR} = \frac{\text{ADT (cars/day) x Slope Length (km) /24 (hour/day)}}{Posted\ Speed\ Limit\ (\frac{Km}{hour})} \text{ x } 100\% \quad (2)$$

Percent of Decision Sight Distance

The decision sight distance (DSD) is used to determine the length of roadway in feet a driver must have to make a complex or instantaneous decision. The DSD is critical when obstacles on the road are difficult to perceive, or when unexpected or unusual manoeuvres are required. Sight distance is the shortest distance along a roadway that an object of specified height is continuously visible to the driver.

$$PDSD = \frac{\text{Actual Sight Distance}}{Decicsion\ Sight\ Distance} \text{ x } 100\% \quad (3)$$

Source : Hock, E, Practical Rock Engineering, page 152-155

3. Research Method

3.1 Research Stage

In the first phase of the study done by searching the literature related to Rockfall Hazard Rating System analytical methods. The second stage is the measurement and data collection of joints dissemination with scanline method. Samples taken in the form of rock block location, the slope height, the average risk of the vehicle, the width of the road, analyzing the geological characteristics, the slip surface, block size, incline analysis and the presence of water, as well as rockfall history.

To get shear strength value for rock, the research and testing in the laboratory to determine the physical properties and mechanical properties of rocks had been done. The third stage, entire joints dissemination data analyzed using stereographic projections, and then specify the type of failure of the slope. The final result of this research is to determine the value of the mining slope safety factor based on the type and potential failure.

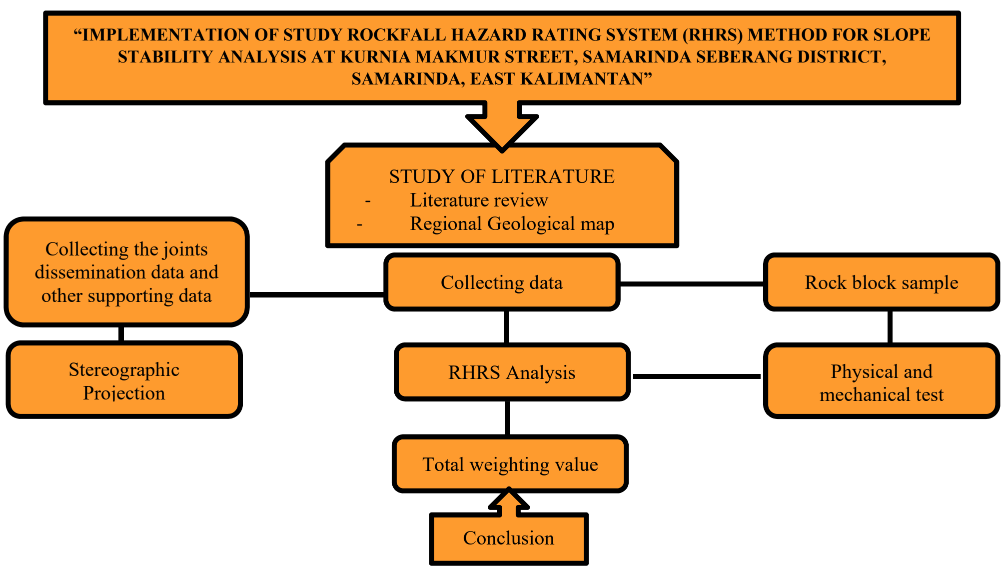

Fig. 6. Research flow chart

3.2 Measurement on the Site

Measurement on the site which is discontinuous joint done on one mining slope, the measurement on the site are measurements of dip and joint's dip Direction, and dip and slope's dip direction as well, slope height, the average risk of the vehicle, the road width, geological characteristics, the block size, the percentage visibility and record from rock falls.

