SENSITIVITY ANALYSIS AND SLOPE STABILITY RISK OF KALIWADAS LIMESTONE HILLS AT KARANGSAMBUNG REGIONS, KEBUMEN, CENTRAL JAVA

Article *in* International Journal of Civil Engineering and Technology · April 2019

4 authors, including:

Masagus ahmad Azizi
Trisakti University

Irfan Marwanza
Trisakti University

Reza Aryanto
Trisakti University

International Journal of Civil Engineering and Technology (IJCIET)
Volume 10, Issue 04, April 2019, pp. 511-527. Article ID: IJCIET_10_04_053
Available online at http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=04
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

SENSITIVITY ANALYSIS AND SLOPE STABILITY RISK OF KALIWADAS LIMESTONE HILLS AT KARANGSAMBUNG REGIONS, KEBUMEN, CENTRAL JAVA

Bani NUGROHO, Masagus A. AZIZI, Irfan MARWANZA and Reza ARYANTO
Mining Engineering Department FTKE Trisakti University Jakarta

ABSTRACT

On the limestone hills, Kaliwadas hill in Karangsambung, Kebumen, Central Java, occurs a crack that have gone on a landslide which have an impact on infrastructure losses. Post-landslide weather conditions that occur are still in position and allow for landslides and can provide greater. To anticipate this, it is necessary to analyze the slope stability with all parameters that can affect the slope of the slope, the sensitivity approach to determine the most dominant parameters, slope measurement speed and landslide field volume, and landslide slope analysis. From the studies that have been carried out, the factors that produce from two-dimensional analysis are 0.505 and from the 3-dimensional analysis of 1.227, the influence of earthquake factors on slope stability is very small, judging from the results of sensitivity, rock mass movement speed of 0.15 meters / month and can As a moderate movement, the results of the landslide analysis, the losses that have occurred due to the previous shift of around 60 million rupiah, and the potential loss if an avalanche is found is the estimated income is 21 million rupiah per year.

Keywords: slope stability, sensitivity analysis, impact analysis, earthquake, fotogrametry.

Cite this Article: Bani NUGROHO, Masagus A. AZIZI, Irfan MARWANZA and Reza ARYANTO, Sensitivity Analysis and Slope Stability Risk of Kaliwadas Limestone Hills at Karangsambung Regions, Kebumen, Central Java, *International Journal of Civil Engineering and Technology*, 10(4), 2019, pp. 511-527.

http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=04

1. INTRODUCTION

It started with the appearance of cracks on the slopes of limestone hills which cut road infrastructure and then have significant movement. Landslide block is still hang on and move slowly toward the river. The impact caused by the movement of landslides has severed access to existing roads and the cost of rebuilding new roads for citizen access. Landslide conditions that still hang on the slopes are still a potential risk of river closure, loss of livelihoods, environmental pollution, to the risk of fatalities due to buried landslides. To anticipate this, a risk analysis of limestone slope stability is required based on fracture measurement data, groundwater measurements, earthquakes, laboratory tests of physical and mechanical properties of rocks, and measurement of slope movement speed. The problem in this study is post movement slope stability on limestone hills, then high rainfall which can be a serious threat to the characteristics of limestone and clay, and earthquake factors that influence slope stability. Therefore the purpose of this study is to determine the safety factors and the probability of slopes on limestone hills with the limit equilibrium method, determine the dominant or sensitive factors of earthquake and groundwater parameters, calculate the velocity of slope movement and landslide volume, as well as the analysis of impacts and potential impacts which can be caused by.

Slope stability is defined as a stable condition for a geometry and slope dimensions. The stability of a slope depends on the driving force and the holding force that is on the slip plane inside the slope. The driving force is in the form of gravity, while the restraining forces are shear force, cohesion and shear strength. If the driving force is greater than the retaining force, the slope is unstable and will slide, whereas if the driving force is smaller than the holding force, the slope will stabilize. One method that adopts this principle is the Limit Equilibrium Method described as Figure 1.

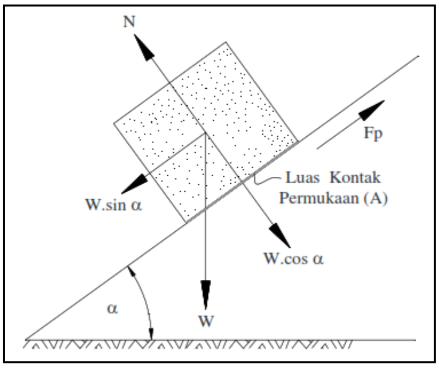


Figure 1 Mass in inclined plane

To state that a slope is stable or not, can be expressed in factor of safety (FS) which is defined as follows:

$$FS = \frac{Resisting\ force}{Driving\ force}$$

Info:

FS > 1.0 = stable

FS = 1.0 = critical

FS < 1.0 = unstable

There are several factors that influence the stability of a slope, that is:

1. Slope geometry
2. Material characteristics
3. Depth of fracture
4. Groundwater level
5. Seismic load (blasing and/or earthquake)

If a small set of elements forms a larger mass, then the stability of the mass can be analyzed based on the limit equilibrium method. Slope stability analysis using limit equilibrium method only uses static equilibrium conditions and ignores the stress-strain relationship in the slope and the slip surface must be known or determined in advance.

FS in the limit equilibrium method is calculated using the equilibrium force or moment equilibrium, or using both equilibrium conditions depending on the calculation method used. A detailed description of this method can be seen in Hoek et al (1981), Franklin et al (1989), Abramsom et al (2002), Wyllie et al (2005).

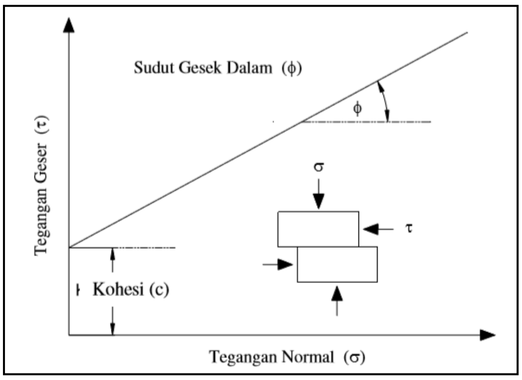


Figure 2 Relationship between shear strength and normal stress

Relationship between shear strength (τ) dan normal stress (σ) expressed by the following equation:

$$\tau = c + (\sigma_n - u).\tan\phi$$

The shear stress needed to crack and shift the rock will increase in accordance with the normal stress increase.

