Influence of geological condition on the parameter of blast vibration attenuation equation

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Abstract

The currently available blast vibration attenuation equations (AEs) usually only accurate for one-location database. The site specific parameters usually changes when the geological condition and blasting pattern changes. This paper is aimed to study the influence of geological condition upon the AE's parameters K and β in Adaro coal mine, Indonesia. In order to achieve the research objective, blast vibration monitor devices, i.e. BlastMate^{III}®, were set up with respect to the geological condition and rock properties. During field monitoring, the blasting was not exclusively designed but was conducted along with the normal production blasting. The blasting experiment revealed that the peak particle velocity (PPV) values were in the range of 0.32 to 67.1 mm/s for scaled distance (SD) value 296.39 to 9.82 m/√kg. The frequency corresponding to the PPV values were in the range of 1.7 to 200 Hz, with dominant frequency in the range of 1.7 to 10 Hz. The provided database consisted of 182 data pairs from which PPV and SD values were analyzed and nine different AEs were produced. The experiments suggest that the parameters K and β of AE were strongly influenced by geological condition. Hence, an integrated blast vibration prediction approaches incorporating geological parameter into prediction formulae may produce an AE more adaptable to any changes in geological condition.

INTRODUCTION

Due to the fact that mining operations become close to the community area, monitoring and controlled blasting in open pit mines have become paramount. When an explosive explodes, the blast hole releases compressive shock wave to the entire rock mass adjacent to borehole. Part of the wave energy could simply be reflected when it meets a free face of bench blasting and transformed into a compressive or tensile stress wave (Saharan et al., 2006). At that moment, those stress waves will continuously fragment the rock mass until their energies are used up, and eventually, the energies fall to levels that are less than the tensile of the rock mass. When the energy intensity diminishes to the level where no fragmented rock is obtained, i.e. beyond the fragmentation zone, the energy will be released through rock mass as seismic wave that can be felt by humans as a blast vibration. It is widely known that the amount of seismic energy that is released through the rock mass should be no more than 15% of the total explosive energy (Sanchidrian et al., 2007).

However, sometimes because of high blast vibration levels, the dwellings that are located near the mining area may be damaged. Moreover, blast vibration in certain condition may also weaken a rock mass and potentially leading to rock stability problems of pit wall. It is therefore important to note that, the accuracy of AE in predicting the blast vibration is indeed a must, and there have been many AEs proposed by different researchers, such as Duval-Fogelson (1962), Langefors-Kihlstrom (1963), Ambraseys-Hendron (1968), Gupta et al. (1988), Roy (1991), Bilgin et al. (1998), Hakan- Konuk (2008), etc.

However, many established AEs are not adequately accurate to predict PPV particularly when the parameter associated with blasting and geological condition changes. Hence, it is of the study interest to find out the influence of geological condition on the parameter of blast vibration attenuation equation.

FIELD INFORMATION

Geological Information

In attempt to pursue the goal of the study, a field study was performed for blasting operation in Tutupan coal mine of Adaro Indonesia. The Tutupan coal mine is consisted of complex seam dip (see Fig. 1). The Tutupan coal deposit comprises basically 3 coal seams, each ranging in thickness between 5 to 50 meters. The coal generally strikes in a northeast – southeast orientation, and dips to the east at between 24 to 58°. The lithology of Tutupan coal mine consist of coal, mudstone and sandstone. Low-wall (LW) of Tutupan coal mine is dominated with sandstone, meanwhile high-wall (HW) of Tutupan coal mine is mostly consisted of Mudstone. The property of coal, mudstone and sandstone is given in Table 1.

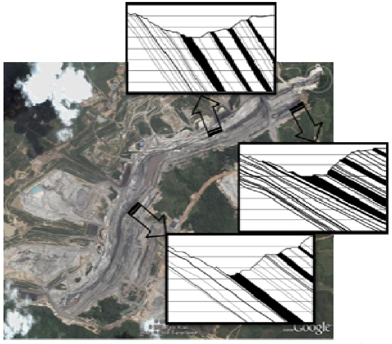

Fig. 1. Tutupan coal mine, Adaro Indonesia (source of aerial photo: Google Earth®)

Table 1. Rock properties

Mate-rial	*Properties*					
	Density	*UCS*	*c'*	*φ'*	*Young's Modulus*	*Poisson Ratio*
	kg/m³	*MPa*	*kPa*	*Degree*	*MPa*	
Coal	1300-1325	2.8	258	20.8	1708	0.33
Mud-stone	2250-2294	2.1	243	18.2	2880	0.33
Sand-stone	2050-2090	2.5	387	17.1	649	0.33

Mining Operation

The coal is being worked by open pit mining method whilst the overburden is excavated by drill and blast method. Production blast holes of 200-mm diameter are drilled in rows with the average of 7-m burden and spaced 8-m apart. Depth of blast hole is designed to have 8-m with 3-m of stemming.

