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Prediction of ground vibration due to blasting: case study in some quarries in Vietnam

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ABSTRACT

In limestone quarries, drilling - blasting is still the most popular and effective method of breaking rocks and used widely today in Vietnam. In blasting process carried out in surface mines, a series of bad impacts on the environment are generated such as ground vibration, air blast, flying rock, dust and toxic gases. The contents of the article present the method for prediction and reduce of ground vibration in blasting at limestone quarries. Ground vibration levels experimental were analyzed by the method analysis ANOVA and the binomial probity regression model such as "Linear Model Fit" with different confidence levels from 85-99%. The methods analysis was estimated and presented the safe explosive charge or the dimensions of dangerous zones with respect to the seismic effect of the blasting at limestone quarries.

1. Introduction

1.1. Ground vibration

Ground vibrations are an integral part of the process of rock blasting. The sudden acceleration of the rock by the detonation gas pressure acting on the drill hole walls induces dynamic stresses in the surrounding rock mass. This sets up a wave motion in the ground. The wave motion spreads concentrically from the blasting site, particularly along the ground surface (Figure 1).

The ground vibrations could damage the civil structures existing near the mining sites and sometimes these could result in the collapsing of the structure. The damage level depends on factors such as type, condition and age of the structure, foundation, frequency of the vibrations, etc. The problem becomes even more with structures like religious monuments, schools, hospitals and other socially important buildings and historically important buildings that are older in age and not stable. These structures are incapable of withstanding even the minor vibrations

1.2. Influencing factors on ground vibrations

There is a number of parameters affect the propagation and intensity of ground vibrations.

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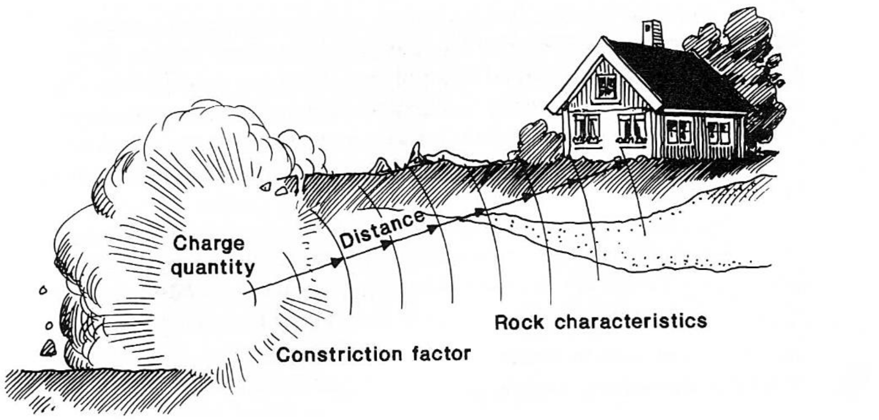


Figure 1. Ground vibration from blasting (Stig Olofsson, 1997).

Table 1. Factor witch influence ground vibration (Rosenthal & Morlock, 1987).

Variables within the control of mine operators	Influence on ground vibration		
	Significant	Moderately significant	Insignificant
Charge weight per delay	x		
Delay interval	x		
Burden and Spacing		x	
Stemming (amount)			x
Stemming (type)			x
Charge length and diameter			x
Angle of bore hole			x
Direction of initiation		x	
Chare weight per blast			x
Charge depth			x
Bare vs. Covered prim cord			x
Charge confinement	x		
Variables not in the control of mine operators			
General surface terrain			x
Type and depth of overburden	x		
Win and weather			x

They may be controllable parameters like basic dimensional factors (burden, spacing, stemming, charge length, sub-drilling, hole depth and bench height), charge weight per delay, total quantity of explosive used in a blasting round, delay timing, type of explosive, direction of blast progression, free face and air decking/decoupling or uncontrollable parameters such as geology, structural condition, rock parameters, distance of structure from the blast site, etc. Table 1 lists a series of blasting factors and their influence on ground vibration control.

