Evaluation of parameters affected on the blast induced ground vibration (BIGV) by using relation diagram method (RDM)

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This paper presents the application of relation diagram method (RDM) to determine contribution of the parameters affected on the blast induced ground vibration. There are two types of parameters: controllable and uncontrollable parameters. The study focused on controllable parameters. The more effective parameters for ground vibration at the point of interest are ground vibration in the point of blast (PPV in-blast) and geological structures. The more effective parameters for the ground vibration at the point of blast are explosive amount per delay, burden and stemming. If desired fragmentation is obtained from the blast, then geological structures should be modified by creating artificial discontinuities. If one desires to reduce the level of vibration in the point of blast, then the following parameters should be modified ; explosive amount per delay, burden, stemming, and hole diameter.

Key words: *Blasting; explosive; blast induced ground vibrations; PPV; relation diagram*

Introduction

Blasting is still an economical and viable method for the rock excavation in mining and civil works projects. The major concern areas of blasting operation are productivity, environmental effects and safety. Productivity is related with obtaining desired fragmentation with uniform or appropriate size and proper displacement of rocks. Environmental effect is undesirable and mainly consists of ground vibration, air shock, fly rocks, excessive dust, noises, etc (Fig. 1). Safety includes explosive handling and blasting procedures. Planning engineer should try to optimize blast design which results in productive and environmentally safe blasting. This is very difficult task because of varying nature of rock, geologic structure of rock mass, and explosive. It is almost impossible to set down a series of equations which will enable the planner to design the ideal blast without some field testing. Several researches have developed a guide to design blast using empirical formulas with geological structural considerations. These concepts provide first approximation for blast design, consisting of estimating burden, spacing, hole length, quantity of explosive, etc. on the basis of blast hole diameter [1-5].

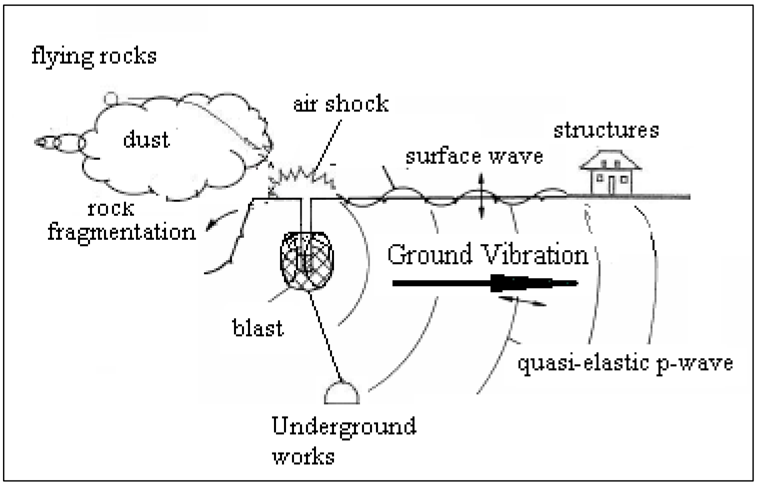

Fig. 1. Environmental effects of blasting.

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A well-designed blast will efficiently utilize the explosive energy generated by the detonation of explosive in a blast hole in order to result in optimum fragmentation and displacement of rock mass. However no matter how well a blast is designed, still only a small portion of this energy is utilized for fragmentation. The remaining energy forms undesirable and unavoidable environmental effects like ground vibrations, air blast, noises, back breaks, etc. [6-8]. Among these side effects, ground vibration known as blast-induced ground vibration (BIGV) is major concern to planning engineers since it may have a detrimental effect on nearby structures such as buildings, roads, etc.

The ground vibration is literally a wave motion, spreading outwards from the point of blast like ripples spreading outward due to impact of a stone dropped into water. As the vibration passes through the structures, it induces vibrations in these structures also. These vibrations induce a resonance in the structures if the frequency of the structure matches with the frequency of ground vibrations [9]. Therefore, the assessment of BIGV is very important for blasting operations. Frequency and peak particle velocity (PPV) are still most commonly used parameters for the assessment of ground vibrations, which is influenced mostly by the characteristics of rock mass, geological structures, blast design parameters and explosive characteristics. Over the years, many researchers have investigated the relationship between PPV and the effective parameters. Most of them have proposed empirical formulas to predict expected PPV as a function of explosive quantity, distance between blast point and point of interest, and the site constants which define geological structures and rock characteristics. By using these formulas, amount of explosive per delay is estimated in order to keep BIGV in a permissible limit. However other parameters are also very important for blast design, and variation in any one can also seriously change fragmentation and resulting ground vibrations. These parameters are dependent upon each other and mostly interrelated.