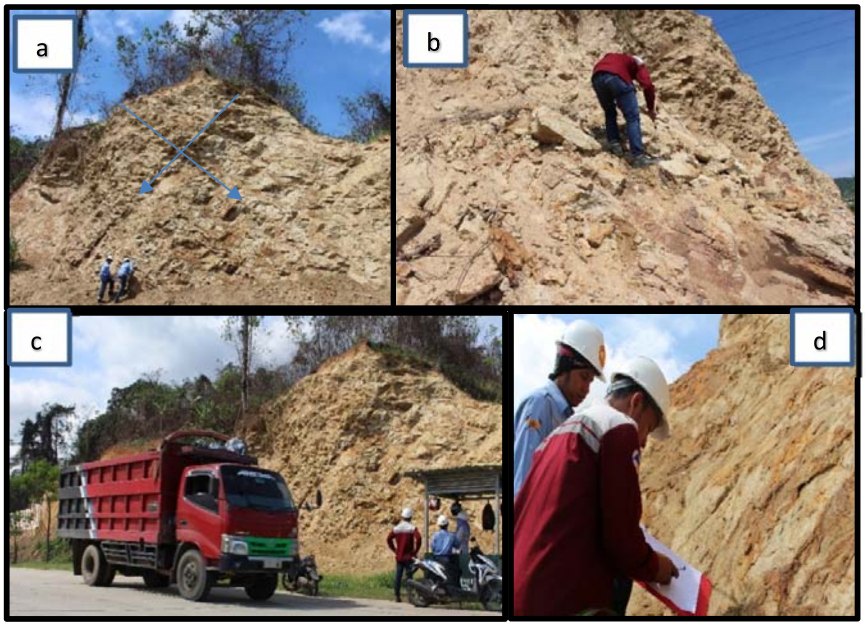

Fig. 7. (a) wedge failure, (b) slope condition, (c) vehicle risk, (d) discontinuities measurements

3.3 Sample Preparation and Laboratory Testing

Sandstone samples are intact rock block from the mining site, taken for preparation and through rock cutting process. After going through the preparation process, the next step is to test the physical properties and testing the mechanical properties of rocks.

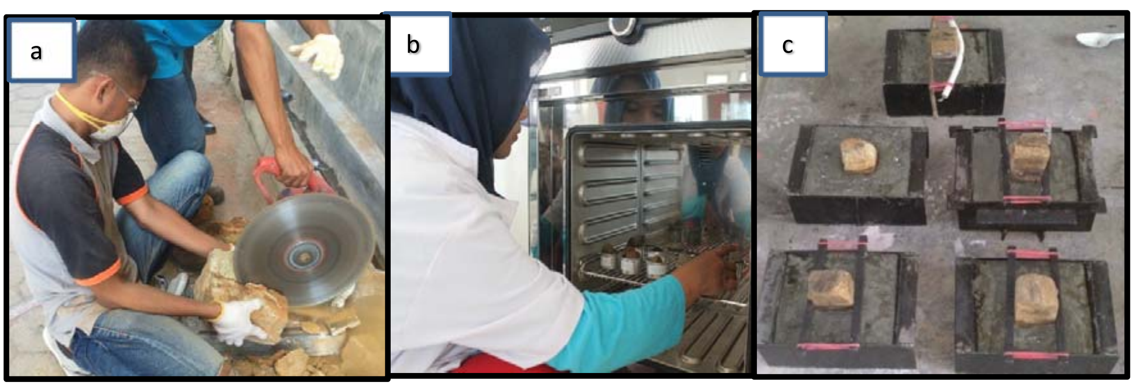

Fig. 8. (a) cutting process rock's block, (b) physical test process, (c) sandstone samples for slide test

Sample preparation, physical properties of rocks, and test for mechanical properties such as direct shear tests, performed in and Mineral Technology Laboratory, Faculty of Engineering, Universitas Mulawarman.