The ground vibration is illustrated by the various available conventional vibration predictor equations in the different researches such as Khandelwal & Singh (2007), Dehghani (2011). There are the number of parameters which affect the propagation and intensity of ground vibrations. The equations attenuate exponentially with distance due to the large quantity of explosive and natural structures. The multiple regression analysis was determined by many blast vibration cases records at different vulnerable and strategic locations as in Table 2. Where, v is the peak particles velocity (PPV), mm/s; Q_{max} is the maximum charge per delay, kg; R is the distance between blast face to vibration monitoring point, *m*; A, B, K, α and n are the site

Table 2. Different conventional predictions.

Name of predictor equation	Equations
USBM (1959)	$v = K\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-B}$
Ambraseys Hendron (1968)	$v = K\left[\frac{R}{\sqrt[3]{Q_{max}}}\right]^{-B}$
Langefors-Kihlstrom (1963)	$v = K\left[\sqrt{\frac{Q_{max}}{R^{2/3}}}\right]^{B}$
Indian Strandard (1973)	$v = K\left[\frac{Q_{max}}{R^{2/3}}\right]^{B}$
General predictor (1964)	$v = KR^{-B}[Q_{max}]^{A}$
Ghosh-Daemen (1983)	$v = K\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-B} e^{-\alpha R}$
CMRI (1993)	$v = n + K\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-1}$

constants, which can be determined by multiple regression analysis. The different vibration predictor equations in Table 3 could not be clearly determined to form this preliminary descriptive analysis. That is the season why statistical tests have also been performed and focused on the three conventional predictions USBM (1959) and Ambraseys Hendron (1968), Khandelwal & Singh (2009).

2. Method analysis

2.1. Analysis of variance method (ANOVA)

The Analysis of Variance method (ANOVA) is a statistical technique used to test differences between two or more means (Scheffé, 1959). ANOVA is a statistical test indicating the influence of qualitative variables on a quantitative variable to be assessed. It is based on the comparison of the mean values of the quantitative variable for each category of the qualitative variable. This case, to compare and highlight the effect of the two factors taken into consideration: the statistical - peak particles velocity (PPV) from ground vibration and the maximum charge per delay due to blasting in open pit mine. After the experiment were carried out, a descriptive statistical analysis was performed to compare the ground vibration with various available conventional vibration predictor equations assessment.

2.2. Chi-square test (χ^2)

The Chi-square independence test allows the dependence between two qualitative variables to be investigated. Let $x_1,..., x_i,..., x_p$ and $y_1,..., y_j,..., y_q$ be the terms of two qualitative variables X and Y. A sample of n individuals from whom the values of the two variables were simultaneously taken yielded following results. n_{ij} is the number of individuals who presented both the x_i value of X and the y_j value of Y. $n_{.i}$ and $n_{.j}$ are respectively the total of line x_i and the total of column y_i. Under the hypothesis that variables X and Y are independent. We can also build a contingency table of the theoretical values equal to $\frac{n_{.i}.n_{.j}}{n}$ at the intersection of row i and column j. It is possible to calculate the following quantity.

$$\chi 2 = \sum_{i=1}^{p}\sum_{j=1}^{q}\frac{\left(n_{ij} - \frac{n_{.i}.n_{.j}}{n}\right)^2}{\frac{n_{.i}.n_{.j}}{n}} \qquad (1)$$

χ^2 obeys a distribution with $(p$-1$)(q$-1$)$ degrees of freedom.

The results of the vibration predictor to assess the significance of the influence of the different conventional predictions. The means of the different were analyzed using the Chi-square independence test and the analysis of variances. Finally, the means of the USBM (1959) and

Ambraseys Hendron (1968) parameters were compared to identify those that most influence the levels of ground vibration.