The relation diagram method (RDM) is a management and planning tools (MPT) to identify the complex casual interrelationships of parameters that may exist in a given situation. The method presumes that there are different factors effect surrounding any given "problem", in our case the problem is BIGV. The objective of the method is to elicit the relationships of parameters so that interrelationships can be addressed to solve the problem. This tool is useful to uncover key parameters, to identify complex cause-and-effect relationships, and to identify the critical parameters to achieve defined objectives [10-12].

This paper mainly focuses on the use of RDM to define the interrelationships of parameters that effects blast induced ground vibrations. The result will provide key and critical parameters to identify complex interrelationships of parameters to control BIGV.

Literature Review for BIGV

When a certain amount of explosive is detonated in a blast hole, very rapid decomposition of the charge takes place forming gases at very high temperature and pressure. This pressure crushes the rock around the blast hole by different breaking mechanisms such as crushing, radial cracking and reflection breakage in the presence of a free face. Following detonation, the shock and stress wave propagation starts through the medium in the form of elastic waves oscillating the particles. These waves in an elastic zone are known as ground vibrations, which closely confirms to the visco-elastic behavior. The wave motion spreads from the blast point in all directions and diminishes due to spreading of fixed energy over a greater mass of material [13-17]. Although the ground vibration diminishes exponentially with distance, it can still be high enough to be harmful for nearby structures.

Extensive researches have been conducted over the years related to BIGV. These researches can be grouped into four main areas;

i) Investigation of the effect of BIGV on nearby structures and development of damage criteria,
ii) Prediction of BIGV at the point of interest ,
iii) Reduction of BIGV at the point of interest,
iv) Determination of the effect of different parameters on the level of BIGV,

i) Investigation of the effect of BIGV on nearby structures and development of damage criteria:

During the last few decades, many damage criteria have been established and implemented with varying degrees of success. First study about damage criteria was made in 1927 by Rockwell and known as "Rockwell's Energy Formula" [18,19]. Nicholls [20] had summarized previous studies and carried out a new research to set up a correlation between BIGV levels and resulting damages on buildings. Siskind [21] investigated structure response and damage resulting from BIGV and developed a chart for safe blasting considering PPV and frequency, known as USBM (US Bureau of Mines) standards. In that publication previous damage criteria were also given. In 1983, US Office of Surface Mining (OSM) published its regulations to control ground vibrations. OSM regulation is different than USBM regulations [19]. In 1986, DIN standards were published for safe blasting [22]. USBM, OSM and DIN standards are applicable only if the PPV and frequency at the point of interest is known.

ii) Prediction of PPV at the point of interest :

A number of researchers have carried out studies to predict the amplitude of BIGV. These studies can be divided into two groups: Scaled Distance (SD) modeling and Simulation Modeling such as Finite Element Method (FEM) and Artificial Neural Network Model (ANNM).

SD Modeling: Most of the studies have assumed that the PPV of BIGV is a function of SD that is the ratio of distance to explosive amount per delay. The equation used most widely was established by USBM as given below [18,20];

$$PPV = K\,x\,(SD)^{-B} \quad and \quad SD = R / Q^{a}$$

where *PPV* the peak particle velocity (mm/s), *R* the distance between the point of blast and the point of interest(m), *Q* the maximum amount of explosives per delay (kg), *a* the explosive power (1/2 for spherical blast and 1/3 for cylindrical blast), and *K and B* the site constants.

On the basis of above relation, different researchers also suggested modified equation to predict PPV at the point of interest. These equations are discussed in [23] and given below in chronological order.