4. Discussion

To determine the safety factor, need the following rock properties, rock density = 18.8 KN / m^3, the slope angle of 33°, slip surface is assumed to 1 m from ground level, the cohesion is 15.98 KN / m^2, internal friction angle is 24^0. From the results of the calculation, the value of the safety factor is

2.5, which means higher than the value of the safety factor applied by the department of public works, which means the slopes in the steady state.

The weighting results to the slopes on Kurnia Makmur rd, Samarinda Seberang districts, East Kalimantan Province, are presented in the table below:

Table 2. Rockfall Hazard Rating System on the residential area on kurnia makmur rd, Samarinda Seberang districts, East Kalimantan Province

Category	Criteria	Weight
Slope Height	10 meters	9
Ditch Effectiveness	No Catchment	81
Average vehicle risk Presentage of visibility for decision making	89,54 %	6
Roads width	9,97 meters	27
Geological characteristics	Discontinuous joint, adverse orientation	27
Slip surface	planar	27
Block size	1 ft	3
Incline and water presence	moderate	9
Rockfall history	Few falls	3
Total		195

Analysis of the type of failure were using streographic projections. The analysis showed that the type of failure is a wedge failure with total weighting value is 195.

From the total amount of weighting, the slope on residential area on Kurnia Makmur Rd, Samarinda Seberang districts, East Kalimantan Province are categorized as slopes that have a low priority for handling action or called with “very low priority for remedial action”. In RHRS conducted in the State of Oregon explained that the slope with the number of total ratings less than 300, categorized as a slope that has a low priority for handling action (very low priority for remedial action), while the slopes with the total ratings is more than 500, categorized as slope which has a high priority for handling action (high priority for remedial action) (Hoek, 2000). However, the potential risk of accidents due to rock falls remain considering the factors that cause the occurrence of rock falls as the increase in pore water tension due to rainwater infiltration, erosion, changes in the chemical composition of rocks, weathering of rocks and roots of plants that grow on rocks found at this location.

From the conclusion of the analysis of the stability of the slope, then there are some actions that can take to reduce the risk of accidents at these locations, which are:

1. Cleaning Blocks Potentially Collapses (Scaling)
   Needs to be done on blocks that are less than 3 m if possible. There are some rocks that the wedge-shaped blocks which are critical and scaling should be taken to anticipate a sudden collapse on the time of rain at the site.
2. Installation of Danger Signs
   On the side of the road along the section needs to be install the failure hazard signs. It is intended that all road users more aware and careful when passing the location.

5. Conclusion

The failure type of the slopes on the residential area on Kurnia Makmur rd, Samarinda Seberang districts, East Kalimantan Province, indentified as wedge failure, with a steady slope conditions and has a low priority handling action. However, actions to protect the rock falls, supervision and care needs to be done.

Thank You Note

We would like to thank our Lecture Mr. Tommy Trides S.T., M.T. for his help during the study.

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Rock Slopes Stability Evaluation Based on Comparison Empirical Methods "Slope Mass Rating" and Analytical Method at Discontinuities Rock Mass Condition (Case Study at Sandstone Mines, Tani Aman Village, Loa Janan Sub District, Samarinda, East Kalimantan, Indonesia)

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Abstract

Engineering challenges in the field of rock mechanics are always faced with the stability of a rock mass in areas that have a discontinuities plane. The selection of appropriate methods, can provide accurate and credible information on the stability of a rock slopes. In this research, the evaluation used is divided into two methods that are Empirical Methods "Slope Mass Rating" and Analytical Methods (Analysis of kinematics). In the empirical method "Slope Mass Rating", provide qualitative information based on engineering judgment, whereas analytical methods provide quantitative information based on the forces acting on a kind of sliding. The results of this research have shown that based on the empirical method (SMR) on the west wall tend partially stable and east wall tend to be unstable, while based on the analytical method (Analysis of kinematics) safety factor on the west wall 11.54 and east wall 12.33.