For blasting operation, Ammonium Nitrate – Fuel Oil (ANFO), heavy ANFO and Titan Black with a density of 850, 1150 and 1300 kg/m^3, respectively, were used as the primary explosive. Meanwhile, a dynamite dayagel with a density of 1360 kg/m^3 was used as primer. The numbers of blast hole loaded and fired in one blasting event varied from 25 to 295 holes.

To reduce blast vibration and improve fragmentation induced by blasting, all blast holes were not exploded at the same instant of time. The delayed Non-Electric (NONEL) caps with surface delay 25, 42, 67 as well as 100 ms delay, and in hole delay 400 ms as well as 500 ms delay were used to initiate hole by hole explosive charge. The illustration of layout of blast design parameters as well as blast delay pattern is shown in Fig. 2.

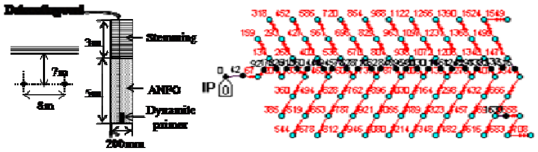

Fig. 2. Illustration of layout of blast design parameter and delay pattern

MEASUREMENT TECHNIQUE AND ANALYSIS METHOD

The blasting experiments was not exclusively designed but were conducted along with the normal production blasting, which in this case means overburden removal. To achieve the objective of this research, the 188 blast vibration data, which consist of 182 blast vibration datasets and 6 validation datasets, were collected.

In this study, while the parameters of SD, i.e. charge explosive per delay and distance, were recorded carefully, the blast vibration component was measured by means of up to three vibration monitors, BlastMate^{III}®. Moreover, the general geological information such as bedding plane and lithology were also carefully studied. By considering the location of vibration monitors which were positioned with regard to geological condition, the effect of geological condition on blast vibration propagation was expected to be elucidated. The results of blast vibration data measurements that were carried out, has been presented in Fig. 3. In the current investigation, one of the most widely AE, i.e., USBM PPV prediction model is employed. The USBM equation is given as below:

$$\mathrm{PPV}=K(R/\sqrt{W})^{-\beta} \qquad (1)$$

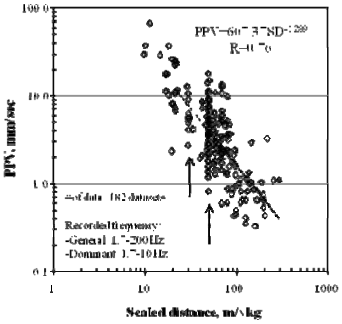

Fig. 3. Recorded database: PPV and SD on log-log curve

The experiment results indicate that, even for similar value of SD, PPV values which are recorded vary differs (see arrows in Fig. 3). It indicates that blast vibration propagation is not only influenced by amount of charge explosive per delay and distance of measurement, but also influenced by various factors such as: (a) geological condition; (b) geotechnical; and (c) other parameters that are associated with blasting. The relationship as shown in Fig. 3, i.e.,

$$\mathrm{PPV}=607.37\mathrm{SD}^{-1.289} \qquad (2)$$

reflects the individual responses due to the influenced parameters as mentioned before even if the influenced parameters are not incorporated in the relationship equation. Due to incomplete influenced parameters taken into account in deriving the Eq. 2, high error of PPV prediction may occur. It is however important to note that should those influenced parameters are neglected; the equation which is written in Eq. 2 may be scientifically unacceptable. Hence, in order to obtain accurate PPV prediction and to accomplish the interest of this study, the measurement technique and analysis method were carried out based on the geological parameter information which exist in research area.

The problem which appears in this study is how to include the geological parameter into the prediction. The solution presented in this study is based on geological condition information. Moreover, since the research area is continuously expanding due to the location of vibration monitor and the blasting area advancements, the effect of anisotropic rock material properties in and around the mine is added to the analysis. Based on seam dip characteristic (see Fig. 1), this has been accomplished by dividing the work into two areas (Fig. 4) such as: (1) Group I or Area I; Seam dip: $\leq 45^{o}$; (2) Group II or Area II: Seam dip: $>45^{o}$.

