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DISPLACEMENT DISTRIBUTION MODEL OF ANDESITE ROCK MASS DUE TO BLASTING ACTIVITY USING FINITE ELEMENT METHOD

MODEL DISTRIBUSI PERPINDAHAN MASSA BATUAN ANDESIT AKIBAT AKTIVITAS PELEDAKAN MENGGUNAKAN METODE FINITE ELEMENT

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ABSTRACT

In mining operation, blasting is the most common method to disperse rocks. Blasting process does not only minimize rock fraction, but also produce less favourable energy for its surroundings. One of less favourable energies is ground vibration. The ground vibration will affect slope stability, because it will increase the driving force of the slope to collapse. Thereby, a research is needed to understand the influence of ground vibration in the slope stability. From the level of ground vibration influence on slope stability, it can be set the limit of the blasting process to keep the slope stable. Numerical method that used in this research is finite element method. One of its advantages is to accomodate time element in its calculations. Analysis results of this method are the displacements distribution model of the rock mass in static and dynamic conditions. On the track of A-A', rock mass displacement took place at the crest of 6.6 mm (static condition) to 8.5 mm (dynamic condition). Likewise, the track of B-B' line of 0.4 mm to 2.5 mm and line C-C' from 0.6 mm to 2.0 mm. The safety factor value on the floor of the lines B-B 'and C-C' in the dynamic conditions is 1.3. This value is quite prone, so it needs a treatment at the mine slope in order not endanger workers' safety, mining equipment and the surrounding buildings.

Keyword : ground vibration, blasting process, slope stability, finite element method

SARI

Pada operasi penambangan, peledakan merupakan metode yang paling sering digunakan untuk memberaikan batuan. Proses peledakan selain memperkecil fraksi batuan, juga menghasilkan energi yang kurang menguntungkan bagi lingkungan sekitar. Salah satunya adalah getaran tanah. Getaran tanah ini akan memengaruhi tingkat kestabilan lereng, karena getaran tanah tersebut akan menambah gaya pendorong lereng untuk runtuh. Oleh karena itu perlu diteliti seberapa besar pengaruh getaran tanah terhadap tingkat kestabilan lereng. Dari besarnya tingkat pengaruh getaran tanah terhadap kestabilan lereng tersebut, dapat ditentukan batasan-batasan peledakan agar lereng tersebut tetap aman. Metode numerik yang digunakan dalam penelitian ini adalah metode finite element. Metode ini digunakan karena keunggulannya dalam mengakomodasi elemen waktu di dalam perhitungannya. Hasil analisis metode ini adalah model distribusi perpindahan massa batuan pada kondisi statik dan dinamik. Pada lintasan A-A' terjadi perpindahan massa batuan pada crest dari 6,6 mm (kondisi statik) menjadi 8,5 mm (kondisi dinamik). Demikian juga pada lintasan B-B', dari 0,4 mm menjadi 2,5 mm dan lintasan C-C' dari 0,6 mm menjadi 2,0 mm. Nilai faktor keamanan lantai pada lintasan B-B' dan C-C' pada kondisi dinamik sebesar 1,3. Nilai ini cukup rawan, sehingga perlu perlakuan pada lereng tambang agar tidak membahayakan keselamatan pekerja, peralatan tambang dan bangunan sekitarnya.

Kata kunci: getaran tanah, proses peledakan, kestabilan lereng, metode finite element

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INTRODUCTION

Demolition activities of andesite are usually carried out by using open pit methods and generally its mining is conducted in the quarry by drilling and blasting as implemented by many mining engineers around the world (Bouzakis et al., 2009; Lu et al., 2011; Jiang and Zhou, 2012; Yilmas and Unlu, 2013; Zhu et al., 2013; Fakhimi and Lanari, 2014; Singh et al., 2014; Yu et al., 2014). The purpose of blasting is to produce rock fragmentation in accordance with the specifications of the stone crusher used to meet the desired production targets in order that front can be easily reached and passed by the heavy equipment for removing rock fragmentation, with keeping it from slope instability/lanslide, especially as the blasting of ground vibration caused (Nateghi, 2011; Faramarzi et al., 2014; Wang et al., 2015; Tripathy and Shirke, 2015).

The effects caused by blasting activities are ground vibration, flying rock, and air blast as well as noise (Dowding, 1985; Shi and Chen, 2011; Ghasemi et al., 2012; Yuanjuan, 2014; Yan et al., 2015). Ground vibration can affect slope stability, therefore, it is necessary to study the influence of blasting vibration on slope stability levels, so that the vibration caused is still in safe condition for the continuation of mining activities (Choi et al., 2013; Faramarzi et al., 2013; Azizabadi et al., 2014).

As a common benckmark used in estimating the effect of blasting vibration on mining activities is Peak Particle Velocity (PPV), the frequency of vibration, and Scale Distance (SD).

GEOLOGICAL SETTING

Administratively, andesite mining PT. Gunung Padakasih is located in Giri Asih village, Batujajar District, West Bandung Regency, West Java. This location is geographically located at 6°53’45 “-6°54’09” South Latitude and 107°30’23”-107-°30’56” East Longitude. Based on the distribution of Van Bemmelen physiographic zones (1949), the study area belongs to the physiographic zones of Bandung. From the middle to north areas, it is developed Quaternary local mountain and volcanic deposits, as well as intrusive rocks, while in the south is dominated by a lacustrine Bandung that is Old Quaternary.

