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Assessment of Blast-Induced Ground Vibration Frequency in Opencast Coal Mine: a Multivariate Statistical Regression Model

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Abstract: ***The blasting is a useful technique to explore and extract the mineral resources. It gives desired output with several negative impacts in surrounding mining areas. The ground vibration is one of the most concern phenomena produced by blasting. The peak particle velocity and frequency assess the seismic hazard, risk, and the human discomfort. Frequency plays a key role to define the damage criteria limits and human discomfort. The frequency of blast-induced ground vibration depends mainly on amount of explosive, characteristic properties of rock mass and distance etc. A total number of 32 datasets have been recorded in the form of velocity components and corresponding frequencies such as; Radial, Vertical, and Transverse at an opencast mine 'A' located in Chhattisgarh. The Indian Standard developed the safe level of peak particle velocity at frequency range (<8Hz, 8Hz - 25Hz, >25Hz) for the various types of structures close to mine. An attempt has been made to establish the relationship among parameters such as; burden, spacing, stemming, charge, hole depth, hole diameters and distance, etc. by multivariate statistical regression analysis (MVSRA) for the prediction of ground vibration frequency. The Coefficient of Determinate (CoD) between measured and predicted frequencies has also been studied.***

Keywords: Frequency; Ground Vibration; Simple linear regression; MVSRA; Blast Design parameters

I. INTRODUCTION

Coal (hydrocarbon) is one of the most essential mineral resource for growing industrial country in the world. It has become the backbone of several countries (i.e. no energy resources no industry). The underground and opencast mines are larger producer of coal with respect to demand. Blasting technique is frequently being used in both cases, underground and opencast mining operations.

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During the charged hole firing, the huge amount of energy released inform of pressure (50GPa) at temperature (5000k) [1-4]. On the other hand, the utilization of explosive is not much reliable due to complex nature of rock mass and irregular formation. Therefore, only small portion (20%-30%) of released energy has been used as desirable output. The remaining portion of released energy is undesirable phenomena, like airover pressure, ground vibration, back break, over break, and fly rock, etc. [5].

In the present scenario, opencast and underground mine operation have been developed at large scale to meet out the and demand of coal. The huge amount of explosive are being used to fragmentation and displacement of overburden rock mass at lower consumption of time and efforts. Blasting creates nuisance to community in nearby villages close to mine [6].

The peak particle velocity may be defined as maximum value among radial, vertical, and transverse velocity. Frequency corresponding to maximum value is defined as main frequency of PPV. Peak particle velocity and corresponding frequency depends mainly on the amount of explosive fired within a delay operator and monitoring distance. They are affected by physical properties of rock and formation of ground where the seismic wave radiating outward away from source [6]. The characteristic of rock mass changes from one place to another place due to complex nature of rock mass (i.e. inhomogeneous character of rock). The direction of seismic wave changes one point to another point due to this cause. In case of homogeneous medium wave propagate in one direction. The intensity of seismic wave changes due to presence of cavity, discontinuity, fractures, and tectonic fault in rock [7-10]. Peak vector sum, frequency and PPV are most effective parameters that are used to evaluate structural response and human discomfort caused by blasting. The frequency plays a key role in evaluation of ground vibration and structural response. If structures come under the strong seismic wave propagation range; it depends on ground vibration frequency [11]. The sensitivity of human being depends mainly on ground vibration PPV, corresponding frequency, event duration and event frequency [12]. When explosive fired within a blast hole, dynamic stress is generated around hole and it produces elastic deformation in form of seismic wave that propagate away from the blast hole [13]. In case of homogeneous medium seismic wave is purely compressive motion and having spherical wave front. It is not practical due to complexity of medium (i.e. inhomogeneous medium).

The seismic waves are classified such as; body wave (longitudinal or p-wave, transverse or s-wave) and surface wave (Rayleigh wave, L-wave) [14]. According to Dowding (1985), ground vibration is a combined result of body wave and surface waves that are induced by blasting. Both waves are combined in a signature as shown in figure (1). Individual wave front of tri-axial component of PPV and corresponding frequency are as shown in figure (2) [6].