Shear strength is influenced by several variables such as:

1. Gravity load
2. Water pressure

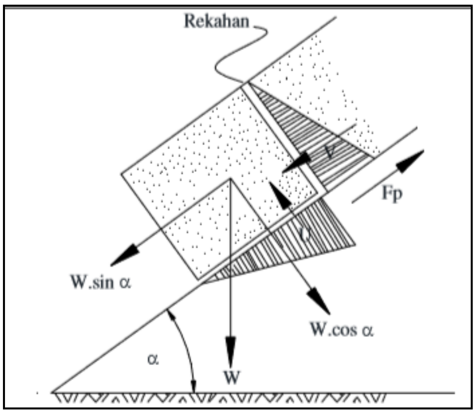


Figure 3 Effect of water pressure on tensile crack

Info:

V = the total force acting on the tensile fracture due to water pressure that increases linearly according to depth

U = total thrust force upward due to water pressure distributed on the surface of the shear plane, reducing normal force

Based on the equilibrium conditions, obtained:

$$W.\sin\alpha + V = c.A + (W.\cos\alpha - U)\tan\phi$$

1.1. External influance

If the slope had horizontal acceleration that caused by an earthquake or blasting, then the rock mass that will slide had additional driving force and a reduction of normal force in the landslide block.

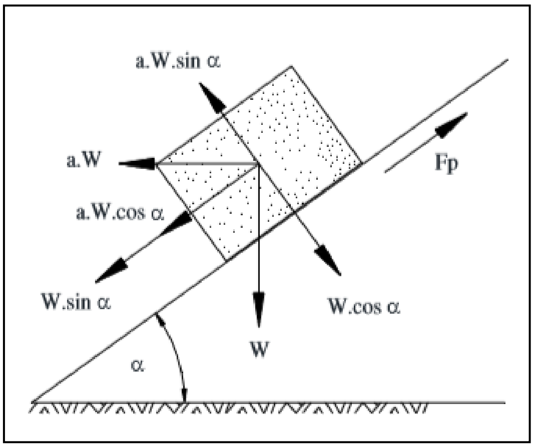


Figure 4 Influence of external acceleration on force equilibrium

$$F_{driving} = W.\sin\alpha + \text{a}.W.\cos\alpha$$

$$F_{normal} = W.\cos\alpha + \text{a}.W.\sin\alpha$$

$$F_{retaining} = c.A + (W.\cos\alpha + \text{a}.W.\sin\alpha).\tan\phi$$

Info: a is horizontal acceleration in g.

The addition of the driving force and the reduction of the retaining force on the landslide surface will be controlled by the magnitude of the horizontal acceleration and the slope of the landslide field of each horizontal plane. Newmark (1965) issued an equation for estimating critical, that is:

$$a_{kritis} = (FK_{statis} - 1).g.\sin\alpha$$

Info:

$a_{critical}$ = Critical acceleration that caused landslide

FS_{static} = Faktor of safety based on static calculation

g = Gravity acceleration (9.81 m/second^2)

α = inclined slope

1.2. Fotogrametry

In addition to the above, a study requires geo-spatial data in the context of mapping an area / region, among others can be done through methods: Terrestrial (direct measurements in the field), Photogrammetry (aerial photography), Remote Sensing, and GPS.

Photogrammetry is a method of mapping objects on the surface of the earth that uses aerial photography as a medium, which is done by Wolf recording objects and geometry measurements, 1983 for photogrammetric processing resulting in spatial data such as orthophoto images, line maps, digital model elevation maps (DEM) . UAV (Unmanned Aerial Vehicle) or in other words unmanned aircraft can be applied to present geospatial data to monitor fractures that occur on the slopes of limestone hills and monitor slope movements in Kaliwadas, Karangsambung, Central Java.

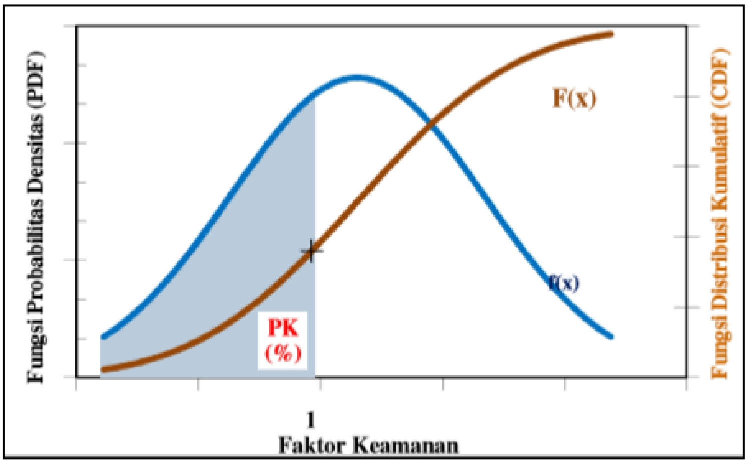
Work steps according to Lillesand and Kiefer (1994):

1. Determine the distance of a horizontal field and the magnitude of the angle based on measurements made on an upright aerial photograph
2. Determine the height of the object from the measurement of the shift in the location by the relief
3. Determine the height of the object and the height of the field by measuring parallax images
4. Use of field control points
5. Make a map in a stereo plotter
6. Make orthophoto
7. Prepare flight plans to get aerial photographs

1.3. Probability of falure

The probability distribution function describes the spread of a random variable used to estimate the probability value of the appearance of a parameter. From the data that is known, there are more than 60 types of distribution functions available today (Tse, 2009).

One well-known geotechnical program that uses boundary equilibrium methods uses 7 distribution functions namely normal, lognormal, uniform, triangular, gamma, beta, and exponential for the application of probabilistic methods. But this does not rule out the possibility that a distribution function is derived from other functions. For example, the exponential distribution function is a special form of a gamma distribution function that has a form (α) parameter of value 1. Likewise a uniform distribution function is a special form of the beta distribution function which has a form parameter value α1 = 1 and α2 = 1. The triangle distribution function is also a special form of the beta distribution function which has the form parameter values α1 = 1 and α2 = 2 (Azizi et al, 2011).



