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Assessment and Prediction of BIGV using Different Attenuation Equation in Opencast Mine

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Abstract: The Drilling and blasting play an important role in opencast mining for exploration and excavation of mineral resources. At the same time, they have some adverse effects on surrounding environment as well as nearby community and structures. The Peak particle velocity (PPV) is the most effective parameter for evaluation of blast-induced ground vibration (BIGV). A number of researchers established an attenuation equation and gave permissible level for structures and environment on the basis of PPV and frequency (i.e. USBM, IS DGMS, DIN, etc.). A total number of 46 datasets have been recorded at an interval of 25m & 50m from blast site to observation points along survey line and also acquire the row data like blast design parameters, explosive parameters, etc. in a Mine 'B' of Madhya Pradesh. The prediction of BIGV Velocity by different empirical predictor models have been made. These attenuation equations have been helpful to minimize the negative effect of BIGV and optimize the blast design parameters. The site-specific constant has been determined by regression statistical analysis. In the present study, correlation and comparison between the measured PPV and predicted PPV for the safe, smooth, and eco-environment blasting operation has been carried out.

Keywords: Blasting, Vibration Velocity, Max. Charge per delay, Regression analysis, Attenuation model

I. INTRODUCTION

The blasting is the most desirable thing for excavation and removal of rock mass. It contains controllable parameters (i.e. burden, spacing, explosive, sub-drilling, delay time, etc.) and uncontrollable parameters (i.e. geological condition, geotechnical characteristics of rock mass, etc.). The blasting gives a negative impact on environment and human life in surrounding mining areas. However, the blasting plays a vital role in civil and mining engineering projects [1]. In explosive technology, only small part (20%-30%) of total energy is utilized in form of breaking and removal of rock mass and its remaining part is wasted as undesirable things such as, ground vibration, airover pressure, fly rocks, beak back, over break backs, etc. [2-4].

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The ground vibration level exceed more than the threshold limits cause the damage to structures and becomes harmful for local humanities close to mines.

The attenuation prediction equation are being used to minimize & prevent the negative impact of BIGV. They have observed their generation and propagation mechanism into subsurface ground [5]. The intensity of BIGV depends mainly on two

basic parameters such as; maximum charge per delay and distance between blast site & observation point. The hazard and damage due to blasting, could be minimized and controlled by blast design, proper time delay operators and suitable initiation sequences. Contrarily, uncontrollable parameters such as; physical properties of rock mass, type of rock mass and behavior of rock mass, etc. are also effective in amount of absorbed, transmitted vibration wave energy [6-7]. When the charged explosive material within blast hole is fired, a large quantity of chemical energy is released that simultaneously changes its form into another form such as; hot gas at high pressure [8]. The firing of blast holes also produces energy in form of ground vibration wave energy and high pressure gas energy [9]. The blast hole walls are strongly influenced by shocked wave & high pressure gas and crushes upto twice the radius of blast hole. Influenced areas or crushed areas around blast hole may be defined as crushed zone which is nonlinear zone characterized by blast hole due to plastic & elastic waves [10]. The frequency is most critical parameter and it has significant impact on intensity of ground vibration propagation as seismic wave. The frequency of a radiating seismic wave causes structural damage. The propagating seismic wave is a function of wavelength & dominant frequency. On the other hand, structures having their own threshold frequency and the structure tends to damage after its limit. The structure's threshold values varies from 4Hz to 18Hz according to their height and width [11]. When the threshold frequency of structures reach as close to dominant frequency of BIGV, the structures accumulate and buildup energy as stress and shaking under it with no damage or hazard. The dominant frequency of BIGV and structure's threshold frequency help for evaluation and prediction of structures damage. The seismic wave propagates in different ways into medium from blast site to the observation point as shown in figure (1).

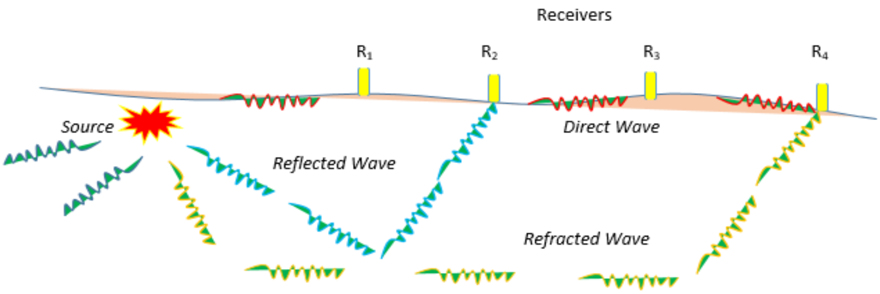

Fig. 1. Seismic wave propagation into medium

$$A(x) = A_0 e^{-\alpha x} \quad (1)$$

$$\alpha = f\pi/\theta v \quad (2)$$

Where A(x) & A_0 are the amplitude of seismic wave at distance x & x=0, respectively. Amplitude of seismic wave is exponentially attenuated as a function of distance (x) and attenuation factor or absorption coefficient (α) as shown in equation (1). v Propagating wave velocity (ms^{-1}), f dominant frequency (Hz) of seismic wave. The attenuation factor depends mainly on the parameters such as; propagating wave velocity, dominant frequency, and quality factor (θ) as shown in equation (2). The amplitude of seismic wave decreases with increasing the distance as evident from figure (2).