Keywords: Empirical Methods (SMR), Analytical Methods (Analysis of kinematics), Safety Factor

1. Introduction

In this research, measurements were performed on a sandstone quarry which is administratively located at H.M. Rifadin street, Tani Aman Village, Loa Janan Sub District, East Kalimantan and geographically located on 0° 35' 37,2" LS and 117° 05' 55,2" BT.

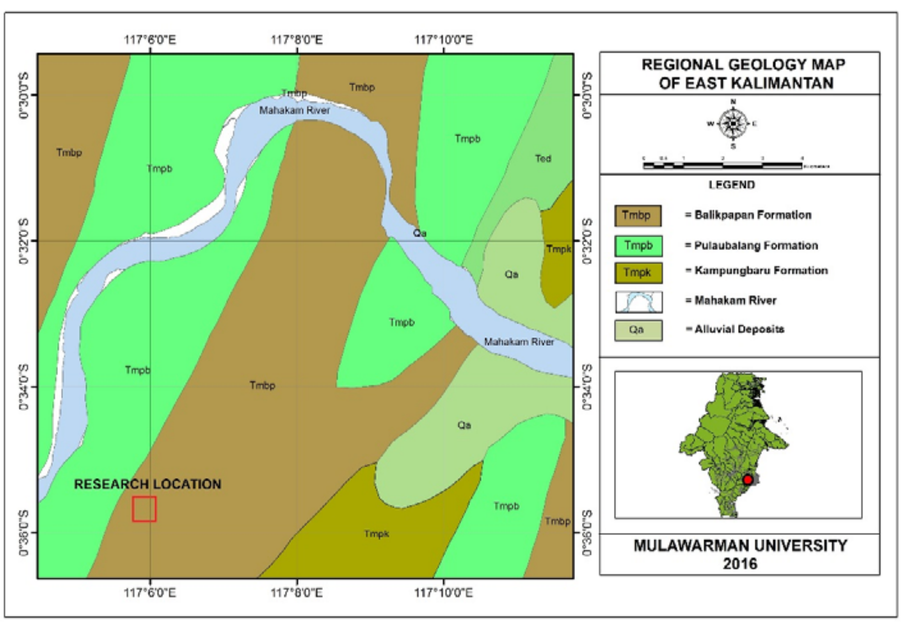

Fig. 1. Research Location

Based on the information regional geological map (Zakaria et al ,2012) as shown Figure 1. The Balikpapan rocks formation aged Middle Miocene Upper to Late Miocene consisting of interstratified sandstone quartz, silty claystone and shales with insertions marl, limestone and coal.

Mining process at the site of this study area mined by conventional manner and using traditional equipment and carry out by the communities surrounding the mine area as shown Figure 2. In the process, sandstone mining in this study sites have no certainty about the mining slope stability. It is deemed very important to do studies on slope stability in sandstone mining area.Based on observations in the field, there are of discontinuities intersecting each other on the sandstone. And this discontinuities can potentially cause instability in the mining slopes.

Fig. 2. Sandstone Mines Location

2. Theories

2.1 Rock Mass Classification

Bieniawski (1973) had proposed a Rock Mass system called Rock Mass Rating (RMR) for engineers to assessing quality of the rock mass on the field. RMR consist five parameters: intact rock strength, rock quality designation, spacing of discontinuities, condition of discontinuities, and groundwater as shown in table 1. Bieniawski (1979) had modificated RMR system, and add some adjustment parameters for rock slopes.

Parameter adjustment for rock slopes divided into five classes, namely very favorable (Rating value 0), favorable (Rating value -5), good (Rating value -25), unfavorable (Rating value -50), and very unfavorable (Rating value -60). Based on adjustment parameters to the rock slopes, there are no guidelines to define the details of each class for rock stability. (Romana ,1985; Romana et al, 2003) proposed a classification system for rock slope mass called Slope Mass Rating (SMR) as shown in table 2, table 3 and table 4, so that engineers can more easily define the detail of each rock mass class.

$$SMR = RMR_{Basic} - (F_1 \times F_2 \times F_3) + F_4 \quad (1)$$

Where :