3. Application from the blast data sets experience

3.1. Case study and data sets

Two limestone quarries have been studied through this research. The Phong Xuan *limestone quarry* belongs to the Dong Lam Cement, it locates in the central province of Thua Thien-Hue. The Ninh Dan *limestone quarry* belongs to the Song Thao Cement. It locates in the Phu Tho province. The quarries are one of the large production cement companies of Vietnam with the output of over 2 million tons per year.

Based on the geologic conditions, properties of rock, current state of blasting operation, used equipment of the Phong Xuan and Ninh Dan limestone quarry, ground vibration has been recorded at the different locations of about 22 blasts and used for the prediction of ground vibration by the method analysis of variance and the binomial probit regression model (Table 3).

According to many researches in mining industry in Vietnam (Nhu Van Bach and et al, 2006), the firing sequence is distinguished instantaneous when the time interval between blasts Δt=0s with all charges are fired simultaneously; delayed Δt=25ms and short-delay firing when individual charges are fired with a time interval measured in milliseconds Δt=17-42ms, (Figure 2). After many different results experimental in Vietnam, the delay and millisecond delay blasting ≥20ms allows to decrease the ground vibrations. Rock fragmentation can be improved by firing with successive initiation with a time delay of parts of a divided in a hole blast.

Table 3. Details of data ground vibrations at Phong Xuan and Nind Dan limestone quarry.

N0	Maximum charge per delay	Total exploisive (kg)	Charge diameter mm	Distance (m)	PPV (mm/s)			
					Tran peak	Vert peak	Long peak	PVS
Phong Xuan limestone quarry								
1	41	1386	165	165	6.22	6.86	8.76	10.8
2	43	1818	165	210	10.4	6.22	4.32	11.5
3	43	2550	245	555	2.29	1.65	3.68	4.13
4	42	2872	230	370	9.91	7.11	17.7	18.1
5	42	3000	230	370	6.35	3.30	9.40	10.2
6	41	1620	165	153	8.00	7.87	7.11	10.5
7	42	2016	165	185	11.0	6.98	7.11	12.0
8	43	3000	245	620	3.56	2.16	3.94	5.32
9	43	3000	230	335	10.7	4.83	13.7	14.9
10	43	3000	230	345	4.06	3.81	9.27	9.29
Ninh Dan limestone quarry								
1	20	2.616	165	208	4.70	7.11	10.5	11.9
2	20	1.244	165	208	5.21	3.05	4.44	7.20
3	20	2.248	245	427	1.78	1.52	1.90	2.17
4	20	3.271	200	465	1.52	1.78	4.32	4.44
5	30	8.887	245	710	1.90	1.27	2.29	2.75
6	30	4.343	230	325	9.78	5.46	6.35	10.2
7	30	2.233	230	210	9.27	4.44	14.5	15.5
8	30	2.445	230	155	26.7	19.0	20.4	29.7
9	40	3.262	230	500	2.54	2.16	4.06	4.73
10	40	2.342	230	145	41.4	39.2	52.2	56.1
11	40	1.850	230	145	13.5	8.64	14.9	19.2
12	40	2.491	230	410	2.29	0.889	1.65	2.41
The use of non-electric blasting: time delay interval between adjacent rows with Δt = 17, 25 and 42ms; time delay respectively at bottom with in-hole delay with Δt = 400ms and 600ms.								

The time delay respectively at the bottom and top for decked charge with in-hole delay Δt=400-600ms, (Figure 2a, b). Results researched for limestone quarries in Vietnam are follows: Suitable explosives consist of ANFO (water resistant and no water-resistant types), NT-13. They can be loaded under individual and combined forms; Appropriate blasting parameters are calculated for all kinds of rocks, different drillhole diameters and bench heights, various types of explosives, different bucket capacities of excavators. The appropriate blasting parameters calculated for specific conditions at Phong Xuan and Ninh Dan limestone quarry as follows Table 4.