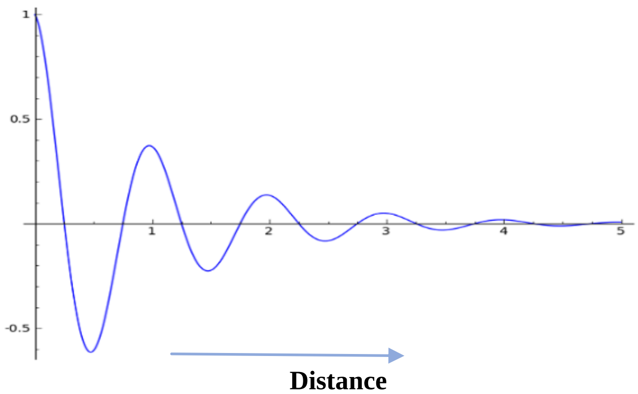

Fig. 2. Amplitude variation with distance

II. GEOLOGY OF THE AREA

The study has been conducted at a opencast coal mine 'B' which lies between latitude 24.1443°N and longitude 82.3886°E located in Madhya Pradesh as shown in figure (3). The overburden rock mass of this mine are mostly medium to coarse grain sandstone, carbonaceous shale, and shaly sandstone (i.e. 90% medium to coarse grain sandstone). The stripping ratio is (2:60) refers to the volume of overburden required to be handled in order to extract some tonnage of mineral resources. The dimension and area of this mine such as; (3.6km) wide along the strike direction, (3.5km) wide along the dip direction, and 11.2km^2, respectively. There are three types of coal seam present like, Purewa top, Purewa bottom, and Turra and their width (6-7m), (11-13m) (17-18m), respectively. The rock mass and bituminous coal of different grade are present since Gondwana age. [12-14].

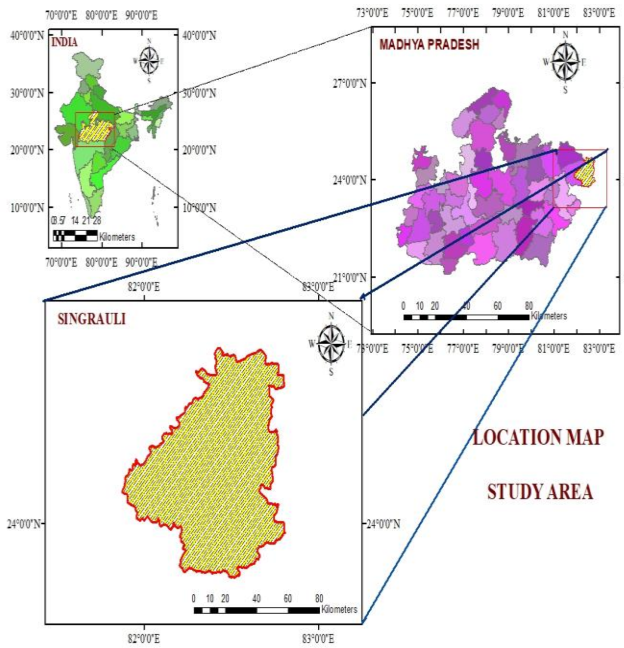

Fig. 3. Opencast coal mine 'B' of Madhya Pradesh

III. MATERIALS AND METHODS

A. Blasting Geometry

The observation plan is not in proper way due to complexity of mine environment. Therefore, for simplicity and smooth observation, survey line (1.3km) is drawn between blast site and observation point toward the face nearby community. The third & fourth bench blasting have been done with appropriate blast design geometry such as; burden (2-10m), spacing (3-12m), stemming (1.5-10m), hole diameter (125-311mm), hole depth (3-28m), and materials such as; total explosive charge (1260-32,300kg), charge per meter (15-95kg/m), maximum charge per delay (225-1700kg), intra row (17ms, 25ms, etc.) & inter row (42ms, 63ms, 150ms, etc.) electronic delay detonators. In case of large hole depth, (30% - 40%) top column charge and (60% - 70%) bottom charge separated by decking and initiation has staggered as shown in figure (4) [15].