RMR_{Basic} = RMR '79
F1 = Depends upon parallelism between joints and slope face strikes
F2 = Refers to joint dip angle in the planar failure mode
F3 = Refers to the relationship between the slope face and joint dips
F4 = Adjustment for the method of excavation

$$RMR_{Basic} = (\sigma_c + RQD + Js + Jc + G_W) \quad (2$$

Where :

σ_c = Strength of Intact Rock (MPa)
RQD = Rock Quality Designation (%)

J_s = Spacing of Discontinuities (m)
J_c = Condition of Discontinuities
G_w = Groundwater

Table 1. Rock Mass Rating (Bieniawski, 1979)

Parameter			Ranges of Values						
1	Strength of Intact Rock	PLI (MPa)	> 10	4 - 10	2 - 4	1 - 2	For This Low Range – Uniaxial Compressive Test is Preffered		
		UCS (MPa)	>250	100 - 250	50 - 100	25 - 50	5 - 25	1 - 5	<1
	Rating		**15**	**12**	**7**	**4**	**2**	**1**	**0**
2	Rock Quality Designation (%)		90 - 100	75 - 90	50 - 75	25 - 50	< 25		
	Rating		**20**	**17**	**13**	**8**	**3**		
3	Spacing of Discontinuities		>2m	0,6 – 2 m	0,2 – 0,6	0,006 – 0,2 m	<0,006 m		
	Rating		**20**	**15**	**10**	**8**	**5**		
4	Condition of Discontinuities		Very rough, surfaces not continuous, no separation, unweathered wall rock	Slightly rough surfaces, Separation < 1 mm, Slightly weathered walls	Slightly rough surfaces, Separation < 1 mm, Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		**30**	**25**	**20**	**10**	**0**		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	<10	10 - 25	25 - 125	>125		
		General conditions	Completely Dry	Damp	Wet	Dripping	Flowing		
	Rating		**15**	**10**	**7**	**4**	**0**		

Table 2. Slope Mass Rating (Romana, 1985)

Case of Slope Failure		Very Favorable	Favorable	Fair	Unfavorable	Very Unfavorable
P	|αj - αs|	>30˚	30-20˚	20-10˚	10-5˚	<5˚
T	|αj - αs - 180|					
W	|αi - αs|					
P/W/T	F1	0.15	0.4	0.7	0.85	1.00
P	|βj|	<20˚	20-30˚	30-35˚	35-45˚	>45˚
W	|βi|					
P/W	F2	0.15	0.4	0.7	0.85	1.00
T	F2	1.0	1.0	1.0	1.0	1.0
P	|βj - βs|	>10˚	10-0˚	0˚	0 - (-10˚)	< -10˚
W	|βi - βs|					
T	|βj + βs|	<110˚	110-120˚	>120˚		
P/W/T	F3	0	-6	-25	-50	-60

αj = Joint Strike
αs = Slope Strike
αi = Plunge direction of line of intersection
βj = Joint Dip
βs = Slope Dip
βi = Plunge of line of intersection.
P = Plane Failue
W = Wedge Failure
T = Toppling Failure

Table 3. Values of Adjustment Factor for Method of Excavation (Romana, 1985)

Method of Excavation	Natural Slope	Pre-splitting	Smooth Blasting	Normal blasting or mechanical excavation	Poor Blasting
F4	+15	+10	+8	0	-8

Table 4. Class Description of SMR (Romana, 1985)

	Description				
Class No.	**V**	**IV**	**III**	**II**	**I**
SMR Value	0-20	21-40	41-60	61-80	81-100
Rock Mass Description	Very Bad	Bad	Normal	Good	Very Good
Stability	Completely Unstable	Unstable	Partially Stable	Stable	Completely Stable
Failures	Big planar or soil like or circular	Planar or big wedges	Planar along some joints and many wedges	Some block failure	No Failure
Probability of Failures	0.9	0.6	0.4	0.2	0

2.2 Safety Factor of Plane Failures and Wedge Failures

In the kinematic analysis (Hoek and Bray, 1981; Wyllie and Mah, 2004) slope failures formed by intersecting discontinuities classified into plane failures, wedge failures, toppling failures, and circular failures. Plane failures and wedge failures as shown in Figure 3 and Figure 4.