Regional Stratigraphy

The research location which includes two formations as volcanic and intrusive rocks in the southwestern of Regional Geological Map of Bandung (Silitonga, 2003), from young to old rocks is as follows:

- Tuffaceous breccia, lava, sandstone, conglomerate; are andesite and basalt breccia, lava, tuffaceous sandstones and conglomerates. The rock formations form irregular ridge, sometimes it is very steep and having Pliocene age.
- Andesite; in general, is augite, hypersthene hornblende porphyry, and leucocitic andesite. There are a lot of feldspar and glass in the base period.

Geological Structure

Joints patterns in this location are N75ºE/73º, N17ºE/32º and N156ºE/32º. The joints have a fairly intensive distance between one to another, it is about 1 to 4 meters. The existence of a fairly intensive joints has a potential for causing avalanches, if there is a quite disturbing vibrations of slopes conditions. It is not only fractures’s condition, but also the rock condition will become supporting factor the occurrence of the potential avalanches.

Slope Stability

In open-pit mining, slope stability design is one of the major issues and challenges in each of mining design and operation. It requires a special knowledge about the parameters or characteristics of the rocks that are often very complex and varied. It needs a practical understanding to implement the design (Wyllie et al., 2004).

Factors that affect the slopes stability in nature can be classified in broad outline as resisting (shear strength) and driving (shear stress) forces. Resisting force can be said as a force that try to keep the stable conditions on the slopes, while driving force is the opposite. Therefore, it can simply be said that when the resisting force is greater than the driving force, the slope will be stable, and while the resisting force is smaller than the driving force, the slope becomes unstable and will trigger an avalanche.

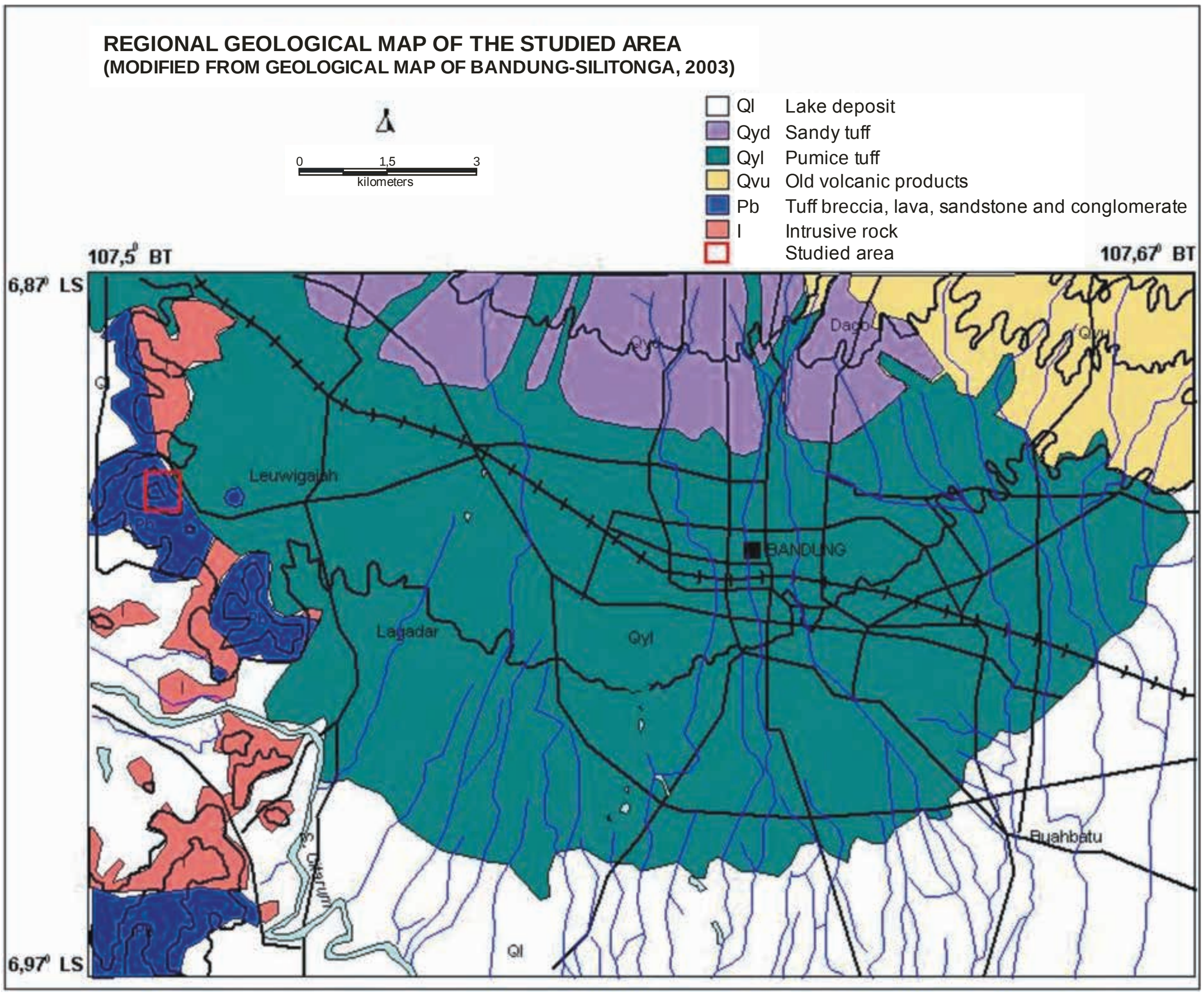

Figure 1. Regional geological map of Batujajar and its surrounding areas (P.H Silitonga, 2003)