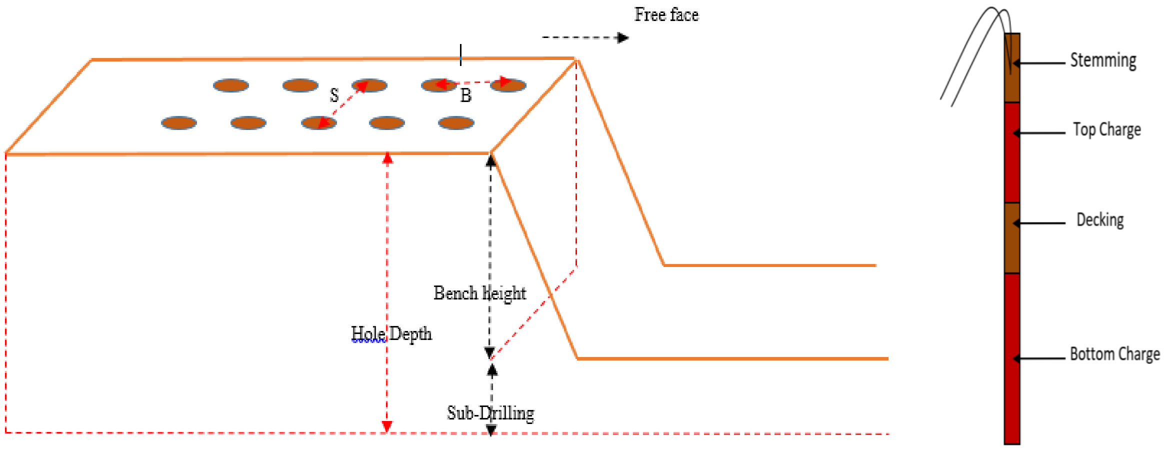

Fig. 4. Decked blasthole sample and blast geometry

B. Instrument Setup and Data Acquisition

The measurement has been done with seismograph (Nomis) which contains tri-axial geophone. The tri-axial geophone measure three components of PPV corresponding frequencies along radial, vertical, and transverse direction. Two seismograph installed simultaneously at 25m, 50m intervals separately. The nearest (50m) and furthest (1250m) location of seismographs from blast site. Seismograph move along survey line with fixed given intervals upto last observation point nearby community. A total number of 46 datasets have acquired in various form like, radial velocity, vertical velocity, and transverse velocity corresponding frequencies and peak particle velocity in number of days and measured & predicted PPV values are listed in table (I).

C. Intensity of Ground Vibration Prediction

The blast induced-ground vibration prediction is more difficult for the predetermined distance because of the properties of rock mass changes from one place to another place (i.e. anisotropic medium). The seismic wave propagation behaviour changes with place and is affected by many factors. Therefore, prediction is almost impossible by single attenuation equation [16]. Several scientists and researchers have developed their attenuation equations for the blast- induced ground vibration level [17-20]. The peak particle velocity is most concerning parameter of these predictors listed in table (II). The attenuation equation depends mainly on maximum charge per delay and distance between blast site and observation point. The generation and propagation of BIGV is affected by a number of parameters. Therefore, the attenuation equations are having lack of accuracy and unable to predict other critical parameters such as; frequency, airover pressure, flyrock, etc. They have significant importance to prevent damage, safe, smooth, and ecofriendly environment blasting operation. At the same field, different attenuation equations having different scale distance (i.e. function of distance and max. charge per delay) give the different values of peak particle velocity [21-22]. Duvall and Petkof 1959 has given the basic relationship between peak particle velocity and scale distance (distance, maximum charge per delay) as shows by equation (3).

$$\mathbf{PPV = k\,(D/\sqrt{Q}\,)^{-b}} \quad (3)$$

Where, the value within the bracket is defined as scale distance (SD; m/$Q^{0.5}$), distance (D; m), and maximum charge per delay (Q; kg). The k, and b is site constants which depends mainly on characteristics properties of rock mass. The site constants can be determined by regression statistical analysis because of the equation (3) looks like equation of straight line on logarithmic scale. Peak particle velocity depends on scale distance (independent variable) so the log-log plot of PPV vs. SD produce linear fit [23]. Thus, k and b treated as intercept and slope of straight line and these values have accepted if the determinant of coefficient (CoD) R^2 is equal or more than 50% are listed in table (III) [24].