Gambar 5

Figure 5 above illustrates the probability distribution functions described as probability density functions and cumulative distribution functions. The probability density function describes the relative probability area where a random number can be assumed as a unique value compared to other values. On the safety factor distribution curve, the area of the shaded curve is the probability of slope failure (PK%). The picture also explains the concept of probability of slope and the amount of uncertainty. Slope PK is determined from the ratio between the area under the curve from the distribution of FK values <1 to the distribution of FK values ≥ 1. The greater the FK distribution range, the higher the uncertainty of the FK value with the same PK value.

1.4. Consequences Analysis

In an effort to assess the probability of fatality, it is necessary to compare with the "benchmark" criteria presented in Figure II.8. The dashed line is a risk constant line. One of the ways in analyzing the impact of slope failure can be done by utilizing slope movement monitoring data. Visual observation was also conducted to confirm the movement of the slope. Eventually the time and radius (including volume) of avalanches can be predicted, allowing preventive measures to be taken to minimize the impact of fatalities and economic losses.

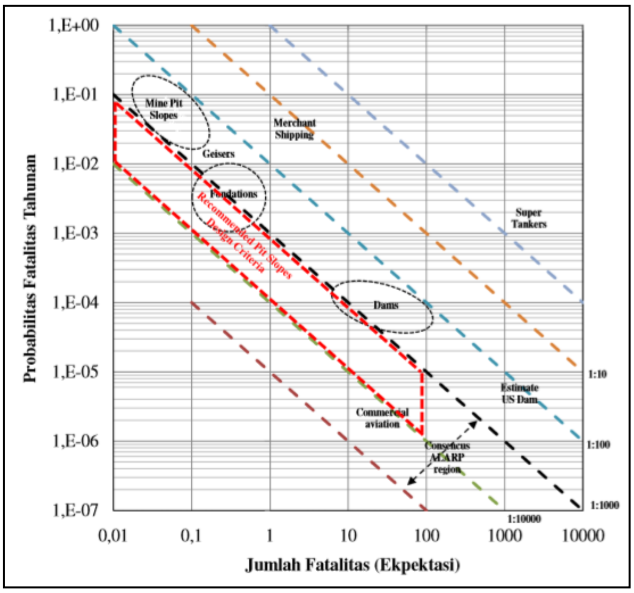


Figure 6 Benchmark criteria for safety impacts (Modifikasi Terbrugge dkk, 2006)

1.5. Risk Analysis

Risk analysis is a systematic activity by using existing information both primary and secondary data to identify the extent of the consequences and the level of probability (Likelihood) of an event that arises. The basis of risk analysis is to estimate the combination of the level of consequences and the degree of frequency of the risks that arise. Assessment of risk levels can be determined mathematically using the following calculations:

$$\text{Risk} = PK \times DK$$

Where:

PK = likelihood

DK = consequances

1.6. Risk Evaluation

Risk evaluation is a decision-making process on risks that are a priority and an assessment of acceptable risks or levels of risk is reduced. Risk values and analysis results are compared with certain risk level criteria or standards in accordance with the analysis standards used. If the risk is at a low level and can be accepted, periodic monitoring and review is carried out, while for the risk with a higher level, the risk mitigation stage is carried out.

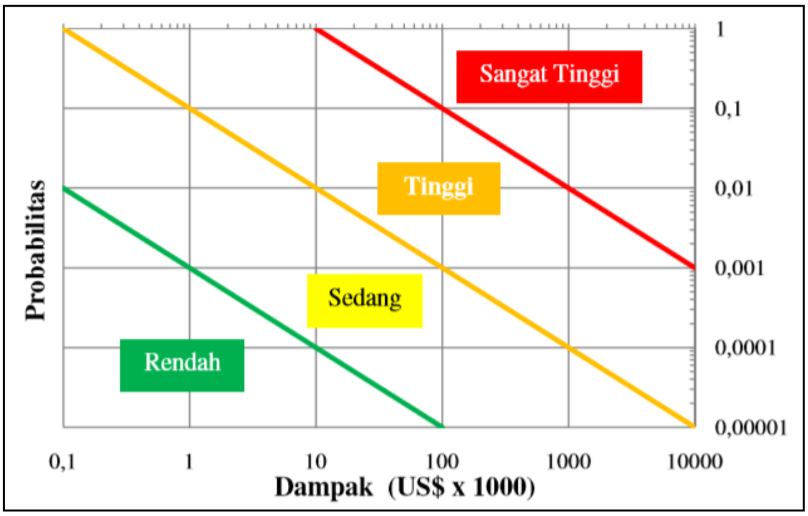


Figure 7 Example of risk (Bowden, 2008)

2. METODOLOGY

This research was carried out within the framework of 3 years of implementation in the scope of mitigating the potential for risk-based natural slope failure. There are several factors that need to be considered in relation to mitigating the potential for natural slope failure, including: material aspects, geospatial aspects, groundwater aspects, earthquake aspects, aspects of the Safety Factor calculation method, as well as aspects of the risk analysis method. This study focused on analyzing the influence of material aspects (based on physical and mechanical properties of intact rock laboratory test results), geospatial effects, groundwater levels, and earthquakes.

1. The first year, examined the effect of fracture depth and width on the stability of slope of limestone hills.
2. The second year, examines the effect of ground water level on the stability of the slopes of the Kaliwadas limestone hills.
3. The third year, examines the effect of earthquake vibrations on the stability of the slopes of the Kaliwadas limestone hills.

During the 3-year period, the study also conducted intensive monitoring of slope movements using photogrammetry methods. The monitoring period is carried out for 3 months. The results of monitoring slope movements can be used to determine the speed of slope movement.