The simple concept developed in an assessment method of slope slope stability is known as Safety Factor (SF). The safety factor is the ratio between the magnitude of the resisting force against the driving force, which is stated as follows (Hoek and Bray, 1991):

$$SF = \frac{\text{Resisting force}}{\text{Driving style}}$$

To estimate the value of ground vibrations obtained from blasting activities, it can be carried out by connecting the ground vibration measurement results with the affected blasting parameters. The blasting parameters are the distance from the blasting location and the amount of explosives that explodes simultaneously. The relationship of the parameters shown by the concept of PPV vs Scaled Distance is introduced by the US Bureau of Mines (Husni, 2008; Basuki, 2011), where the scaled distance is a factor that affects the ground vibration acquired from the interval measurement divided by the root of the load total of explosives per delay. For further information, it can be seen in the following equation:

$$PPV = k \cdot (R / \sqrt{W}) - \alpha = k \cdot (SD) -\alpha$$

where:

PPV	=	peak particle velocity (mm/s)
k, α	=	coefficient field (site factor)
R	=	distance from the location of explosion (m)
W	=	total explosives exploded simultaneously (kg)

Correlation between slope stability and ground vibration of blasting result as shown in Figure 2 can be stated that if the slopes receive the ground vibration of blasting in the a (in unit of g), then the rock mass increases driving force and reduces normal force in the landslides areas, when it is going to get avalanche. Thus, it can be stated that the horizontal acceleration leads to reduce slope stability.

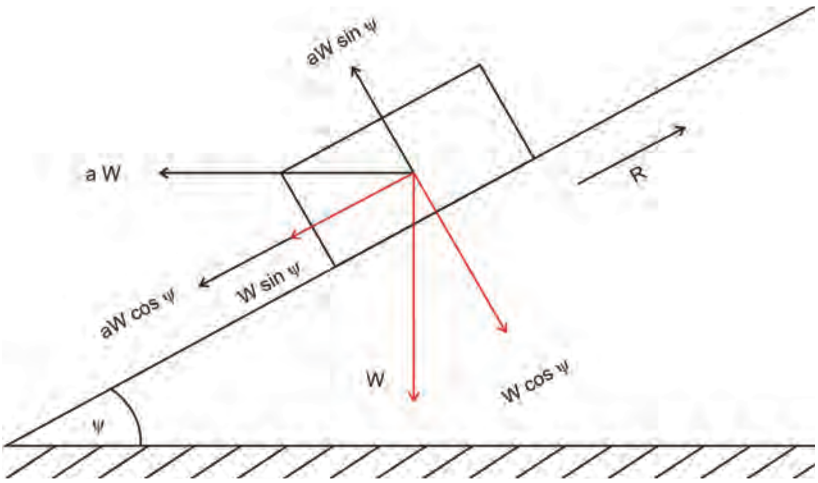

Figure 2. Effect of acceleration against force equilibrium

Terzaghi (1950) divides the causes of slopes avalanche into two things: as external and internal effects. The external effect is the impact that causes the increase of shear force with there is no changes of shear strength of its ground. While, the internal effect is the avalanches that occurs with no changes in external conditions or earthquakes.

METHODOLOGY

The method used to analyze slope stability of andesite quarry is finite element method. This method uses the distribution of small elements of a slope, thus dividing the slope into a block (rectangular, triangular) and the nodal point. This modeling considered that the rock is a continuous material, but with some finite element methods enable to calculate and analyze a variety of existing materials in the slope. The material is divided into elements with certain parameters, including the parameters of discontinuous areas.

Type of explosive used in mining operations is ANFO with a weight ratio of ammonium nitrate (94.5 wt%) and fuel oil (5.5% weight). The amount of ANFO loaded for each shot hole is average of 10 kg. Primary explosive is: Damotin Powergel 3151, with the use of any shot holes weight of 60 g. Detonators used are type of MSD (Mili Second Delay) with leg wire length of 3 m, the interval delay time between two numbers for 25 ms in sequence. Equipment used to measure vibration is Blastmate III. It is equipped by a geophone which can record blasting vibration of three (3) types of waves, namely: transverse waves, longitudinal and vertical waves.

Geometry of blasting (Figure 3) is applied, among others: burden of 2.5 m, 3 m spacing, extension subdrilling 0.8 m, stemming 1.6 m, high levels of 5.2 m and 4.4 m column stuffing. The drilling hole is made perpendicular to the front ladder with a diameter of 2.5 inches and a depth of 6 m.

The method of filling blasting material into shooting holes is carried out by means of column loading, in which a primary explosion consisting of damotin and detonator is put at the bottom of the shooting holes. Then, ammonium nitrate mixed with fuel oil in an anfo mixing is filled into the shooting holes with an amount of 10 kg per hole. The anfo is then covered with cutting powder.

The blasting pattern applied is a per line delay blasting, where the blasting is carried out simultaneously on a single line, whereas the next line, respectively, is exploded in certain interval. An explosive series used is the series-parallel method and each hole is connected to leading wire and connecting wire of the blasting machine. Before carrying out the blasting, the circuit is checked and controlled at first by blasting ohmmeter.