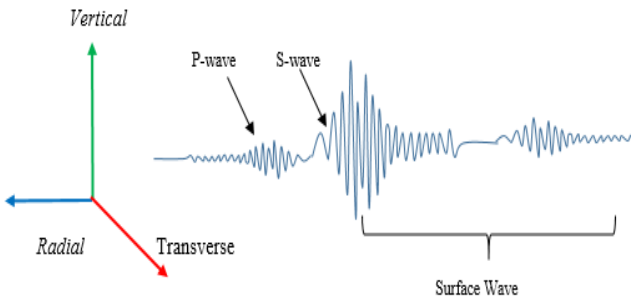

Fig. 1. Typical combined signature of seismic waves

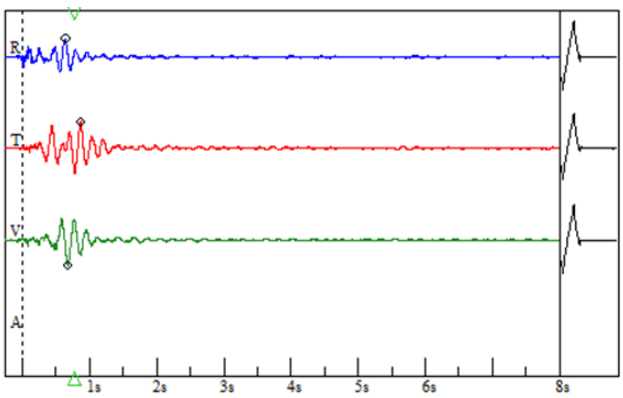

Fig. 2. Wave fronts of radial, transverse, and vertical direction

The frequency of propagating seismic wave is one of the most crucial parameter that impact ground vibration. The ground vibration contains wider range of frequency which depends on amount of explosive and monitoring distance. However, the structures and human being have their own natural frequency under its limit, it goes oscillation without any hazard or damage. When the frequency of ground vibration more over the natural frequency of structures and human being, it comes under hazardous criteria. According to Medearis (1978) natural frequency of structures varies (4Hz-18Hz) with its height and width [15].

$$A=A_0\, e^{-\pi f x/vQ} \qquad (1)$$

Where A, A_0 are amplitude of seismic wave at monitoring distance x= x(m) and x= 0(m); f (Hz) is dominant frequency of seismic wave velocity v (m/s) with quality factor Q. The amplitude of seismic wave varies exponentially with frequency in case of homogeneous medium as shown in figure (1).

II. STUDY AREA

The study has been conducted at an opencast coal mine 'A', which lies at latitude 22° 19' 14.988" N and longitude 82° 31' 30.67" E located in Chhattisgarh and shown in figure (3). Granite, Dolerite, Bauxite, fireclay, and Limestone deposits are also found in this area. The overburden rock mass is of medium to coarse grain sandstone, shale, shaly sandstone, and mostly weathered sandstone, etc. The mine has mostly semi-consolidated to unconsolidated sedimentary rock and bituminous coal of Gondwana age [16-17].

Fig. 3. A blasted site location in mine

III. MATERIALS AND METHOD

A. Geometry, Equipment and Data acquisition

It is difficult to monitor or acquire field data sets due to complex environment of mine. Therefore, a survey line has been drawn approximately 1400m long from blast site to last monitoring point. Along the survey line, 3-4 seismographs (Nomis) are put down simultaneously at a particular interval (100m). Nearest and farthest location of seismographs are 50m, 1400m, respectively from blast site. Seismographs contains tri-axial geophone and one microphone that measure the three components of PPV with their corresponding frequencies as well as resultant peak particle velocity, frequency, peak vector sum and airover pressure, respectively as shown in figure (4). A total number of 32 datasets have been acquired for this study and several other parameters such as; burden, spacing, stemming, sub-drilling depth, maximum charge per delay, total charge, monitoring distance, hole depth, hole diameter, booster per hole (100- 1200gm), and charge per hole (42.88-475kg), etc. are listed in table (I). The delay operators such as; 17ms, 42ms inline and cross line, respectively along with DTH delay (200-250ms). At present blasting sequence is staggered as shown in figure (5).