3.1.1. Phong Xuan quarry

From results blasting of 10 data sets experiment in Phong Xuan quarry, the prediction of peak particle velocity (PPV, mm/s) was determined by the method analysis of variance and the binomial probity regression model from empirical formula:

$$Log(PPV) = 4.4613 - 0.7833\ Log\left[\frac{R}{\sqrt{Q_{max}}}\right] \quad (2)$$

$$PPV = 10^{4.4613}.\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-0.7833} \quad (3)$$

Follow the regression model in equation (2) and (3), it was determined that the peak particles velocity PPV = ν by USBM equation with the value of K is $10^{4.4613}$ and the value of B is -0.7833.

Results of ANOVA from the binomial probit regression model from empirical formula in Phong Xuan quarry shows influence of the level of the statistical- peak particles velocity (PPV) from ground vibration and the maximum charge per delay (Q_{max}) due to blasting, Table 5.

Now the USBM equation for the Phong Xuan quarry such as:

$$v = 28926\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-\,0.7833} \quad (4)$$

Figure 4 shows the predicted and measured PPV by USBM method with the slope line and indicates correlation between measured and predicted values of PPV. The plot of the cumulative distribution function (CDF) measured PPV against CDF of PPV (a) and the plot of CDF measured PPV against CDF of PPV (b).

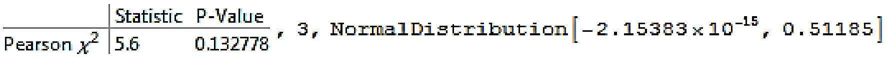
3.1.2. Ninh Dan quarry

The USBM equations $v = K\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-B}$ for PPV with plotting the graph between the square-root-scaled distance on log - log scale. The data sets represent the symbolic fitted model obtained from functions like "Linear Model Fit" in the Figure 5.

Table 4. Appropriate blasting parameters for some quarries in Vietnam.

Blasting parameters	Phong Xuan limestone quarry	Ninh Dan limestone quarry
Specific charge, kg/m^3	0.4	0.37 ÷ 0.40
Burden, m	2.9 ÷ 3.2	2.5 ÷ 2.9
Spacing, m	2.9 ÷ 3.2	2.9
Distance between rows, m	2.9 ÷ 3.2	3.2
Bench height, m	8 ÷ 10	5 ÷ 8
Subdrilling, m	0.8 ÷ 1	0.5÷0.8
Stemming, m	3 ÷ 3.5	2 ÷ 2.6
Charge length, m	5 ÷ 7.5	3 ÷ 6.5
Charge weight, kg	41 ÷ 43	20 ÷ 40
Drillhole diameter, mm	102	102

Table 5. Results of analysis variance ANOVA the blast data sets experience in Phong Xuan quarry.

Quarry	Degrees of freedom	RS quared	Estimated Variance	Sum of squares	Mean squares	Ficher-Snedecor	*p*-value
Phong Xuan	1	0.212	0.327	0.708	0.708	2.162	0.1796
Chi-square test (χ^2)	 Statistic P-Value Pearson χ^2 5.6 0.132778 , 3, NormalDistribution[-2.15383×10^{-15}, 0.51185]						