Name of Predictor Equation	Equation
Duvall and Fogelson (1962)	$PPV = Kx(R/Q^{1/2})^{-B}$
Ambrasey and Hendron (1968)	$PPV = Kx(R/Q^{1/3})^{-B}$
Langefors and Khilstrom (1973)	$PPV = Kx[(Q/R^{2/3})^{1/2}]^{B}$
Indian Standard Predictor (1973)	$PPV = Kx[(Q^{2/3}/R)]^{B}$
Davies et al (1964)., Attewell (1964), Daemen et al (1983)	$PPV = KxR^{-B}xQ^{A}$
Ghosh and Daemen (1983)	$PPV = Kx(R/Q^{1/3})^{-B}xe^{-\alpha R}$ *or* $PPV = Kx(R/Q^{1/2})^{-B}xe^{-\alpha R}$
CMSR (Gupta et al 1987)	$PPV = Kx(R/Q^{1/2})^{-B}xe^{-\alpha(R/Q)}$
CMSR (Roy 1991)	$PPV = n + Kx(R/Q^{1/2})^{-1}$

Where α and *n* are also site constants.

The above equations are mainly based on statistical relations. The field tests have to be carried out to determine the site constants by means of multiple regression analysis. There are many studies that have been carried out to determine specific site constants [24-28] to control the BIGV.

ANNM Modeling: A number of researchers has attempted to predict the ground vibrations using an Artificial Neural Network which incorporates large number of parameters [29-31]. These approaches take into account hole diameter, number of holes, hole length, burden, spacing, stemming, charge per delay, horizontal distance and radial distance to predict PPV and frequency. The ANN prediction work mainly on non-linear and non-bias basis. Authors claim that ANN model provide better prediction PPV than the other compared predictors [30,31].

FEM Models: Torano et al. [32-34] has developed a FEM model to predict the PPV. In their model, they have tried to simulate the factors that have influence on the vibration. By doing so, artificial vibrations were generated to analyze the behavior of real complex waves.

iii) Studies on the reduction of vibration level at the point of interest

There have been various research studies to eliminate or reduce the negative effect of BIGV at the point of interest. One group of investigations have tried to decrease BIGV in-situ by changing the quantity of explosive, type of explosive, blast hole geometry, etc., while the others have aimed at reducing the vibration at the point of interest by creating artificial discontinuities such as pre-splitting, barrier holes or trenches between the point of blast and the point of interest. The first group has mainly utilized scaled distance modeling to determine site constants. After determining site constants for the specific area, they have estimated the amount of explosive per delay for safe blasting [24-27].

Some of the researchers [35-40] have created pre-splitting, barrier holes or trenches between the point of blast and the point of interest. Their study proved that these artificial discontinuities behave like barrier in front of blast wave and decrease the level of BIGV.

iv) Study of parameters affected on Vibrations

The intensity of ground vibrations depend on various parameters. These parameters can be divided into two categories namely controllable parameters and uncontrollable parameters [21,29]. Controllable parameters are mainly related to blast design and explosive characteristic. Uncontrollable parameters are geological structures and rock characteristics that are taken into consideration as a site constant and their effect on PPV have been determined by means of regression analysis.

Nichols[20] had studied the effect of delay time, charge weight, delay interval, overburden, geology and direction of propagation. Hagan and Kendal [7] had investigated the effect of stemming length, Wiss and Lien [41] investigated the influence of local geology, lithology and rock characteristics. Roy [42] has investigated the influence of initiation mode of explosives. Similar studies have been carried out by different researchers [43,44].

The result of these studies can be summarized in Table 1. As it can be seen in Table 1 that, the level of ground vibrations at the point of blast and at the point of interest are different. PPV at the point of blast affects the PPV at the point of interest.

Tab. 1. The parameters affect the PPV(s).

Parameters effects PPV in the point of blast		
Uncontrollable Parameters	**Controllable Parameters**	
	Explosive Dependent	**Blast Design Dependent**
Geological Structures Rock Characteristics	Explosive type Amount of explosive per delay # of holes per delay Delay time Decoupling charge	Blast hole diameter Burden Spacing Charge length Stemming Sub drilling Hole length
Parameters effects PPV at the point of interest		
PPV in the point of blast Distance between the point of blast and the point of interest Geological structures between the point of blast and the point of interest Characteristics of rock		