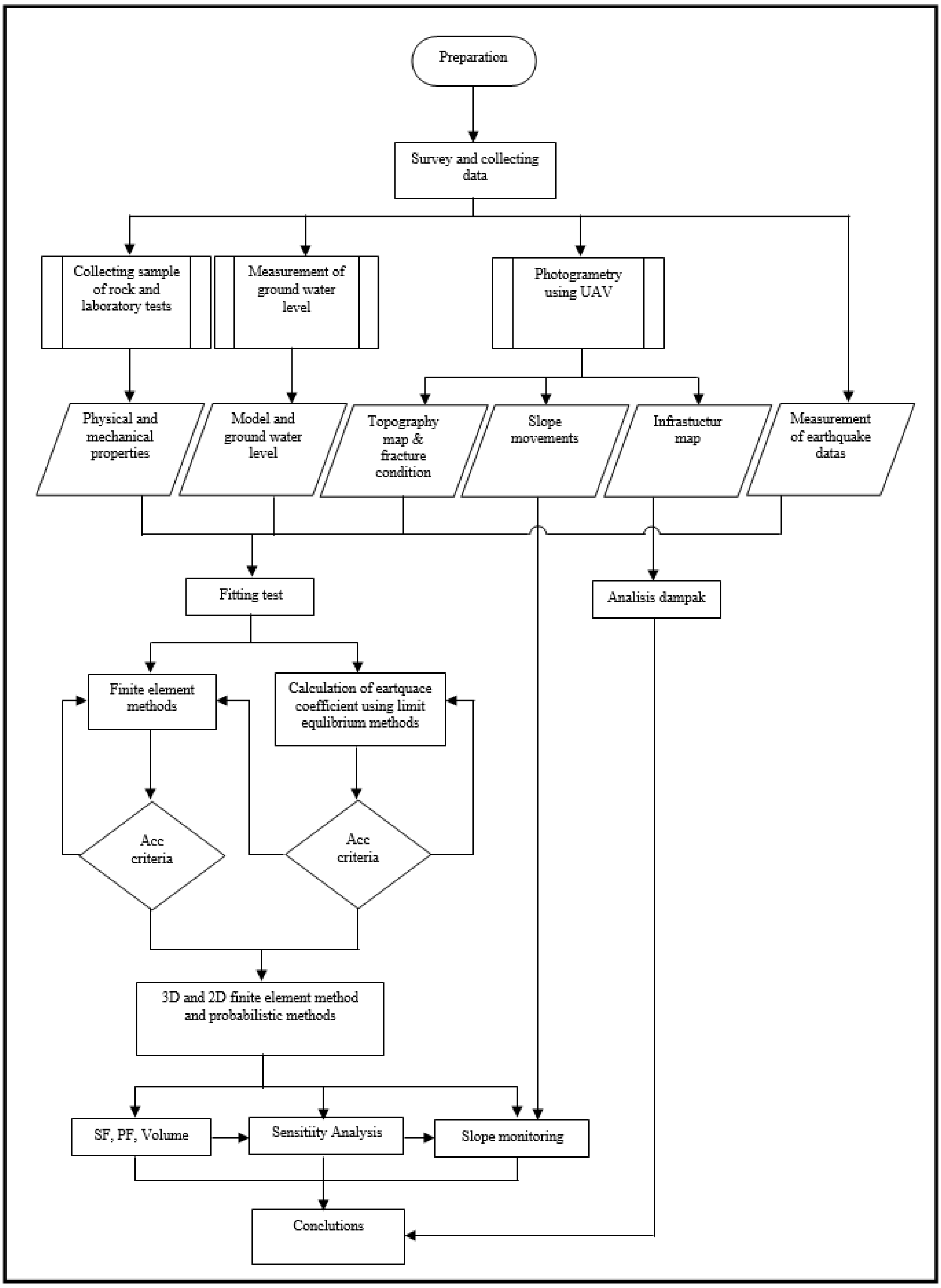


Figure 8 Flowchart of research

3. DATA AND DATA PROCESSING

3.1. Rock sampling and laboratory test

Samples are taken in the area around the slope, in a stable area, in the area of landslides, and in the clay layer exposed at the bottom of the fracture. Samples are taken in the form of rock blocks, then coring is carried out in the laboratory so that the sample is obtained in a cylindrical form. The results of sample preparation were tested for physical and mechanical properties (direct shear).

Table 1 Density testing result

Sample	BG-A	BG-B	BG-C	BG-1	BG-3	CL
Natural Density (γn)	2.1	2.07	2.03	2.02	2.08	1.65
Saturated Density (γw)	2.2	2.15	2.08	2.06	2.16	1.73
Dry Density (γo)	1.9	1.84	1.76	1.85	1.85	1.32

Table 2 Cohesion and internal friction angle from direct shear test result (stable zone)

Lithology	**Limestone (Stable)**			
Parameter	Cohesion (kPa)		Internal friction angle	
Peak/Residual	Peak	Residual	Peak	Residual
BG-A	247.74	34.8	40.79	31.93
BG-B	184.18	29	36.57	26.57
BG-C	289.88	45.414	39.95	29.83
BG-1	221.36	37.24	40	28.8
Mean	235.79	36.61	39.33	29.28

Table 3 Cohesion and internal friction angle from direct shear test result (sliding block)

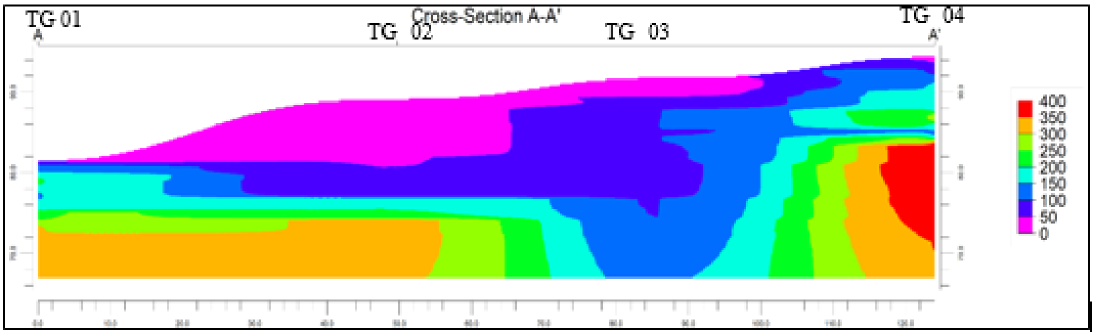
Lithology	**Limestone (Sliding block)**			
Parameter	cohesion		Internal friction angle	
Peak/Residual	Peak	Residual	Peak	Residual
BG-3	168.36	34.06	36.57	24.27
BG-4	152.6	28.85	39.21	24.26
Mean	160.48	31.46	37.89	24.27