Table- I: Input Parameters

Input Parameters	Range
Monitoring distance (m)	50-1400
Maximum charge per delay (kg)	85.76- 475
Total charge (kg)	2230-8880
Total booster (kg)	3.1-23.4
No. of blast hole	14-75
Blast hole diameter (mm)	159-381
Blast hole Depth (m)	6.3-27
Burden (m)	8-Apr
Spacing (m)	9-Apr

Fig. 4. Seismograph with geophone and microphone

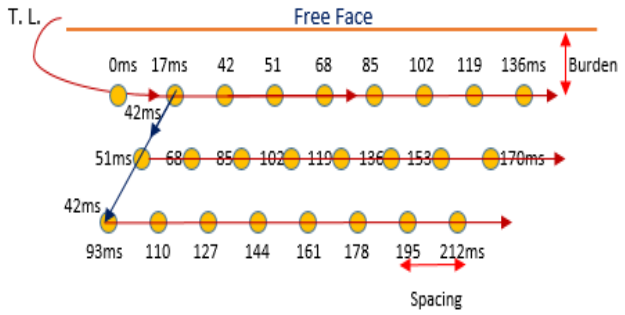

Fig. 5. Staggered blasting sequence

B. Simple linear Regression Analysis

Regression analysis is a set of statistical approaches to establish the relationship between a dependent (output) and independent variables (input). Linear regression is one of the most common statistical analysis. Simple equation (2) of regression analysis is like an equation of straight line. The constant β_0 is defined as intercept and coefficient of independent variable β defined as slope.

$$y = \beta_0 + \beta X \quad (2)$$

C. Multivariate Statistical Regression Analysis

Multivariate statistical regression analysis refers to multi-advanced approaches to establish the relationship among multiple variables at the same time. Multiple regression analysis is one of the most common approaches of MVSRA and it often, referred simply as regression analysis. It establish relationship among a dependent variable and more than one independent variables. It calculate the coefficient of independent variable as well as statistical significance.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \ldots \ldots + \beta_5 X_5 + E \quad (3)$$

Where, β_0 - intercept and $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_n$. are the coefficient of determinant or slope of the independent variables X_1, X_2, X_3, X_4, X_5, ... X_n, respectively, and error E as shown in equation (3). Multivariate statistical regression analysis (MVSRA) has been used to establish a new relationship among the Frequency (output variable) and such as; distance, maximum charge per delay, total charge, burden, spacing, number of holes, total booster, hole depth, and hole diameter (input variables).

IV. RESULT AND DISCUSSION

The amplitude of propagating seismic wave decays exponentially with dominant frequency and distance covered by it only in homogeneous medium. In case of inhomogeneous medium, the frequency of ground vibration changes with direction. Thus, all the frequency components are monitored in radial, transverse, and vertical direction at particular interval to assess the intensity of ground vibration and their impacts on surrounding structures and community close to mine. Indian standard has proposed a frequency (<8Hz, 8Hz-25Hz, >25Hz) based on peak particle velocity damage criteria limits for domestic structures. The multivariate statistical regression analysis (MVSRA) has been used to determine the coefficient of input variables and statistical significance. A relationship has been established among measured output variable and input variable parameters for the prediction of frequency. The relations are shown in equations (4), (5), (6), and (7). The measured output and input variables with predicted output are listed in tables (I & II). Simple linear regression is used to check the correlation between measured and predicted output the Coefficient of Determinant (CoD) has also been determined such as; 58.60%, 60%, 57.46%, and 51.41% as shown in figures (6), (7), (8), and (9) for radial, transverse, vertical, and corresponding PPV's, respectively.

A. Radial Frequency (R_f) Estimation

$$R_f = 18.894 - 0.00785[D, m] + 0.1082[MCPD, kg] + 0.00102[TC, kg] + 6.5308[B, m] - 2.571[S, m] - 0.462[NH] + 0.7733[TB, kg] - 4.0647[HD, m] + 0.057[HDI, mm] \quad (4)$$

B. Transverse Frequency (T_f) Estimation

C. Vertical Frequency (V_f) Estimation

$$V_f = 9.676 - 0.00795[D, m] + 0.12278[MCPD, kg] + 0.000709[TC, kg] + 7.0416[B, m] - 1.245[S, m] - 0.3907[NH] + 0.35589[TB, Kg] - 3.9162[HD, m] + 0.04088[HDI, mm] \quad (6)$$

D. Corresponding PPV's Frequency (C_f) Estimation

$$C_f = 18.702 - 0.0097[D, m] + 0.10095[MCPD, kg] + 0.00108[TC, kg] + 5.1174[B, m] - 1.789[S, m] - 0.4416[NH] + 0.9458[TB, kg] - 3.968[HD, m] + 0.06435[HDI, mm] \quad (7)$$

Where, D- Distance (m), MCPD- Maximum charge per delay (kg), TC- Total Charge (kg), B- Burden(m), S- Spacing (m), TB-Total Booster (kg), NH- No. of Holes (cont.), HD- Hole Depth (m), and HDI- Hole Diameter (mm).