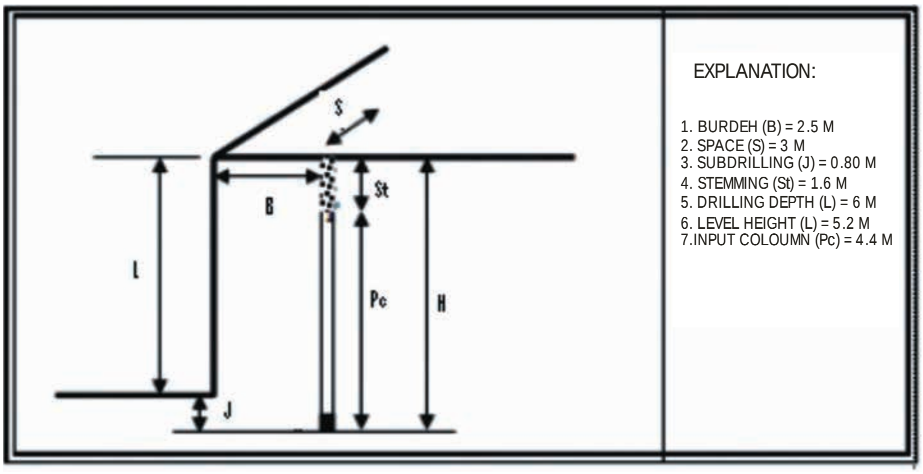

Figure 3. Blasting geometry

RESULTS AND DISCUSSION

To conduct slope stability analysis, it needs to identify the condition of slope geometry that covers height and tilt angle of slope, the rock mass strength of slope, the general orientation or directory and the general slope of the structure of discontinues areas of the rock mass of slope to the slope orientation of mine openings as well as the external load that work on the slope model, both in static and dynamic loads (vibrations).

Cross sections used are taken from the line (trajectory) A-A ‘, B-B’ and C-C ‘on the slope design as shown in Figure 4.

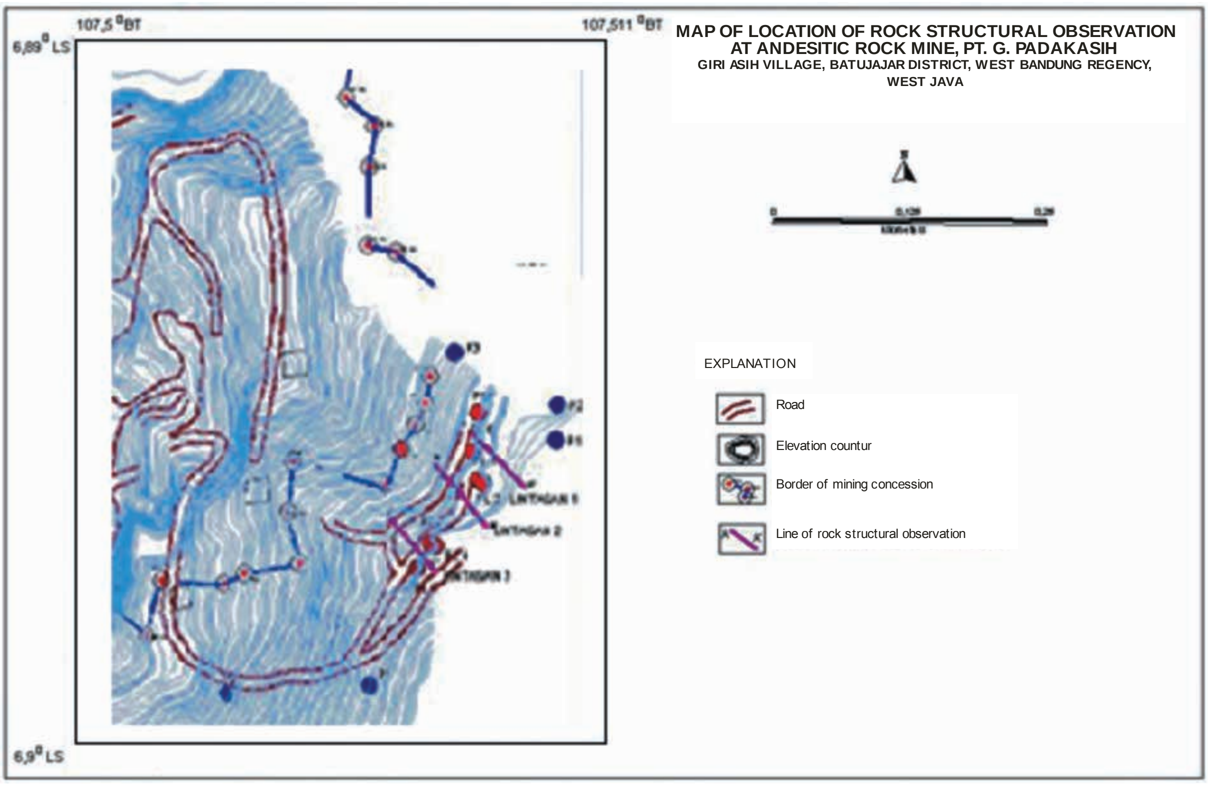

Figure 4. Map of observation and blasting location for rock structure

The following data required are the measurement of slope geometry of the mining as shown in Table 1.

Table 1. Slope Geometry of the Mining

Level Geometry	Cross Section		
	A-A'	B-B'	C-C'
Height	20 – 35 m	15 -20	40
Level slope	70 - 80º	70 - 75º	70º
Level width	15 m	15	15
Total	2	3	1

Meanwhile, the observation results of the joints can be seen in Table 2, in which the results show that there are three different sectors of research location represented by the cross-section A-A', B-B' and C-C'.