Tabel 4 Hasil uji sifat mekanik batulempung

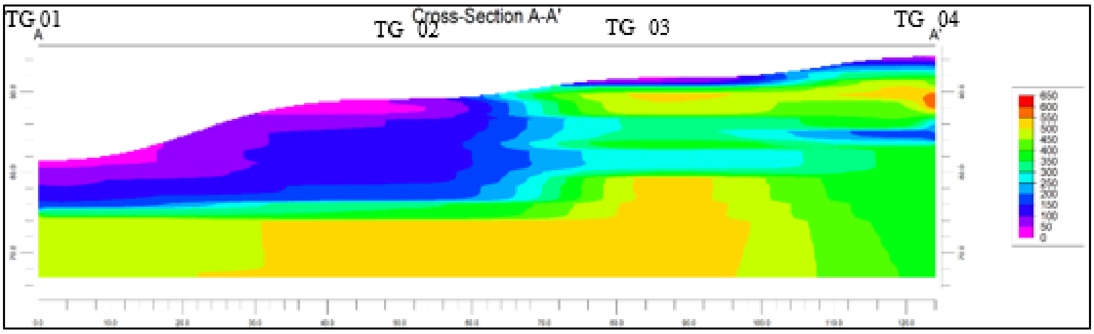
Batuan	**Batu Lempung**			
Parameter	Kohesi		Sudut Gesek Dalam	
Peak/Residual	Peak	Residual	Peak	Residual
BL-1	77.28	8.1	26.5	14.19
BL-2	47.76	6.3	25.39	12.84
Mean	62.52	7.20	25.95	13.52

3.2. Ground Water Measurement

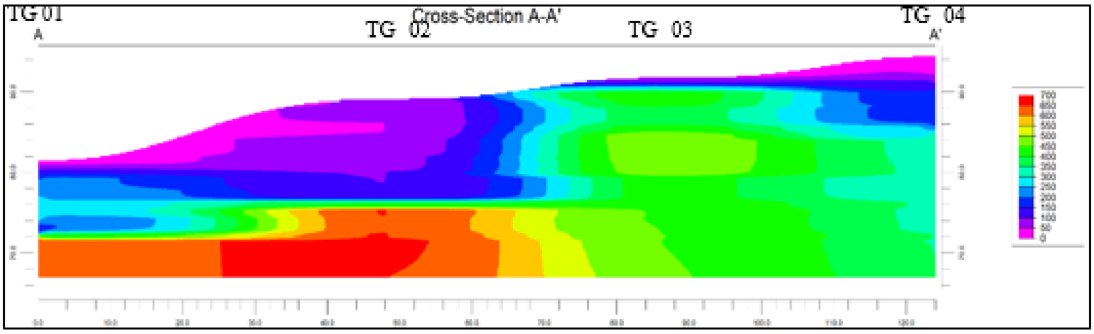
The measurement of groundwater level was carried out using a 1D geoelectric measurement of Schlumberger configuration. The use of Schlumberger method has advantages such as saving time in data acquisition, the effects of lateral variation are less due to the position of the electrode at a fixed location, and can detect non-homogeneity of the rock layer. The results of the actual resistivity interpretation on 3 measurements are as follows:



Gambar 9 Results of interpretation of resistivity in measurement 1



Gambar 10 Results of interpretation of resistivity in measurement 2



Gambar 11 Results of interpretation of resistivity in measurement 3

The results of resistivity data interpretation based on the color scheme, and recapitulation of groundwater level values based on the resistivity section can be seen in the table below:

Table 5 Nilai resistivitas

Nilai Resistivitas (ωm)	Keterangan
0 – 50	Lempung pasiran
50 – 100	Napal
100 – 150	Pasir lempungan
150 – 200	Pasir
200 – 250	Pasir gampingan
250 – 300	Gamping pasiran
300 – 450	Kalsilutit
350 – 600	Gamping

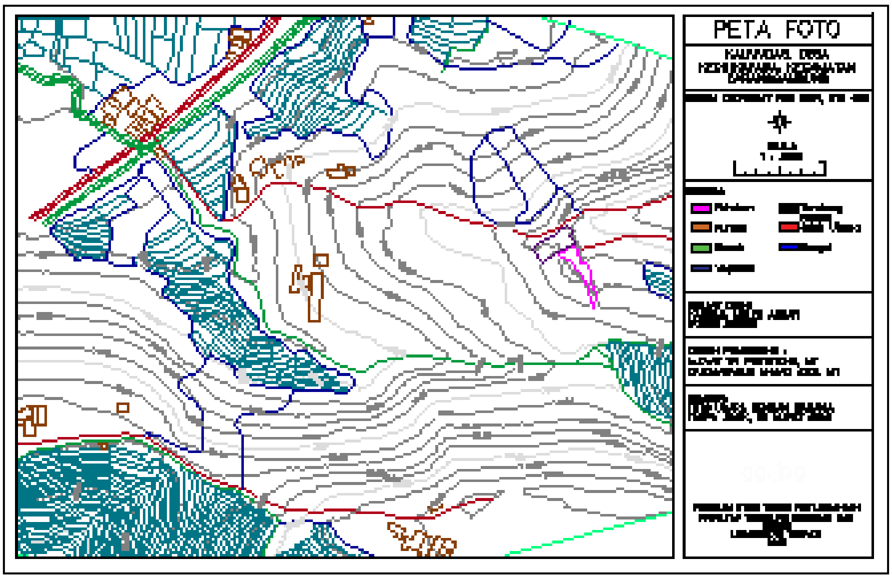
Table 6 Hasil pengukuran ketinggian air

Nilai	Pengukuran 1	Pengukuran 2	Pengukuran 3
Elevasi max	75	82.2	77
Elevasi min	72.2	80	74
Rata-rata	73.6	81.1	75.5

3.3. Photogrammetry

Making topographic maps through photogrammetric measurements using drones. Aerial photography results are processed using Agisoft software to combine aerial photography. Aerial photos already have coordinates. To get more accurate measurement coordinates, when processing aerial photos in agisoft, GCP (*ground control point)* coordinate data is entered which is obtained from measurements with Geodetic GPS with accuracy levels up to 5-10mm.