Table- II : Output events by Measured and Predicted (MVSRA)

	Output parameters	Range
Measured Frequency (Hz)	Radial	1.2-25.2
	Vertical	1.3-19.1
	Transverse	1.2-23.5
	Corresponding PPV's	1.6-25.2
Predicted Frequency (Hz) (MVSRA)	Radial	1.52-15.89
	Vertical	2.36-15.98
	Transverse	1.51-14.89
	Corresponding PPV's	1.39-15.85

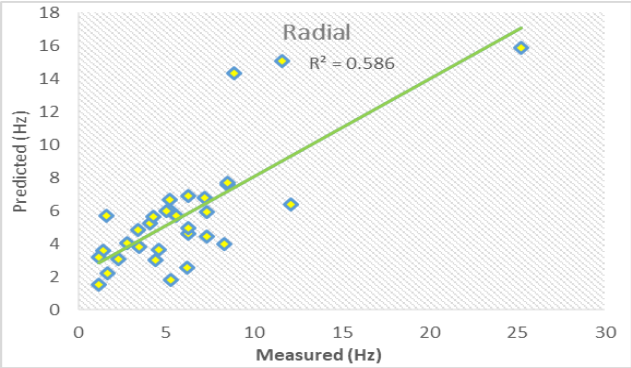

Fig. 6. Regression plot on radial's output

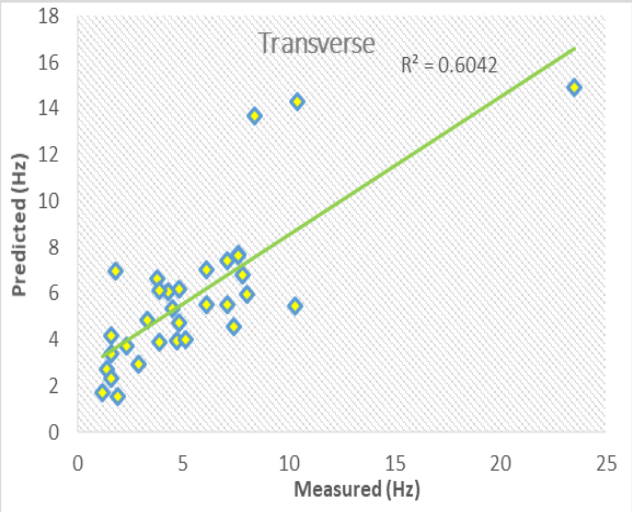

Fig. 7. Regression plot on transverse's output

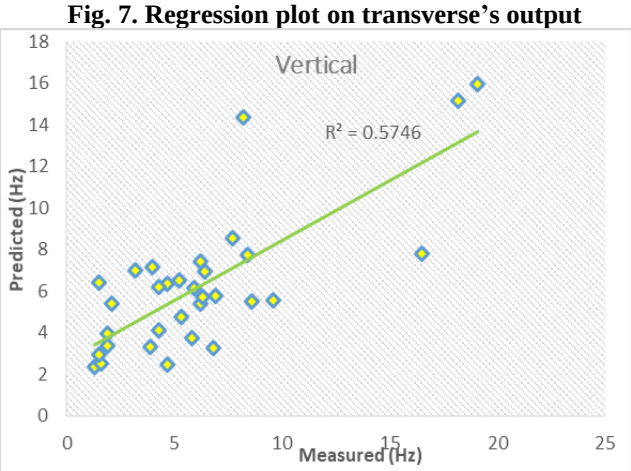

Fig. 8. Regression plot on vertical's output

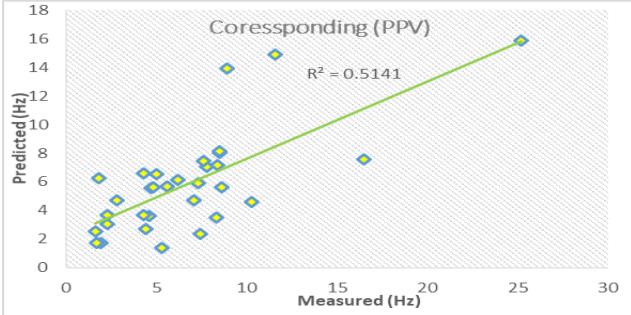

Fig. 9. Regression plot on corresponding PPV's output

On the basis of used datasets, the percentage distribution of measured and predicted frequency at different range are shows by pi-chart in figures (10 & 11), respectively. Lower frequency contain higher percentage of risk but it depends on ground vibration velocity. The measured values are 68.75% at (<8Hz), 28.11% at (8-25Hz), and 3.11% at (25Hz<) while predicted values 84.36% at (<8Hz), 15.63% at (8-25Hz), and 0.0% at (25Hz<). However, all the frequency range having no causes of hazard due to lower strength