From the observation of the joints in three lines on the andesite mine area, there are obtained the main directions of discontinuous planes as follows:

Table 2. General direction of discontinuous planes at the mining

No		Cross section	Main discontinuous direction
1	N 2700 E/730	A – A'	N 2290 E/320
2	N 3290 E/630	B – B'	N 550 E/830
3	N 2850 E/430	C – C'	N 810 E/170

Blasting activity data collected are the distance from the blasting location and the amount of explosives that explode simultaneously. Explosives are considered exploding simultaneously when the blasting interval time between ≤8 ms (Lucca, 2003). The measurement results can be seen in Table 3.

From measurements of ground vibration at the mining area, it is obtained equation of Peak Particle Velocity and the Scaled Distance (Figure 5) with confidence level is 95% as shown by the equation V, namely:

$$PPV = k \cdot (SD) - \alpha = 984 \cdot (SD) - 1.66$$
$$= 984 (R/\sqrt{W}) - 1.66$$

Table 3. Measurement result of blasting vibration at the mine area (Basuki, 2011)

Type	Serial No.	No. Chan	Trigger	Tran Peak (mm/s)	Vert Peak (mm/s)	Long Peak (mm/s)	Mic Peak (dB)	PVS1 (mm/s)	Weight (Kg)	Distance (m)	Peak Acceleration (g)
W	BA8917	4	Vert	7.78	9.84	6.92	112.3L	10	31.8	71.7	0.2
W	BE10292	4	Vert	10.3	9.65	8.51	71.1A	12.4	31.8	56.2	0.3
W	BA8917	4	Vert	10.3	12.9	13.7	117.9L	17.3	31.8	72	0.3
W	BE10292	4	Vert	18	12.8	12.2	70.9A	19	31.8	55	0.4
W	BA8917	4	Vert	2.92	3.76	3.76	114.8L	4.19	42.4	131	0.07
W	BE10292	4	Vert	4.35	3.83	5.7	68.6A	5.92	42.4	113	0.1
W	BA8917	4	Vert	2.02	1.73	4.73	115.9L	4.74	42.4	131	0.09
W	BE10292	4	Vert	4.76	3.27	3.59	70.4A	5.18	42.4	113	0.1
W	BA8917	4	Vert	1.46	1.94	2.54	119.3L	2.73	42.4	160	0.02
W	BE10292	4	Vert	1.44	0.683	0.587	61.1A	1.5	42.4	331	0.02
W	BA8917	4	Vert	0.81	0.651	1.16	112.3L	1.24	42.4	257	0.02
W	BE10292	4	Vert	1.37	1.67	1.9	57.8A	2.55	42.4	187	0.06
W	BA8917	4	Vert	1.24	0.889	1.35	110.9L	1.84	42.4	255	0.02
W	BE10292	4	Vert	1.7	1.37	2.79	60A	2.9	42.4	185	0.1

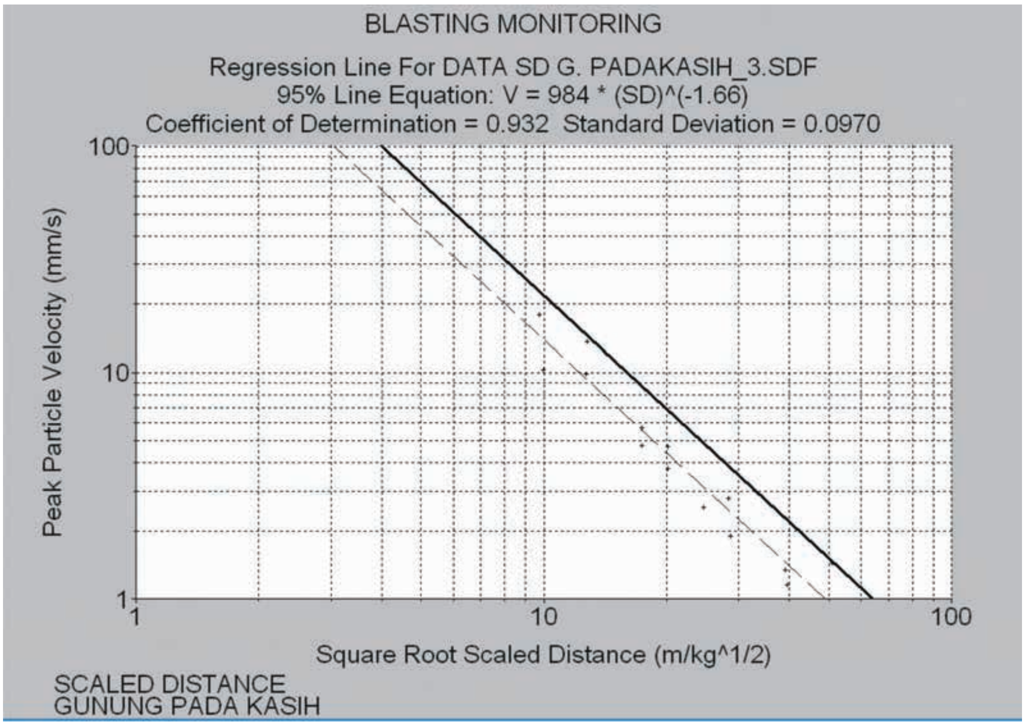

Figure 5. Graph of correlation between PPV and scaled distance (Basuki, 2011)

R is the distance from the blasting location and W is the amount of charge explosives that explode simultaneously. While the values of k = 984 and α = 1.66 are constant fields that indicate the condition of the ground vibration measurements at slopes of the andesite mine. Both constants are different for each different location. The above equation is generated from the 95% confidence level, which means that for every 100 pieces of sample data obtained are using these equations, it is only 5 data in maximum that its value of which are over the estimated value (Lucca, 2003).