Furthermore, by regarding seam dip characteristic and property information of blasted rock material, the shots are monitored in each part along five directions (see Fig. 4), such as,

1. Directional local attenuation equation 1 (DAE_1)
   Blasted rock material: Sandstone
   Vibration monitors direction: LW to HW
2. Directional local attenuation equation 2 (DAE_2)

Blasted rock material: Sandstone
Vibration monitors direction: Lowest LW to Highest LW

3. Directional local attenuation equation 3 (DAE_3)
   Blasted rock material: Mudstone
   Vibration monitors direction: HW to LW
4. Directional local attenuation equation 4 (DAE_4)
   Blasted rock material: Mudstone
   Vibration monitors direction: Lowest HW to Highest HW
5. Directional local attenuation equation 5 (DAE_5)
   Vibration monitor is located parallel with seam strike of blasted rock material.

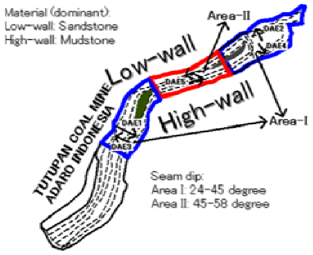

Fig. 4. Research sketch

DISCUSSION

Parameter Affecting Blast Vibration Propagation

From the Fig. 3, it is obviously that the blast vibration propagation is affected by others parameters despite of charge explosive per delay and distance. Based on condition which was stated in measurement technique and analysis method, the influence of geological condition and blasted rock material properties toward blast vibration propagation has been investigated.

In attempt to understand the effect of geological parameters toward AE, the parameter *K* and *β* of AE has to be obtained. The parameter *K* and *β* of AE_{USBM} has been determined by multiple regression analysis for each DAE. The result is given and illustrated in Table 2 and Fig. 5, respectively.

Table 2. The AE, $PPV=K(R/\sqrt{W})^{-\beta}$, to the 182 datasets which were used in the present study

	DAE	*K*	*β*	*R*
Area I	DAE_1	1464.2	1.467	0.76
	DAE_2	201.17	1.094	0.77
	DAE_3	1823.9	1.571	0.6
	DAE_4	270.14	0.952	0.66
	DAE_5	845.48	1.343	0.8
Area II	DAE_1	1256.7	1.474	0.68
	DAE_2	240.83	1.153	0.6
	DAE_4	17.819	0.317	0.49
	DAE_5	607.41	1.23	0.98

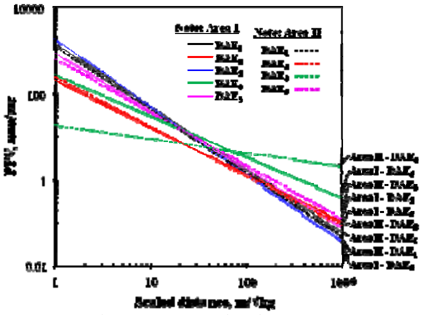

Fig. 5. DAEs on log-log paper

Moreover, in order to make clear the influence of blasting pattern and involve the geological parameter in the PPV prediction model in this study, the interrelationship of parameters *K* and *β*, as given in Table 2, was plotted as showed in Fig. 6. The interrelationship is illustrated with a linier line.

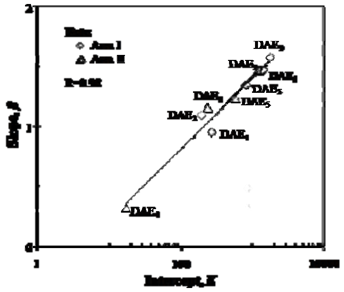

Fig. 6. Interdependence of site parameters *K* and *β*

As given and presented graphically in Table 2, and Fig. 5 and 6, respectively, the established AEs from the working area are summarized at below,

a. Parameter *K* can be physically considered to represent the strength of the blast vibration in adjacent to blasting bench, which attenuates with distance as per the slope *β* of attenuation curve (see Fig 5).
b. In general, an increase in *K* value was commonly associated with an increase in *β* value (see Table 2 and Fig. 6).
c. Due to the geological parameters, *K* and *β* value for DA_{E1}, DA_{E2}, DA_{E3}, DA_{E4} and DA_{E5} exhibit divergences each other. Therefore, the AEs must be established separately.
d. In term of trend of attenuation slope (see Fig. 5), the same needs and facts, exist in Area II as Area I except for DAE_4. It indicates that the influence of blasted rock material properties toward blast vibration propagation does not so strong. However, DAE_4 of Area I has a steeper attenuation slope than that in Area II. It may be caused seam dip which exist in Area I more ramps than that in Area II (see Fig. 1).
e. The best correlation relationship is given by DAE_5. Meanwhile the worst value is given by DAE_4 (See Table 2).
f. There is a linear line with correlation coefficient of 0.98 in the interrelationship between parameters *K* and *β*. This strong relationship indicates stronger influence of transmitting media on AE's parameters than that of blasting pattern (See Fig. 6).