The results of this aerial photo processing are primary products in the form of *digital elevation model* (DEM), ortho image (orthomosaic) and extracted (vector) features. By using AUTOCAD Civil 3D DEM and Orthomosaic data topographic,maps are created and then obtained infrastructure maps.



Gambar 12 Topographic maps and infrastructure

To find out the movement of the area after landslide, the determination of the area that is still moving is done first. In this area will be paired in the form of a red tape spread in the form of the symbol "X". This benchmark must be in an open area so that it can be photographed using a drone.

Photogrammetric measurements are three time periods, namely January 16 2018, April 1 2018 and June 30 2018. The amount of movement in one year is 1.78 m / year.

3.4. Earthquake

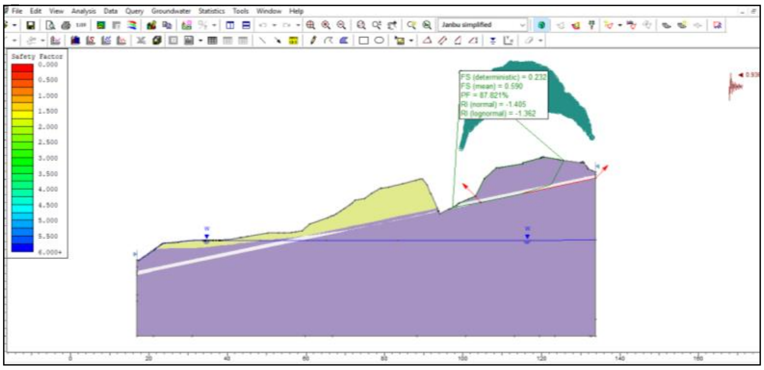
Source of earthquake data in the form of epicenter location, earthquake magnitude, and depth was obtained from the Meteorology, Climatology and Geophysics Agency (BMKG) with the last 10 years, namely on 27 November 2008 - 26 October 2017 and with earthquake strength more than ≥2 Richer Scale. A total of 333 earthquake data were detected around the scope of the study area over the past 10 years.

Table 7 Earthquake coefficient results with fitting test

Distribution Type	Eksponential
Mean	0,936
Varians	0,877
Standar Deviasi	0,936
KV	1,00

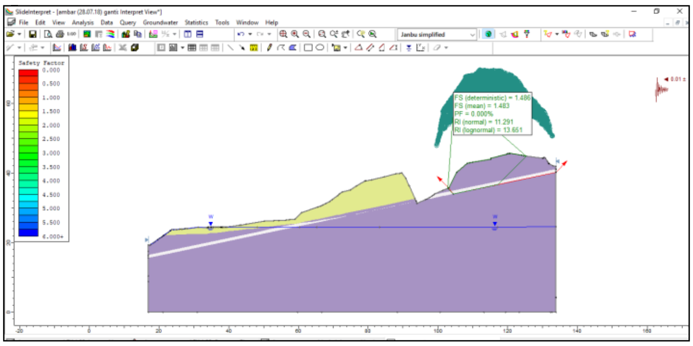
Theoretically, exponential distribution is used to determine the occurrence of an earthquake. Slope stability analysis was carried out to determine the value of the safety factor on the slope. Parameters used in calculating slope stability factors are physical properties of rocks (weight of rock content) and mechanical properties of rocks (cohesion and deep shear angle), earthquake coefficient values, and groundwater level values using Simplified Janbu and Probabilistic methods. The slope conditions of the Kaliwadas limestone hills after landslides have resulted in slope conditions being divided into two parts, namely: the area of the slope is still stable and the area of the slope hanging after the landslide.

The following is the determination of slope safety factors on slope landslide conditions using slide 6.0 software:



Gambar 13 FK and PK results on the slope area that are still stable

The results of the calculation of the Security Factor value in software slide 6.0 by using the Simplified Janbu method of 0.590 and the potential slide of 87.821%. These results did not present the field conditions because the slope conditions in the field were still in a stable condition, so an earthquake coefficient reduction scheme with Slide 6.0 software was carried out, until an earthquake coefficient was included in the range of earthquake zoning maps in the study area with an earthquake acceleration of 0.05 g - 0.1 g, referring to the criteria of the Ministry of Public Works with a medium risk level.



Gambar 14 FK and PK in areas that are still stable after conducting an earthquake coefficient reduction scheme

Safety factor (FK) and earthquake coefficient are inversely proportional. The greater the value of the earthquake coefficient, the smaller the value of the security factor (FK), so that if the slope gets an additional burden, the seismic load will reduce the value of the safety factor. The type of earthquake data distribution is an exponential distribution. From the results of sensitivity analysis without including an earthquake factor of 0.5178, allow the earthquake factor to be equal to 0.01, the safety factor value is 0.505. Earthquake factors have no effect on slope stability in limestone hills in Kaliwadas.

3.5. Back analysis using three-dimensional slope stability analysis

Slope stability analysis using finite element method has been widely used, one of which is due to the ability to analyze displacement on slopes. The results of the initial analysis using the RS3 program, the resulting safety factor is 1.95 and the displacement location is still not in accordance with the actual slope movement.

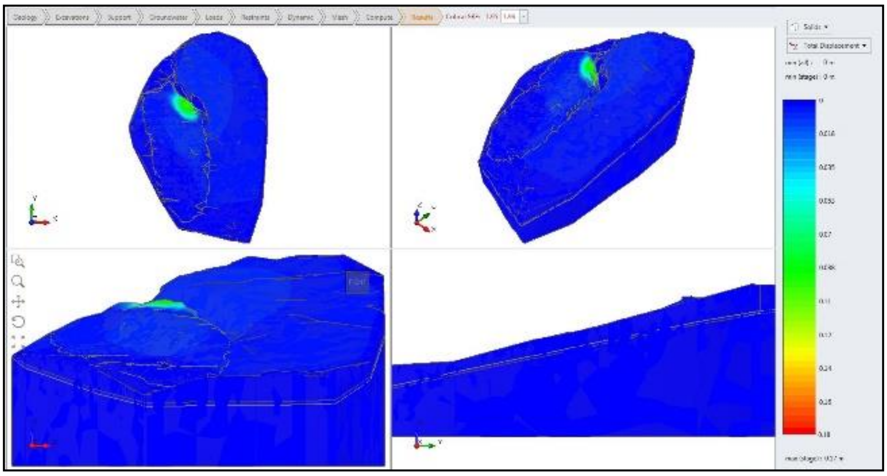


Figure 15 Displacement interpretation on the slope with intact rock properties

The clay layer as a slip surface has a large effect, as well as the impact of rainfall which causes the clay layer to become slippery and weaker become the assumption for decreasing the strength of the clay layer. The decrease in the strength of the clay layer also refers to the criteria for natural slope stability from dirjen PU No. 38 / KPTS / 1987.