In this research, modeling and slope stability analysis use numerical modeling with Finite Element Method, FEM. The advantages of using this method according to Griffiths et al. (1999) are:

1. It does not require the assumptions of determining landslide position. This area will be formed naturally at this zone where the shear strength of rock is unable to withstand shear tension that occured.
2. This method is able to monitor the development of progressive failure, including overall shear failure.

Input of geotechnical parameters (physical and mechanical characteristics) of rocks for all forming layers of rock slope model specified by the rock mass characterization as the results of geotechnical investigation and geotechnical laboratory test results, with some professional adjustments. FEM modeling input parameters as listed in Table 4.

Modeling at each research location was conducted on three observation areas, by inputting parameters of the slope geometry, the general directory of structure on the slopes, rock properties and vibration factor 0.2 to 0.4 as the effect of blasting activities.

Tabel 4. Input of geotechnic parameters for slope-former rock

Geotechnic parameters	Type of rock	
	Andesit 1	Andesit 2
1. Unit weight, MN/m^3	0.0247	0,0231
2. Module elasticity, MPa	7516	7510
3. Poisson's ratio	0.34	0.35
4. Tensile strength, MPa	0.5	0.5
5. Peak shear strength, °	40	40
6. Residual shear strength, °	35	35
7. Peak cohesion, MPa	0.75	0.7
8. Residual cohesion, MPa	0.09	0.1

Then, it was conducted a simulation process (analysis) of displacement distribution and the safety factor with the finite element method by using Phase 2.0 program at static conditions (without the vibration effect) and dynamic condition (with the vibrations effect), in this case, it is represented by the line A-A 'as shown in Figures 6 to 9.

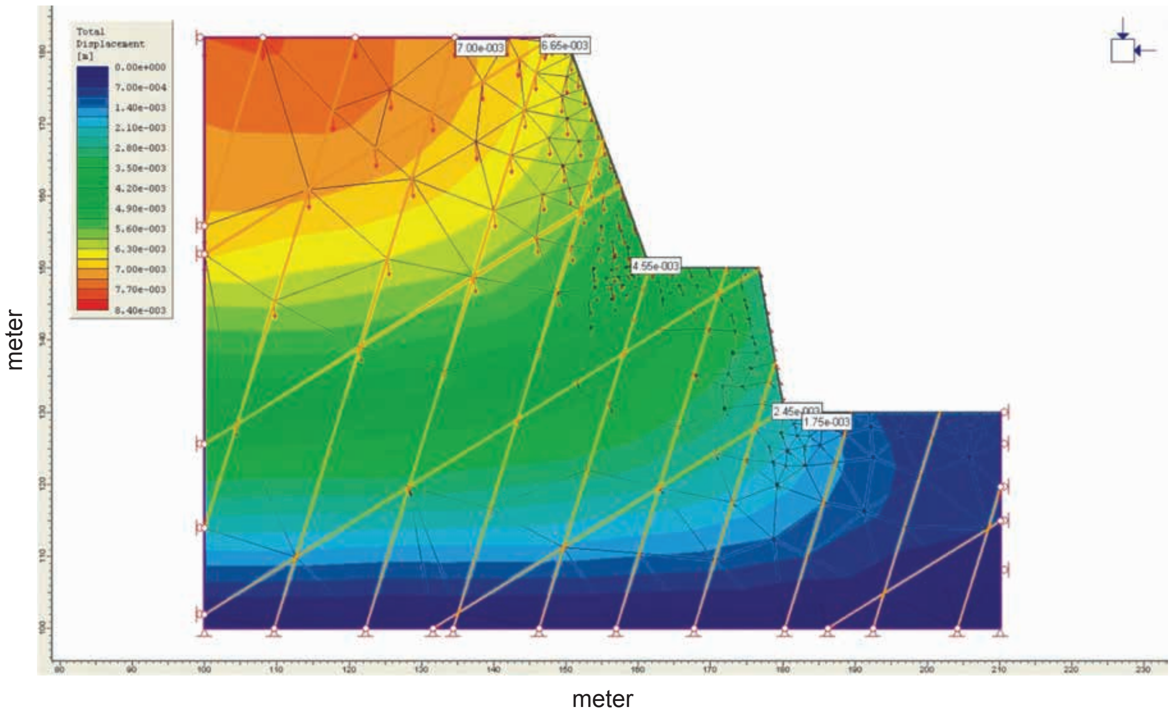

Figure 6. Simulation model of displacement distribution in static condition at line A-A'