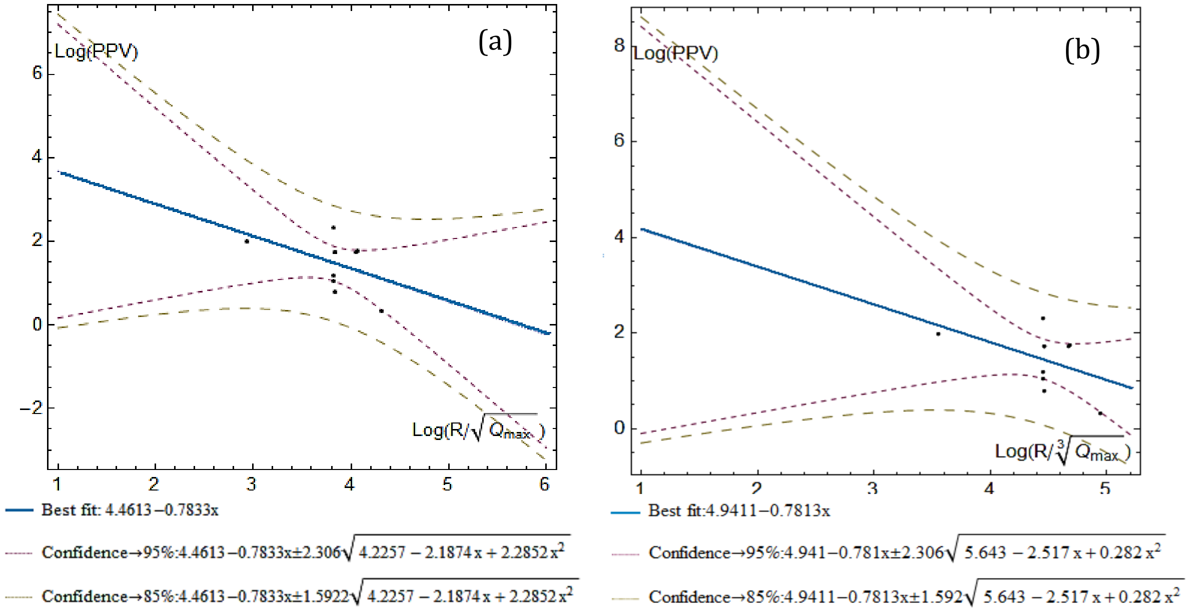


Figure 3. Plotting the graph between the square-root-scaled distance on Log-Log scale for Phong Xuan quarry with (a) USBM (1959) equation and (b) Ambraseys Hendron (1968) equations.

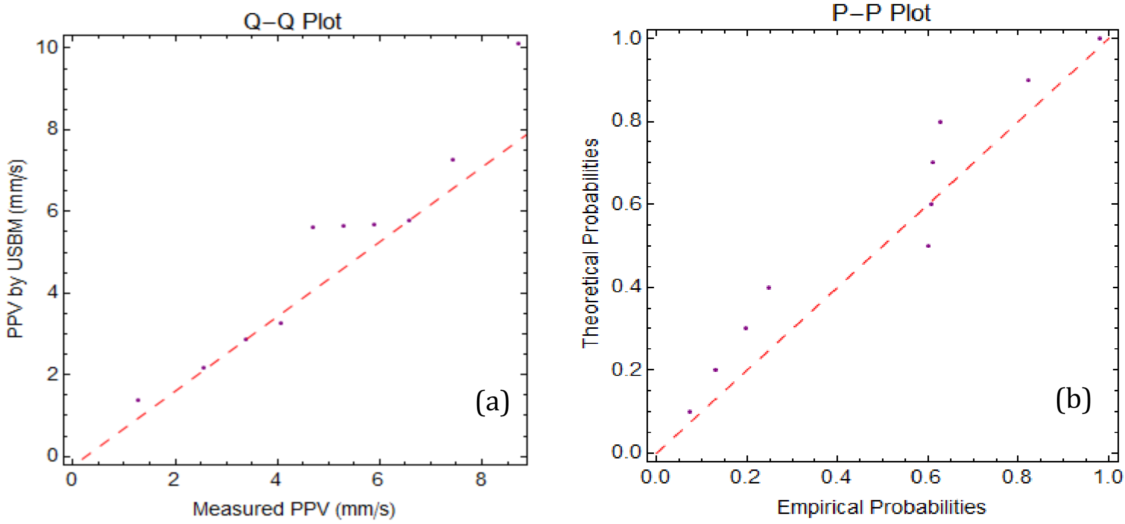


Figure 4. Measured and predicted PPV for Phong Xuan quarry by USBM equation: the plot of CDF measured PPV against CDF of PPV (a); plot of CDF measured PPV against CDF of PPV (b).