Table 17 Criteria for the stability of natural slopes from dirjen PU No. 38 / KPTS / 1987

Risk	Load condition	Shear strength parameter			
		Peak		Residual	
		accurate	inaccurate	accurate	inaccurate
High	With earthquake	1.50	1.75	1.35	1.50
	Without earthquake	1.80	2.00	1.60	1.80
Intermediate	With earthquake	1.30	1.60	1.20	1.40
	Without earthquake	1.50	1.80	1.35	1.50
low	With earthquake	1.10	1.25	1.00	1.10
	Without earthquake	1.25	1.40	1.10	1.20

Interpretation results from the simulation after back analysis can describe the condition of field displacement with a safety factor value of 1.39 and peak cohesion properties and clay residuals of 22.49 and 2.59 kPa and friction angle in peak and the residual is 5.19^o and 2,704^o.

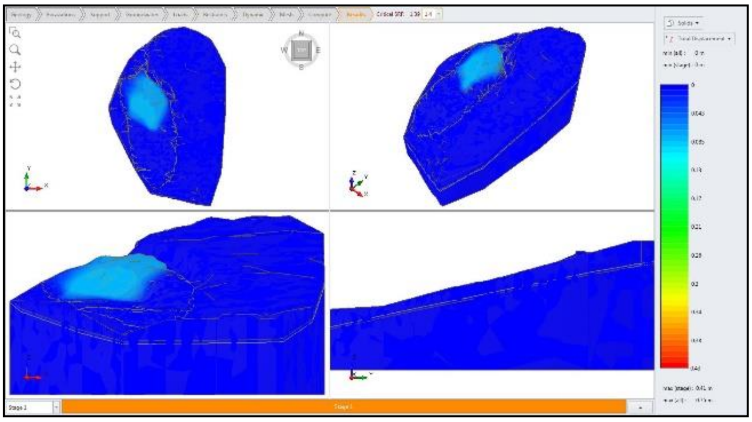


Figure 16 Interpretation result from slope stability simulation after back analysis

3.6. Limit Equilibrium Method 2D dan 3D

Slope stability analysis using limit equilibrium method with Rocscience Slide3 software to determine slope geometry in three dimensions. In this case using the working principle of Particle Swarm Optimatizion (PSO) with a security factor of 1.229.

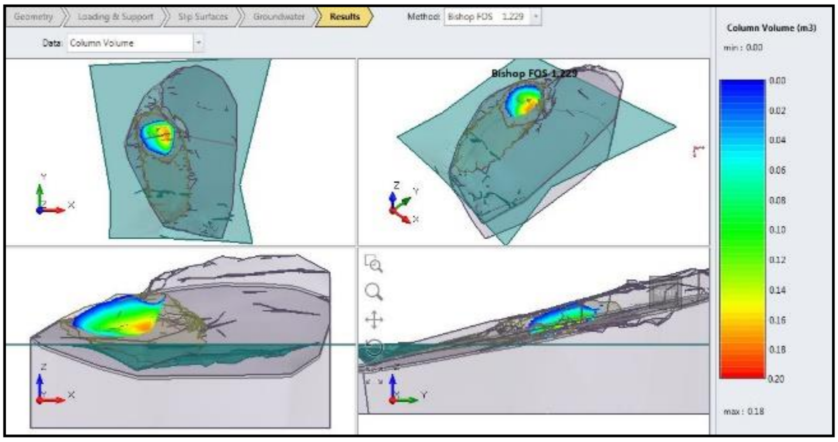


Figure 17 Slope geometry modeling software slide 3

Parameters used in this study by changing the number of particles 15 and Maximum column x or y axis.

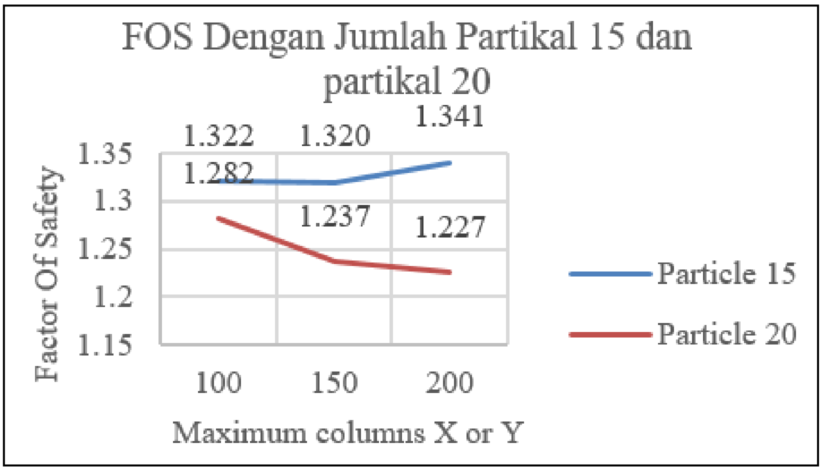


Figure 18 FOS with the number of particles 15 and 20

The number of particles 20 with the maximum number of columns 200 has lower safety factor results. This is because the number of particles inputted in the PSO application is higher. In the application of PSO the greater the number of particles, the lower the value of the Security Factor. But the amount of particles is too large will also make the calculation not optimal, therefore the optimal number of particles is from 20 to 30.

Table 8 Volume and Weight Landslide

Maksimum X or Y	Volume	Weight
100	2556,37	51056,1
150	2687,11	53572,77
200	2689,66	53622,29

After a three-dimensional slope stability analysis, a probabilistic approach is carried out with two-dimensional analysis.