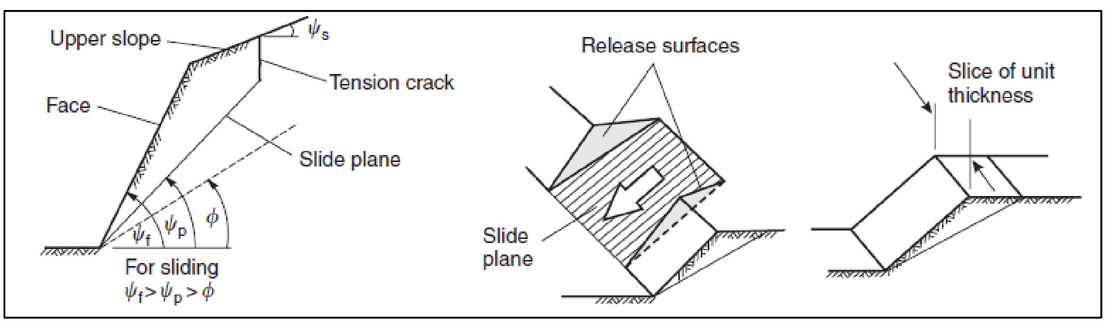

Fig. 3. Ilustration Plane Failure Geometry (Wyllie et al, 2004)

$$F = \frac{cA + (W\cos\psi_p - U - V\sin\psi_p)\tan\phi}{W\sin\psi_p + V\cos\psi_P} \quad (3)$$

$$A = (H - z)cosec\psi_p \quad (4)$$

$$U = {}^1\!/_4\,\gamma_w H_w{}^2 \operatorname{cosec}\psi_p \quad (5)$$

$$V = {}^1\!/_2\,\gamma_w z_w{}^2 \quad (6)$$

$$W = {}^1\!/_2\,\gamma H^2 \left\{ \left(1 - \left({}^z\!/_H\right)^2\right)\cot\psi_p - \cot\psi_f \right\} \quad (7)$$

Where :
c = Cohesion (t/m^2)
ϕ = Internal friction Angle (°)
H = Slope Height (m)
H_w = Water table height (m)
z = Depth of tension crack (m)
z_w = Height of water in tension crack (m)
ψ_p = Dip of discontinuities plane (°)
ψ_f = Dip slopes (°)

a. Wedge Failure

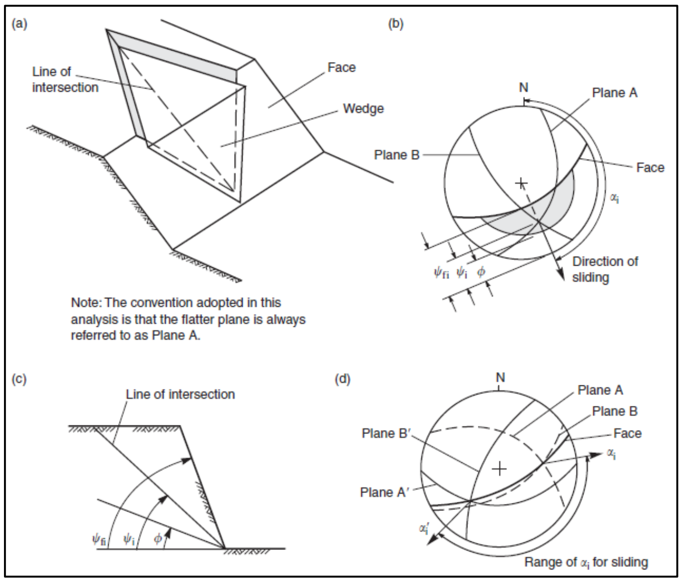

Fig. 4. Ilustration Wedge Failure Geomtery (Wyllie et al, 2004)

$$F = {}^{3}/_{\gamma H}\,(C_A X + C_B Y) + \left(A - {}^{\gamma_w}/_{2\gamma}\,X\right)\tan\phi_A + \left(B - {}^{\gamma_w}/_{2\gamma}\,Y\right)\tan\phi_B \quad (8)$$