The results of ANOVA for Ninh Dan quarry show in Table 6, Figure 6. The bold values highlight the significantly influencing factors, for which the p values are lower than 1% . The value of K is $10^{7.816}$ and the value of B is -1.542. Now the USBM equation for the particular Ninh Dan site is:

$$v = 6.557\text{x}10^{7}\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-1.542} \quad (5)$$

The Ambraseys Hendron (1968) equations $v = K\left[\frac{R}{\sqrt[3]{Q_{max}}}\right]^{-B}$ for PPV is presented such as equation (6). The value of K is $10^{8.792}$ and the value of B is -1.571. Now the Ambraseys Hendron equation for the particular Ninh Dan site has the form:

$$v = 6.194\text{x}10^{8}\left[\frac{R}{\sqrt{Q_{max}}}\right]^{-1.571} \quad (6)$$

This equation has been established from PPV of 12 data sets. The Figure 4 shows the measured and predicted PPV by USBM equation. It shows the variation from the slope line and indicates

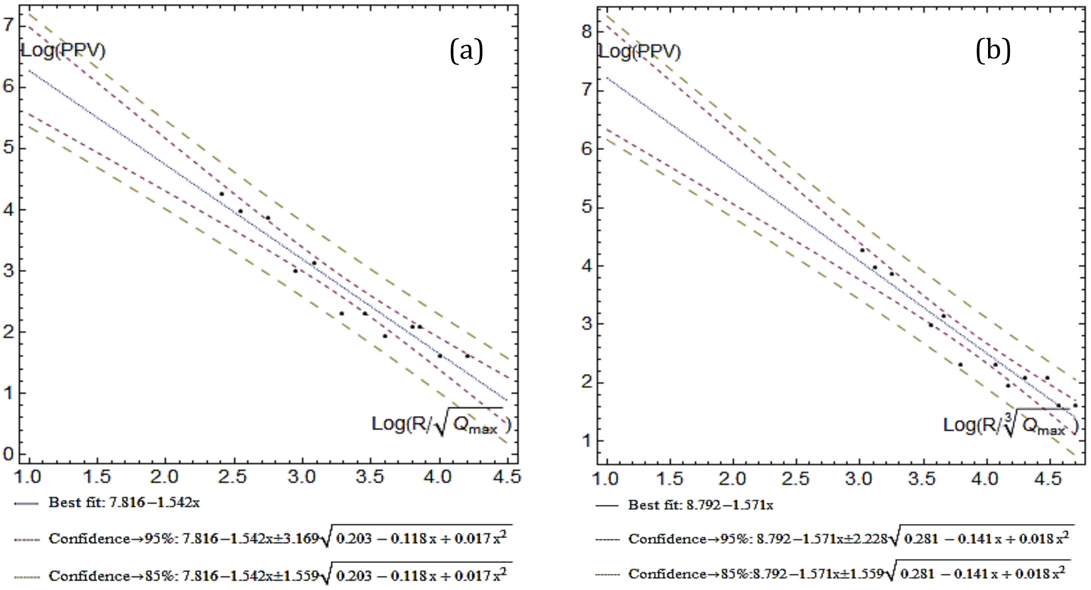


Figure 5. Plotting the graph between the square-root-scaled distance on Log-Log scale for Ninh Dan quarry with (a) USBM (1959) equation and (b) Ambraseys Hendron (1968) equations.

Table 6. Results of analysis variance ANOVA the blast data sets experience in Ninh Dan quarry.