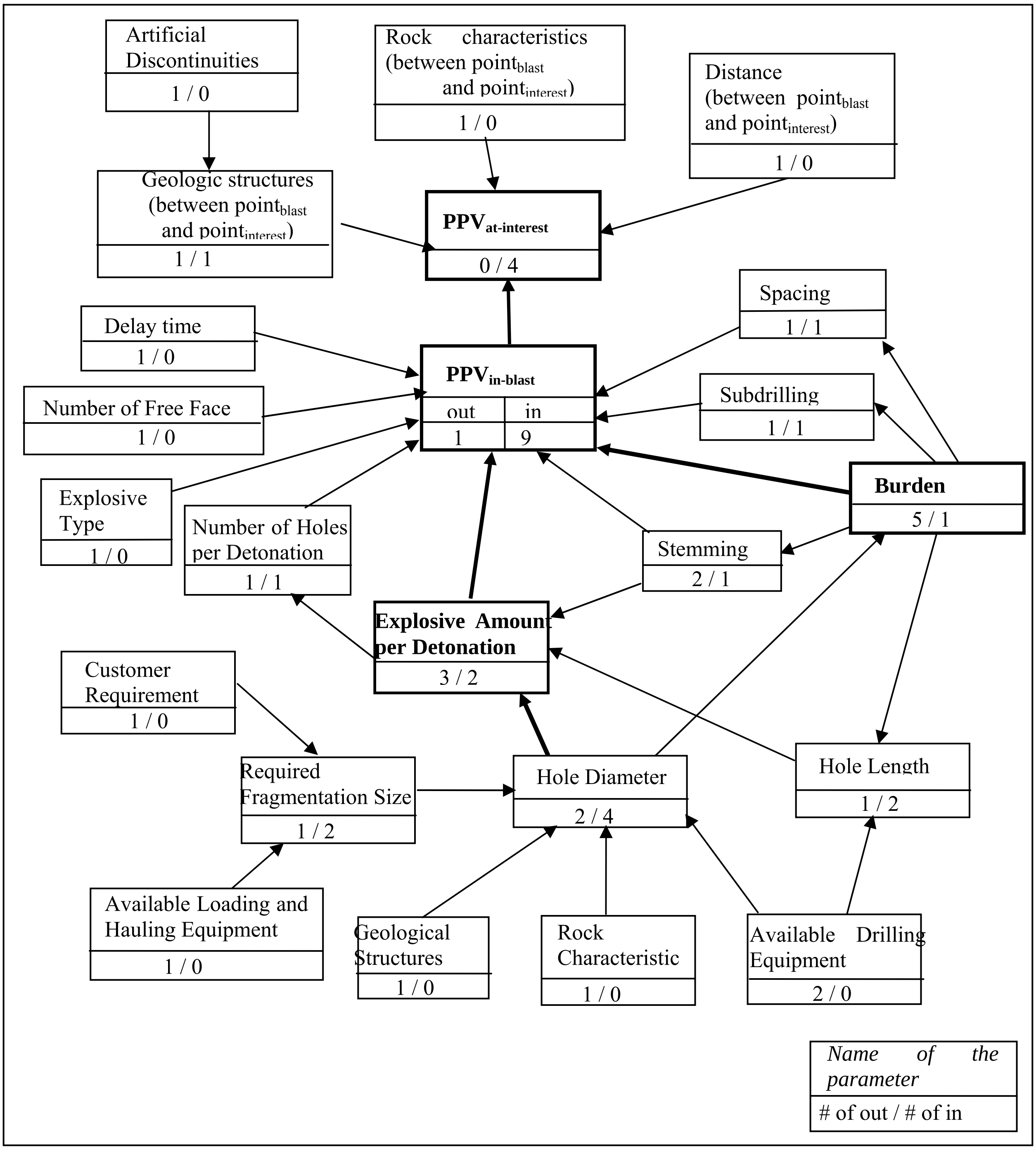
The parameters given in Table 1 are dependent upon each other and mostly interrelated. If any one of them is changed, others parameter will also be changed. Their, their relation and effects on each other must be identified in order to control/minimize/reduce the effect and magnitude of BIGV.

Relation Diagram of Blast-Induced Ground Vibration Parameters

Previous studies have indicated relationships among the blasting parameters which contribute to the BIGV. The overall trend of relationship among the parameters of ground vibration is given in Fig. 2 as relation diagram. In this relation diagram, if the arrow points from box A to box B it means that the parameter A contributes to the parameter B. The relative importance of parameters is signified by the number of arrows coming into or going out from each box, respectively. The result from this analysis is used to identify the most contributors of ground vibration with known parameters. The main contributors of ground vibration at the point of blast identified during the relation diagram are explosive amount per detonation, burden, and stemming. The main contributors to the ground vibration at the point of interest are PPV in-blast and geological structures between the point of blast and the point of interest.