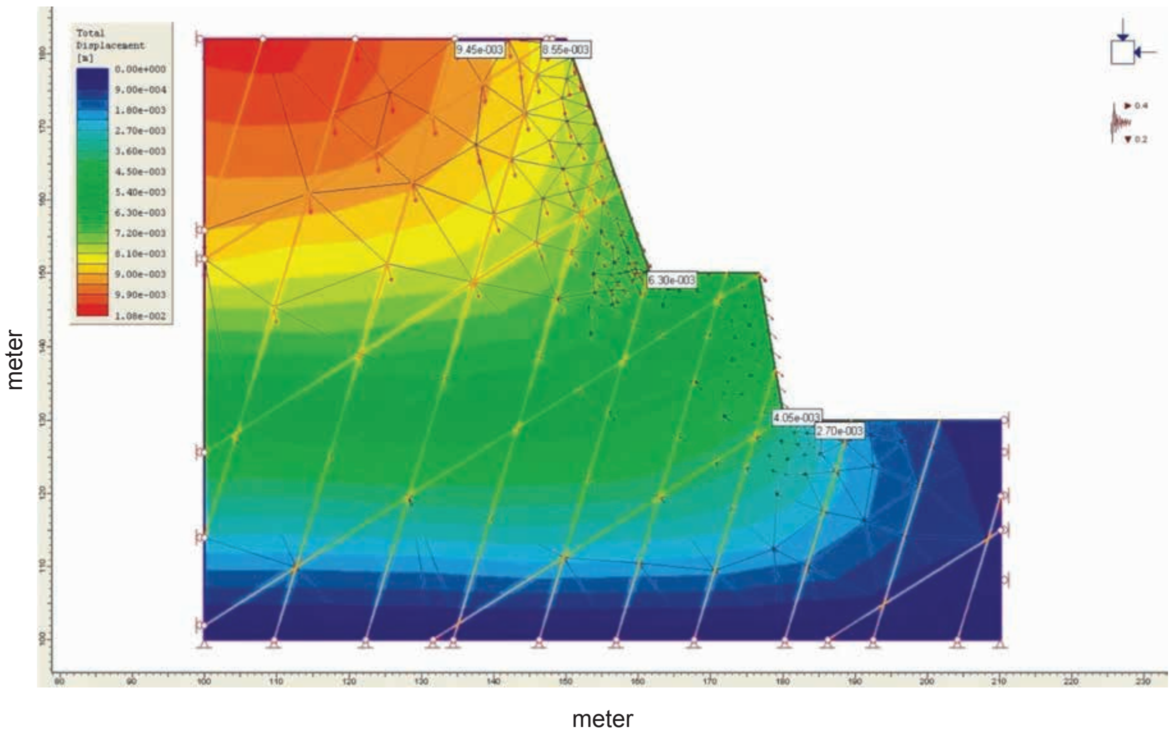

Figure 7. Simulation model of displacement distribution in static condition at line A-A'

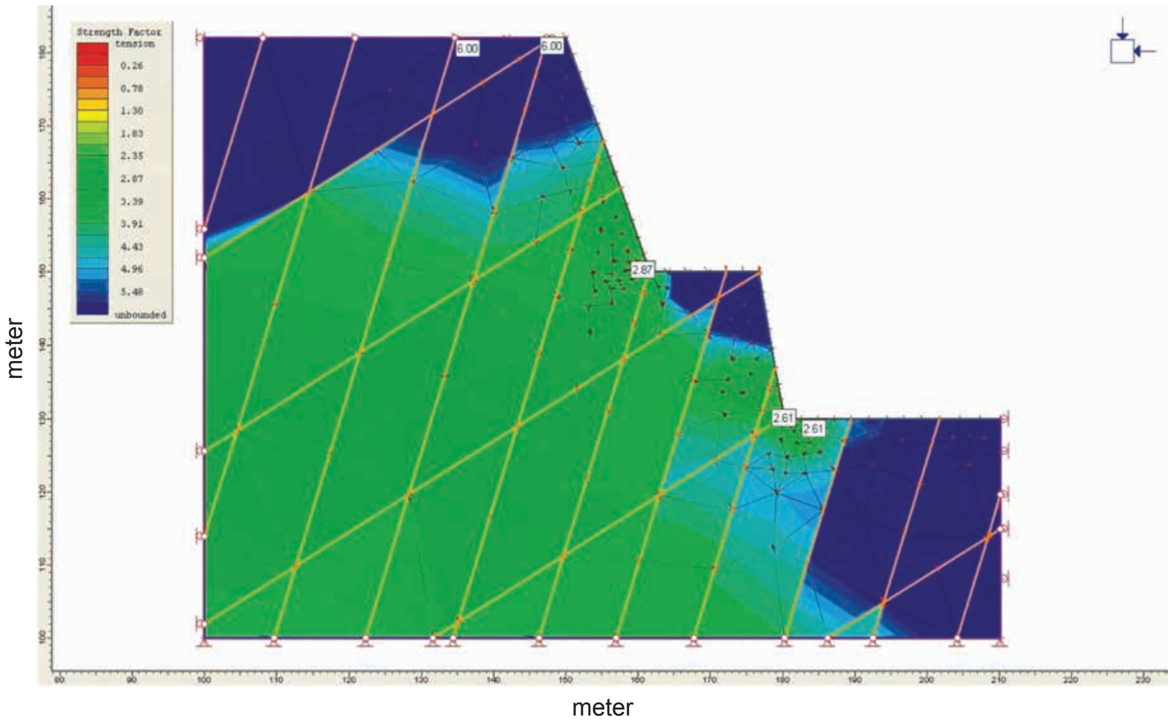

Figure 8. Simulation model of safety factor in static condition at line A-A'