Table 9 Material input parameters after back analysis

Material Name	Bulk Density (kN/m^3)	Cohesian (residual)	Phi (residual)
Limestone	20.3	36.61	29.28
limestone Landslide	20.3	31.46	24.27
Clay	16.17	7.20	11.52
Bottom Clay	16.17	2.59	2.704

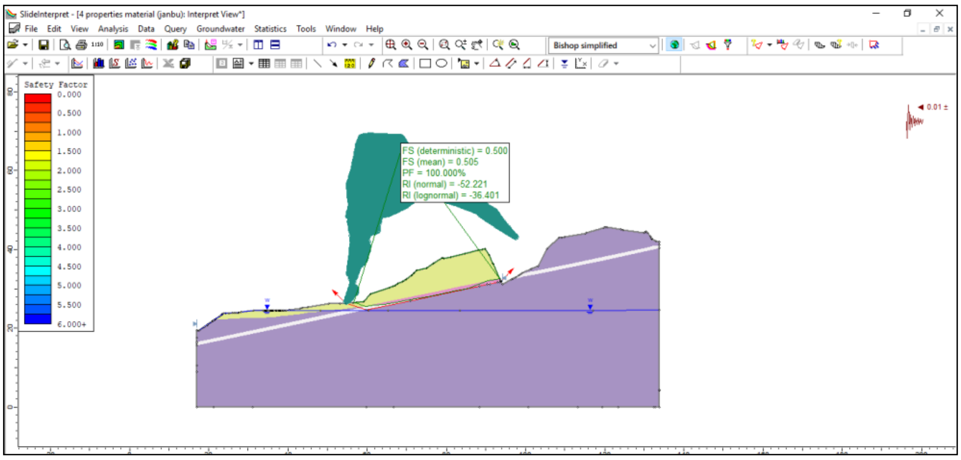


Figure 19 Model 2D

The results of the calculation of the Security Factor value in slide 6.0 software using the Simplified Janbu method of 0.505 with a potential slide of 100%.

3.7. Analysis the impact of slope failure

Slope failure have impacts and potential impacts that may occur. This slope failure has an impact on:

3.7.1. Infrastructure

Access the road was cut off and caused a loss of thirty four million rupiah, including in the construction of new roads by the local government. In addition, the connecting power pole also suffered damage and loss of fourteen million rupiah.

3.7.2. Environment

Potential for river water pollution, where the pH is still within the quality standard range of 7 because the limestone is alkaline, the TDS and TSS values are still below the PP standard. 82 of 2001.

3.7.3. Livelikehood

The majority of residents work as farmers, if the river closed, rice fields do not have access to irrigation and the estimated total loss is twenty-one million rupiahs.

4. CONCLUSION

From the research that has been done, the results are obtained, as follows:

1. Safety factors obtained from two dimensional analysis is 0.505 and from three dimentional analysis is 1.227.
2. The effect of earthquake factors on slope stability is very small, it seen from the results of sensitivity analysis.
3. Rock mass movement is 0.15 meters/month and can be classified as moderate movement.
4. The direction of rock mass movement in the research location towards the south, which is towards the river.
5. The impact of landslide on the research location is sixty million rupiahs and the potential impac of landslides is twenty-one million rupiahs.

ACKNOWLEDGE

Thank you to the Ministry of Research and Technology of the University, the local government of Karangsambung and LIPI Karangsambung for their cooperation in this research.

REFERENCE

[1] Abramson, L.W., Lee, T.S., Sharma, S., and Boyce, G.M., 2002, Slope Stability and Stabilization Methods, John Wiley & Sons Inc.

[2] Azizi, M.A., Kramadibrata, S., Wattimena, R.K., dan Arif, I., 2010, Aplikasi Pendekatan Probabilistik Dalam Analisis Kestabilan Lereng Tunggal Menggunakan Metode Kesetimbanan Batas; Seminar Nasional Statistik, UNDIP Semarang.

[3] Azizi, M.A., Kramadibrata, S., Wattimena, R.K., dan Sidi, I.D., 2013, Characterization of Physical & Mechanical Properties Distribution of Indonesian Coal; ISRM International Symposium, EUROCK 2013, Wroclaw, Poland.

[4] Baecher, G.B., and J.T. Christian, 2003, Reliability and statistics in geotechnical engineering. Wiley, Chichester, U.K.

[5] Duncan J.M., Navin M., and Wolff T.F., 2003, Discussion of "Probabilistic slope stability analysis for practice", Canadian Geotechnical Journal, 40: 848–850.

[6] Franklin J.A., Dusseault M.B., 1989, Rock Engineering, Revised 3rd edition, McGraw-Hill Publishing Company.

[7] Genske D.D., and Walz B., 1991, Probabilistic Assessment of the stability of rock slopes.

[8] Hoek E., Bray J., 1981, Rock Slope Engineering, Revised 3rd edition, The Istitution of Mining & Metallurgy, London.

[9] Hoek E., 1987 (edisi 1), 2000 (edisi 2), 2007 (edisi 3), Practical Rock Engineering

[10] Hoek E., Carranza C., Torres C, Corkum B., 2002, Hoek-Brown Failure Criterion-2002 Edition, Proc. NARMS-TAC Conference, Toronto, pp.267-273

[11] Kramadibrata, S., Wattimena, R.K., Sidi, I.D., Azizi, I.D., and Adriansyah, Y., 2012, Open Pit Mine Slope Stability and Uncertainty; Prosiding 7th Asian Rock Mechanics Symposium (ARMS7), South Korean.

[12] Rai, M.A., Kramadibrata., S., Wattimena, R.K., 2012, Mekanika Batuan, Penerbit ITB.

[13] Tse, Y.K., 2009, Nonlife Actuarial Models, Theory, Methods and Evaluation, Cambridge University Press.

[14] Wolf, P.R, 1983, Elements of Photogrammetry, 2nd edition, McGraw Hill Book Company, New YorkWyllie D.C., Mah C.H., 2005, Rock Slope Engineering (Civil & Mining), Revised 4th edition, Based on the 3rd edition by E Hoek and J Bray, The Istitution of Mining & Metallurgy,London