To get a clearer picture of the trend and relationship of the parameters, further analysis is carried out to measure the relationship rating among the parameters. The concept of this analysis is based on the number of relationship between one parameter to other parameter. From this analysis the percentage value of each contributor is evaluated. Table 2 shows the percentage of each parameter that contributes to the PPV in-blast: burden (26.2 %), explosive amount per delay (21.7 %), stemming (13.1 %), #of holes per detonation(8.7 %), subdrilling(8.7 %), spacing (8.7 %), #of free face(4.3 %), delay time(4.3 %) and explosive type (4.3 %). The value gained from the above analysis will be significant information for finding out the solutions for next analysis. In order to identify the best strategies for reducing the level of BIGV, decision is made to focus on those contributors that contribute 10 % and above.

Fig. 2. The relation diagram analysis of BIGV.



The relationship of parameters that affects PPV at-interest is given in Tab. 3. The main contributor to PPV at-interest is PPV in-blast with 76.9 % contribution. Although the hole diameter is not directly effective on PPV in-blast, its contribution to PPV in–blast is very high due to its effect on the other parameters as seen in Fig. 2.

Tab. 2. The percentage contribution of each parameter to PPV in-blast.

	Explosive Amount	**Burden**	**# of holes per detonation**	**Stemming**	**Subdrilling**	**Spacing**	**# of free face**	**Delay Time**	**Explosive Type**
In	3	1	1	1	1	1	0	0	0
Out	2	5	1	2	1	1	1	1	1
Total	5	6	2	3	2	2	1	1	1
(%)	21.7	26.2	8.7	13.1	8.7	8.7	4.3	4.3	4.3

Tab. 3. The percentage contribution of each parameter to PPV at-interest.

	PPV in-blast	**Geological Structures**	**Characteristics of rocks**	**Distance between the point of blast and interest**
In	9	1	0	0
Out	1	1	1	1
Total	10	2	1	1
(%)	71.5	14.3	7.1	7.1

It should not be forgotten that the parameters of rock characteristics and distance between two points can not be controlled. Geological structures also can not be changed but the artificial discontinuities might be created as a geological structure. In this case, the best strategies for reducing the level of BIGV at-interest is either the reduce PPV in-blast or to create artificial discontinuities between the point of blast and the point of interest.

Conclusion

The objective of the blasting is to fragment the rock into desired size. The desired size of fragmentation depends on the end use of the rock and the type and size of equipments which are used for subsequent handling of the rocks. The blast design is made to obtain desired fragmentation after blasting. The blast induced ground vibration is undesirable but unavoidable side effect of blasting occurs right after detonation of blasting. This ground vibration travels thorough surrounding media by reducing its level and still might be destructive to surface structures.

In order to eliminate destructive effect of BIGV at the point of interest, one of the two approaches are utilized. The one is to reduce the level of ground vibration in the point of blast by changing blast design parameters as given in Table 1. This approach will also change the resulting fragmentation size. The second approach is to create artificial discontinuities between the point of blast and the point of interest so that the level of ground vibration will be reduced to the nondestructive level before reaching at the point of interest. In order to reduce the level of vibration at the point of interest, either the level of PPV in-blast should be reduced or artificial discontinuities should be created between two points. The decision should be made on the basis of desired fragmentation is obtained or not. If the desired fragmentation is obtained, then artificial discontinuities should be created, otherwise planner should focus on reducing the level of vibration in the point of blast by changing proper parameters.

The RD method of the Management and Planning Tools (MPT) is utilized to identify the interrelation of parameters that effects the BIGV at the point of blast and at the point of interest. The results showed that the most effective parameters on the *PPV at-interest* is the *PPV in-blast*. The effective parameters on the *PPV in-blast* are burden, explosive amount per delay and stemming. Those parameters are also related to blast hole diameter and hole length. Blast hole diameter is selected on the basis of required fragmentation size. So, any changes of these parameters will also change the resulting fragmentation size.

As a result, RDM displays the interrelation of parameters affected on the *PPV at-interest* and *PPV in-blast*, and leads to estimation of each parameters contribution to resulting vibrations. The planning engineer should developed strategies to optimize blast design by considering resulting vibrations and fragmentation size. RDM provides information where to start for optimization.

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