Quarry	Degrees of freedom	RS quared	Estimated Variance	Sum of squares	Mean squares	Ficher-S nedecor	p-value
Ninh Dan	1	0.964	0.0681	9.099	9.099	133.437	$4.17x10^{-7}$
Chi-square test (χ^2)		{ Pearson χ^2 | Statistic 4. | P-Value 0.261464 , 3, `NormalDistribution[4.62593 x 10^-16, 0.238389]` }					

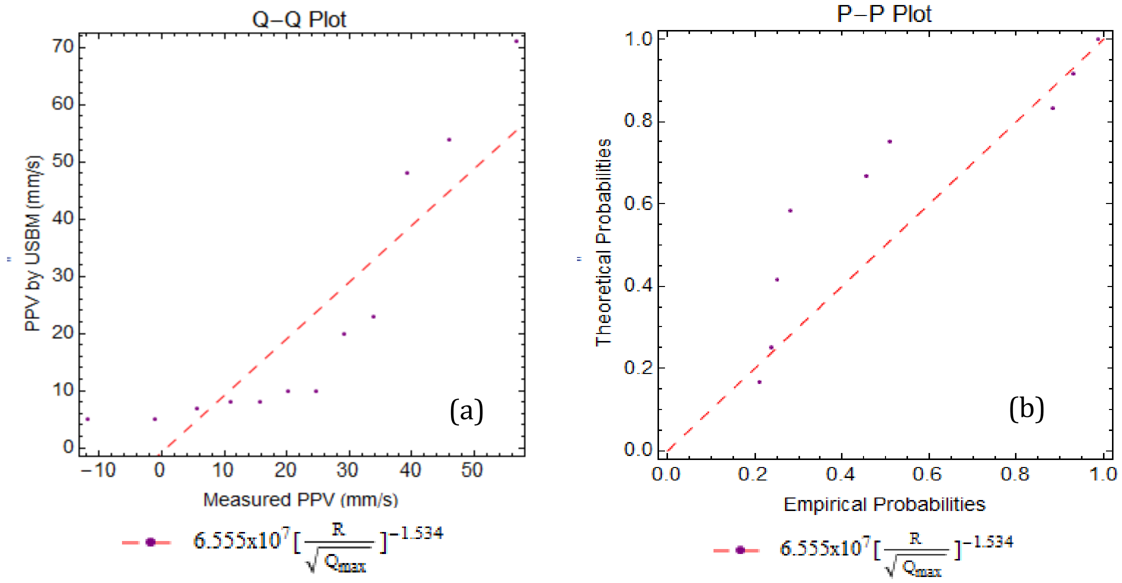


Figure 6. Measured and predicted PPV for Ninh Dan quarry by USBM equation: the plot of CDF measured PPV against CDF of PPV (a); plot of CDF measured PPV against CDF of PPV (b).

correlation between measured and predicted values of PPV.

3.2. Reduce of ground vibration in blasting

Based on the geological conditions, properties of rock, current state of blasting operation, used equipment of the open pit mine, we propose the methods for reducing ground vibration:

Increasing the effect of the use of explosive energy to break rocks: to increase the effect by using the explosive energy needs to utilize all solutions (using suitable types of explosives, using appropriate blasting parameters, using reasonable blasting methods, etc.);

Applying absolutely the delay and millisecond delay blasting: according to many researches in mining industry, the delay time ≥ 20ms allows to decrease the ground vibrations;

*Using the suitable blasting pattern and detonating direction: w*ith the same blasting patterns, the ground vibrations can be changed when using different detonating directions;

Creating the stopping surface to prevent the vibration waves: the stopping surface can be a blasted rock dump or some trenches dug to prevent the vibration waves transmitting to objects protected.

4. Conclusion

From results blasting, the PPV has been recorded at different locations and some experimental results in the limestone quarries in Vietnam, ground vibration levels were presented and analyzed by the ANOVA analysis method and the binomial probity regression model. The regression model obtained functions like "Linear Model Fit" with different confidence levels from 85-99%. The "Lineare Model Fit" is following the measured PPV line or curve in close manner with the data sets experience but the results of PPV predictors unable to predict the PPV which were observed in the site. The analysis methods in the study need more number of data sets in-site for estimating the safe explosive charge or the dimensions of dangerous zones with respect to the seismic effect of the blasting in the mining area under the safe limit.

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