Where :
C_A dan C_B = Cohesion discontinuities plane A and B (t/m^2)
ϕ_A dan ϕ_B = Internal friction angle discontinuities plane A and B (°)
γ = Natural density of rock (t/m^3)
γ_w = Density of water (t/m^3)
H = Slope Height (m)
X = $\sin\theta_{24}/(\sin\theta_{45}\sin\theta_{2.na})$
Y = $\sin\theta_{13}/(\sin\theta_{35}\sin\theta_{1.nb})$
A = $(\cos\psi_a - \cos\psi_b\cos\theta_{na.nb})/(\sin\psi_5\sin^2\theta_{na.nb})$
B = $(\cos\psi_b - \cos\psi_a\cos\theta_{na.nb})/(\sin\psi_5\sin^2\theta_{na.nb})$

3. Research Methodology

The first stages of this study by refer search of the literature related to the empirical method Rock Mass Rating (RMR), Slope Mass Rating (SMR), and analytical method to define safety factor of rock slopes. The second stages is collected data in the field: discontinuities orientation measurements, spacing of discontinuities, conditions of discontinuities, and groundwater directly on the sites.

Rock samples for laboratory tests carried out on a series of rock samples have been taken from the site location. Discontinuities orientation measurements used to determine potential failures types, and later useful for determine SMR and factor of safety.

4. Discussion

4.1 Discontinuity Plane Orientation

Analysis based on stereonet projection as much as 78 discontinuities plane that in research area consist 5 joint set orientation. In stereographic projection, joint set 4, 5 intersect joint set 2, 3 and dip joint sets 2, 3, 4, 5 tend to be less steepest than the joint set 1 as shown table 5. The intersection of the joint sets have the potential to form the plane failures and wedge failures.

Table 5. Joint Set Orientation

Joint Set (JS)	Dip Direction (N…ºE)	Dip (º)
Joint Set 1	201	83
Joint Set 2	111	32
Joint Set 3	171	31
Joint Set 4	278	23
Joint Set 5	284	51

4.2 Physical and Mechanical Properties of Sandstone

Physical properties and mechanical properties of sandstone suggested ISRM 1981. Physical properties of sandstone test as many as four samples, and mechanical properties test of rocks in the form direct shear of discontinuities test and uniaxial compressive strength test of intact rock. Physical and mechanical properties of sandstone shown in table 6 and table 7.

Table 6. Physical properties of sandstone

Parameter	Sample Code				Average
	9	XI	E 11	21	
γ_n (gr/cm^3)	1,78	1,82	1,87	1,95	1,85
γ_d (gr/cm^3)	1,67	1,70	1,72	1,79	1,72
γ_s (gr/cm^3)	1,92	1,93	1,95	2,01	1,95
ω_n (%)	6,50	7,05	8,38	8,59	7,63
ω_s (%)	15,02	13,77	13,24	11,82	13,46
S (%)	43,25	51,20	63,28	72,61	57,59
n (%)	25,14	23,39	22,83	21,21	23,14
e	0,34	0,31	0,30	0,27	0,30

Table 7. Mechanical properties of sandstone

Mechanical Properties			
Direct shear test			Uniaxial compression test
Parameter	Cohesion (MPa)	Friction Angle (°)	σ_{c50} (MPa)
Peak	0,541	37,51	8,013
Residual	0,245	23,99	

4.3 Joint Spacing and Rock Quality Designation

Spacing of discontinuities of the research area varies between 0.50 m to 2.91 m (medium - very wide) as shown in table 8. Rock quality designation on west wall 99,49%, north wall 99,94%, and 98,27%. Based on the rock quality designation rating for west wall, north wall, and east wall are 20 and classified as very good (excellent) as shown table 9.