Hence, based on above summarizes, the geological condition plays important role than that blasted rock material properties and blasting pattern, subsequently, the evaluation can be focused on the influence of geological parameters toward AE.

Evaluation and Validity of the result

In this last stage of this study, six validation datasets were employed to find out the response of established DAEs. In this respect, a validation process was done based on a comparison of predicted and recorded values of PPV. In this regards, an example given for DAE_1 of Area I is as follows:

Putting the value of *W*: 100.4 kg; *D*: 650 m yields a value of 64.87 for the SD, into DAE$_1$ of Area I for PPV=1461SD$^{-1.467}$ to find the predicted value of PPV$_{DAE}$=2.6 mm/sec which is 21.3% higher than the value of recorded 2.14 mm/sec. Meanwhile, the general AE for PPV=607SD$^{-1.289}$, the predicted value of PPV$_{AE}$=2.8 mm/sec which is 31.02% higher than the of recorded PPV value. Compared with general AE, DAE$_1$ gives a better result.

In the same manner, other validation data are evaluated in order to find out goodness of prediction performance of DAEs. The evaluation and validation result is given in Table 3. Generally, DAEs give better result than the general AEs.

Table 3. Comparison of AEs and goodness of prediction performance

Area I	*Blasting bench location*	*Vibration monitors location*	Area II	*Blasting bench location*	*Vibration monitors location*
	LW	HW		LW	HW
	DAE$_1$: PPV=1464SD$^{-1.467}$			DAE$_1$: PPV=1256.7SD$^{-1.474}$	
	W	100.4 kg		*W*	100 kg
	R	650 m		*R*	500 m
	SD	64.87 m/√kg		SD	50 m/√kg
	PPV$_{DAE}$	2.6 mm/s		PPV$_{DAE}$	3.94 mm/s
	PPV$_{AE}$	2.8 mm/s		PPV$_{AE}$	3.92 mm/s
	PPV$_{rec}$	2.14 mm/s		PPV$_{rec}$	2.78 mm/s
	Goodness of prediction performances: PPV$_{DAE}$: 21.3% PPV$_{AE}$: 31.01%			Goodness of prediction performances: PPV$_{DAE}$: 41.55% PPV$_{AE}$: 41.07%	
Area II	*Blasting bench location*	*Vibration monitors location*	Area I	*Blasting bench location*	*Vibration monitors location*
	LW	HW		HW	LW
	DAE$_2$: PPV=240.83SD$^{-1.153}$			DAE$_3$: PPV=1823.9SD$^{-1.571}$	
	W	100 kg		*W*	100.4 kg
	R	500 m		*R*	800 m
	SD	50 m/√kg		SD	79.84 m/√kg
	PPV$_{DAE}$	2.65 mm/s		PPV$_{DAE}$	1.87 mm/s
	PPV$_{AE}$	3.92 mm/s		PPV$_{AE}$	2.15 mm/s
	PPV$_{rec}$	2 mm/s		PPV$_{rec}$	1.17 mm/s
	Goodness of prediction performances: PPV$_{DAE}$: 32.39% PPV$_{AE}$: 96.09%			Goodness of prediction performances: PPV$_{DAE}$: -60.11% PPV$_{AE}$: -83.36%	
Area I	*Blasting bench location*	*Vibration monitors location*	Area I	*Blasting bench location*	*Vibration monitors location*
	LW	HW		LW	HW
	DAE$_4$: PPV=270.14SD$^{-0.952}$			DAE$_5$: PPV=845.48SD$^{-1.343}$	
	W	100.4 kg		*W*	47.04 kg
	R	500 m		*R*	175 m
	SD	49.9 m/√kg		SD	25.52 m/√kg
	PPV$_{DAE}$	6.53 mm/s		PPV$_{DAE}$	10.91 mm/s
	PPV$_{AE}$	3.93 mm/s		PPV$_{AE}$	9.33 mm/s
	PPV$_{rec}$	8.13 mm/s		PPV$_{rec}$	17.4 mm/s
	Goodness of prediction performances: PPV$_{DAE}$: -19.67% PPV$_{AE}$: -51.64%			Goodness of prediction performances: PPV$_{DAE}$: -37.31% PPV$_{AE}$: -46.35%	

CONCLUSION

Based on the measurements and analysis the following conclusions can be drawn:

(a) Due to the geological conditions, predicted value of PPV exhibit divergences for each other. Therefore, in PPV prediction, geological parameter has to involve to prediction model.

(b) The same needs and facts were found in Area I and Area II. Hence, the material type and properties which was blasted is not significantly influencing blast vibration propagation.

(c) Furthermore, this study also found that the transmitting media plays important role in blast vibration propagation compared with blasting pattern.

(d) By involving geological parameter into the AE, PPV prediction model become more adaptable.

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