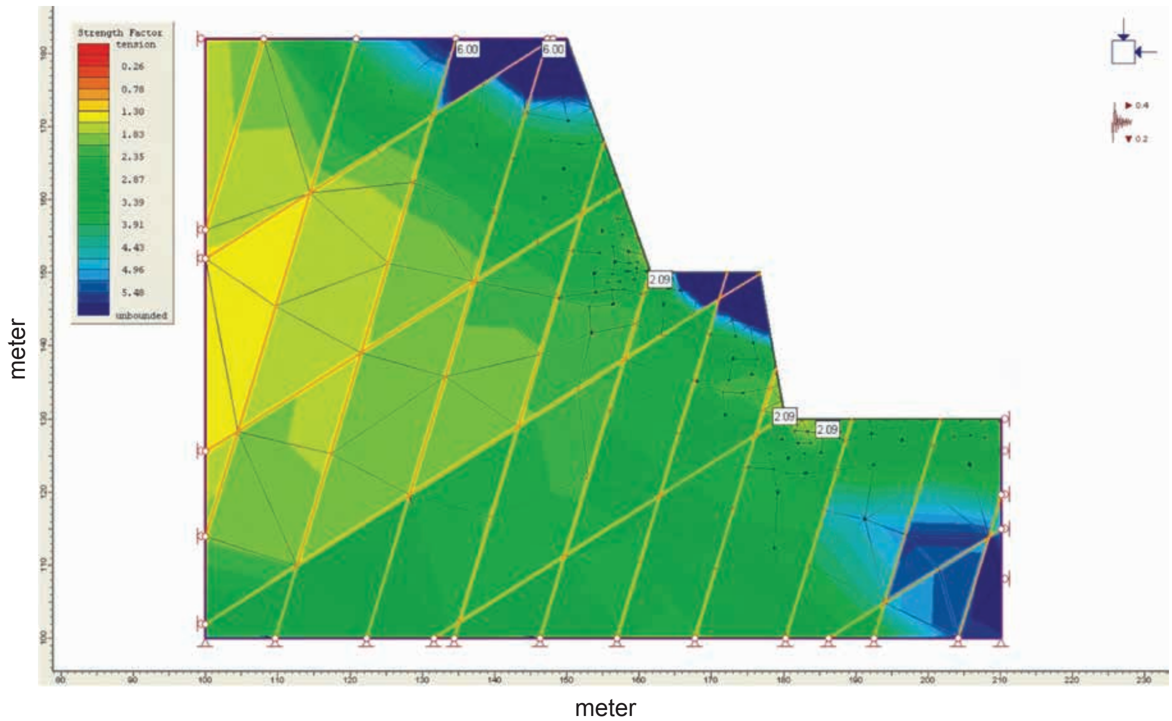

Figure 9. Simulation model of safety factor in dynamic condition at line A-A'

From the modeling (Figures 6 to 9), it is identified that there is a change of Safety Factors and displacement vector at static to dynamic conditions as the blasting effect. Displacement vector on the top of slope in the same direction with surface slope, while at the under of slope is relatively flat. Table 5 is the resume of the static and dynamic analyses at the slope of the mining area.

the closest distance of the building/ residents housing is 800 meters. The results are still below the threshold. The theshold value for the building by using standards of India (DGMS) of 5 mm/s, according to the USBM of 20 mm/s and according to SNI 7571 of 5 mm/s. Based on these results, it can be concluded that the activities carried out in the mine blasting is still relatively safe for the building.

Table 5. Resume of the static and dynamic analyses at the slope of the mining area

Lines	Static condition			Dynamic condition		
	Floor	Toe	Crest	Floor	Toe	Crest
A-A'	0.00175 m	0.00245 m	0.0066 m	0.0027 m	0.0040 m	0.0085 m
B-B'	0.0028 m	0.0028 m	0.0004 m	0.0037 m	0.004 m	0.0025 m
C-C'	0.0021 m	0.0021 m	0.0006 m	0.0026 m	0.0028 m	0.002 m

Tabel 6. Resume of the safety factor analysis at the slope of the mining area

Lines	Static condition			Dynamic condition		
	Floor	Toe	Crest	Floor	Toe	Crest
A-A'	2.61	2.61	6.0	2.09	2.09	6.0
B-B'	1.83	2.03	6.0	1.3	1.83	6.0
C-C'	1.57	2.09	6.0	1.3	1.83	6.0

From the results of the three cross-sectional slope modeling, it is resumed that in the static and dynamic conditions, it can be seen that there is the effect of blasting vibration on mine slope stability in the mining area.

In the displacement distribution, there is not found any significant displacement from the effect of vibration (dynamic conditions), and the value is not much different from the static condition. Whereas the analysis of the safety factor in the dynamic condition on the floor cross-section B-B' and C-C' has values that is quite vulnerable, namely the value of the safety factor is 1.3 and this needs to be treated at the mine slope, so that it does not endanger to the workers safety and the mining equipment as well as the surrounding buildings.

CONCLUSION

1. The large of vibrations generated in blasting at mining activities of the mining operation is about 2.73 mm/s at a distance of 160 m, while the closest distance of the building/ residents housing is 800 meters. The results are still below the threshold. The theshold value for the building by using standards of India (DGMS) of 5 mm/s, according to the USBM of 20 mm/s and according to SNI 7571 of 5 mm/s. Based on these results, it can be concluded that the activities carried out in the mine blasting is still relatively safe for the building.
2. The results of the mine slope stability analysis shows that at the line A-A', it occurred the rock mass displacement of 6.6 mm to 8.5 mm, the line of B-B' of 0.4 mm to 2.5 mm and the line of the C-C' of 0.6 mm to 2.0 mm in dynamic conditions (vibration factor of 0.2 to 0.4). These results indicate a relatively small difference, which is an average of ±2 mm. Whereas the results of the safety factor analysis of B-B' and C-C' in the dynamic conditions have the considerable values that is prone to the safety factor value of 1.3. Therefore, it is necessary to evaluate the design of the slope to reach the minimum value of a safety factor of 1.5.

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