of ground vibration velocity because of acceptable amount of explosive used with appreciable distance to community from mine face. A comparative building block between main measured and main predicted frequency is shown in figure (12).

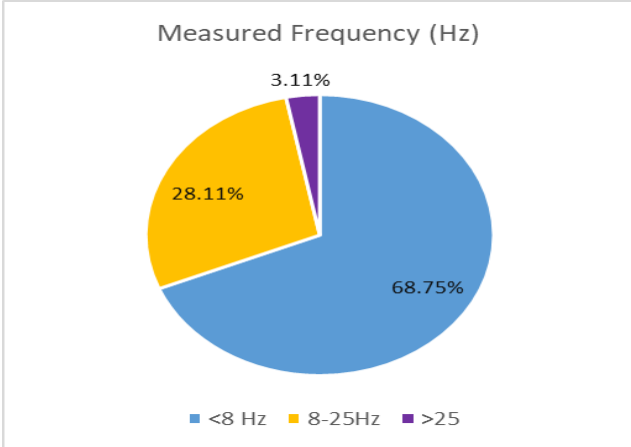

Fig. 10. Percentage distribution of measured frequency

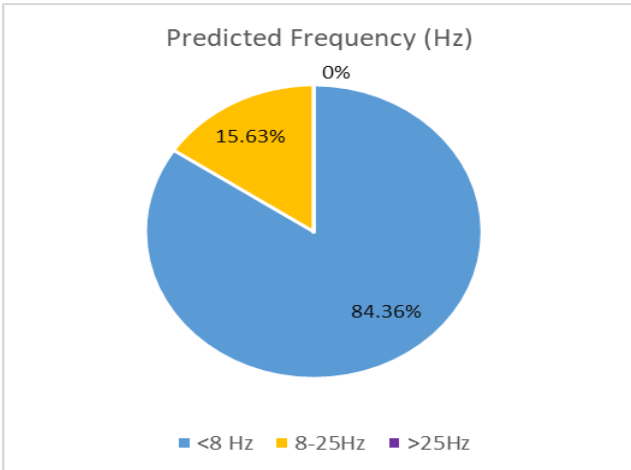

Fig. 11. Percentage distribution of predicted frequency

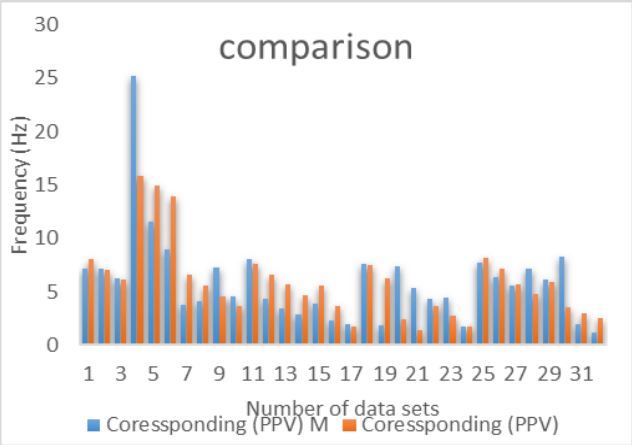

Fig. 12. Comparison of main measured and predicted with frequency datasets

V. CONCLUSION

The prediction of main frequency and their components in radial, transverse, and vertical directions has been made to optimize blasting parameters for the reduction of unusual events produced during blasting. Multivariate statistical regression analysis (MVSRA) has been used to design a model equation for this prediction. Simple linear regression analysis has been used to obtain the Coefficient of Determinant (CoD) between measured and predicted values such as; 58.60%, 60%, 57.46%, and 51.41% for radial, transverse, vertical components and main frequencies, respectively.

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