Table 8. Spacing of discontinuities

Wall	Joint Set	Spacing of discontinuities (m)	Average (m)
West wall	1	1,20	0,96
	2	0,71	
North wall	3	4,65	2,91
	4	1,18	
East wall	5	0,50	0,50

Table 9. Rock Quality Designation

Wall	Rock Quality Designation (%)	Description
West wall	99,49	Very good
North wall	99,94	Very good
East wall	98,27	Very good

4.4 Rock slope failure type

The results of stereographic projection shown that on the west wall, the north wall, and west wall potentially forming plane failures type and wedge failures type as shown table 10. West wall potentially forming planes failures type against JS2 and potential wedge failures type against JS1 and JS2, also and JS2 and JS3. The north wall had not similar things that there are none potential failures at JS1, and none potential wedge failures against JS2 and JS4, JS5 and JS2, JS3 and JS4, and JS3 and JS5. Meanwhile, on the east wall potential plane failures type against JS5 and none potential failure against JS4.

Table 10. Rock slopes failure types

Wall	Failure Type			
	Joint Set (JS)	Plane Failures Type (P)	Joint Set (JS)	Wedge Failures Type (W)
West Wall	JS 2	Yes	JS 1 and JS 2	Yes
			JS 2 and JS 3	Yes
North Wall	JS 1	None	JS 2 and JS 4	None
			JS 2 and JS 5	None
			JS 3 and JS 4	None
			JS 3 and JS 5	None
East Wall	JS 4	None	-	-
	JS 5	Yes		

JS = Joint Set

4.5 Slope Mass Rating and Factor of Safety Result

On the west wall based SMR methods shown that plane failure type is partially stable and wedge failure type is completely stable, meanwhile based on analytic method shown that safety factor plane failure type 11,54 and safety factor wedge failure type 5,62 until 23,31. East wall based SMR methods also shown that plane failure type is unstable and based analytical method shown that safety factor plane failure type 12,33 as shown table 11.

It can be see that from these different analysis method: SMR and analytical method (analysis of kinematics) has contrast opposite slope stability result. It cause both of these methods had different input parameter and assume had been used. Input parameters for SMR methods is not only considering strength of intact rock, but also discontinuity condition, ground water condition, slope failure type orientation, and excavation method had been used. These parameters has major influence in slope stability based on empirical methods.

Meanwhile input parameter for analytical method only based on physical properties, shear strength of discontinuity, water table and geometry of slope failures type. Factor of safety calculated based on equilibrium state.

Table 11. Slope Mass Rating and Safety Factor

Wall	Slope Failure Type	Joint Set	RMR Basic	(F1xF2xF3)	F4	SMR	Stability	Failures	Safety Factor
West wall	Plane	JS 2	74	-42	15	47,00	Partially Stable	Planar along some joints and many wedges	11,54
	Wedge	JS 1 & JS 2	74	-6,3	15	82,70	Completely Stable	No Failure	23,31
		JS 2 & JS 3	74	-3,6	15	85,40	Completely Stable	No Failure	5,62
East wall	Plane	JS 5	71	-50	15	36,00	Unstable	Planar or big wedges	12,33

JS = Joint Set

5. Conclusion

The results showed that the study site consists of 5 joint set which potentially forming plane failures. The stability of the rock slopes with the empirical method (SMR) and the analytical method (kinematic analysis) on the west wall and the east wall giving different slope stability information. Based on the empirical method (SMR) on the west wall tend partially stable and east wall tend to be unstable, while based on the analytical method (analysis of kinematics) safety factor on the west wall 11.54 and east wall 12.33.

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