Table- II: Different predictor equations

Sl. No.	Researchers	Empirical predictor Equation
1	Duvall and Petkof (1959)	$V = k\,(D/Q^{1/2})^{-b}$
2	Langefors and Kihlstrom (1963)	$V = k[\sqrt{(Q/D^{2/3})}]^{b}$
3	General predictor (1964)	$V = k\,D^{-b}\,Q^{a}$
4	Ambraseys and Hendron (1968)	$V = k(D/Q^{1/3})^{-b}$
5	Indian Standard DGMS (1983)	$V = k\,(Q/D^{2/3})^{b}$

Table- III: Represent the site constants and correlation coefficients

References	k	b	a	CoD
Duvall-Petkof (1959)	440.25	1.6797	……	0.7434
Langefors-Kihlstrom (_1963)	0.11223	-2.716	…….	0.7375
General predictor 1964	566.50	1.69	0.3329	0.7426
Ambraseys-Hendron (1968)	3449.05	1.7358	……	0.7428
Indian Standard (DGMS) 1983	0.11223	-1.358	……	0.7375

Table- IV: Predicted PPV values by various predictors

D (m)	Q (Kg)	Scale Distance				Measured PPV (mm/s)	Predicted PPV (mm/s)				
		Duvall	Langefors	Ambraseys	Indian Standard		Duvall	Langefors	Ambraseys	General predictor	Indian Standard
50	950	1.6222	8.4762	5.2038	71.8461	50.673	195.335	37.2382	196.928	197.417	37.2382
100	950	3.2444	6.7431	10.4076	45.4698	38.862	60.973	20.006	59.1263	61.1849	20.006
150	240	9.682458	2.9648	24.5822	8.79004	11.43	9.7171	2.1474	13.300	10.110	2.1474
200	240	12.9094	2.6962	32.7763	7.2699	9.729	5.9934	1.6594	8.0721	6.2175	1.6594
225	665	8.7251	4.3170	26.3421	18.6372	21.717	11.574	5.958	11.795	11.6388	5.958
250	665	9.6945	4.1695	29.2690	17.3852	14.732	9.6967	5.4219	9.8244	9.7404	5.4219
275	576	11.4583	3.7603	33.7592	14.1404	8.001	7.3230	4.0956	7.6685	7.3798	4.0956
300	576	12.500	3.6539	36.8283	13.3512	6.731	6.3273	3.788	6.5935	6.3707	3.788
325	700	12.2838	3.9230	37.4111	15.3905	5.588	6.5154	4.5949	6.4162	6.5173	4.5949
350	700	13.2287	3.8283	40.2889	14.6559	4.191	5.7528	4.2997	5.6418	5.750	4.2997
375	510	16.6052	3.1941	47.9218	10.2025	5.461	3.9269	2.6291	4.1747	3.9588	2.6291
400	510	17.7123	3.1268	51.1165	9.7771	4.318	3.5234	2.4814	3.7323	3.5498	2.4814
425	1600	10.625	5.4286	37.2416	29.4702	5.08	8.3133	11.1023	6.4670	8.0939	11.1023
450	1600	11.250	5.3272	39.4323	28.3791	3.931	7.5522	10.5479	5.8562	7.3486	10.5479
475	700	17.9533	3.4613	54.6778	11.9806	2.54	3.4443	3.270	3.3205	3.4319	3.270
500	700	18.8982	3.4032	57.5556	11.5818	2.286	3.1600	3.1232	3.0376	3.146	3.1232
525	280	31.3747	2.1180	81.7705	4.4859	2.794	1.3486	0.8614	1.6512	1.3789	0.8614
550	280	32.8687	2.0857	85.6644	4.3502	1.905	1.2472	0.8263	1.5231	1.2747	0.8263
575	360	30.3051	2.3305	82.4305	5.4315	1.905	1.4295	1.1169	1.6283	1.4495	1.1169
600	360	31.6227	2.2980	86.0144	5.2810	1.778	1.3309	1.0751	1.5124	1.3489	1.0751
625	350	33.4076	2.235598	90.43521	4.9978	1.524	1.2136	0.9975	1.3864	1.2306	0.9975
650	350	34.7439	2.2068	94.0526	4.8701	1.397	1.1362	0.9631	1.2951	1.1517	0.9631
675	225	45.00	1.7475	113.0013	3.0538	0.978	0.7358	0.5109	0.9417	0.7553	0.5109
700	225	46.6667	1.7266	117.1866	2.9813	0.899	0.6922	0.4945	0.8841	0.7102	0.4945
725	320	40.5287	2.0354	108.0534	4.1431	1.905	0.8772	0.7732	1.0179	0.8905	0.7732
750	320	41.9262	2.0128	111.7794	4.0514	1.651	0.8287	0.7501	0.9597	0.8409	0.7501
775	336	42.2797	2.0403	113.6605	4.1629	0.895	0.8171	0.7782	0.9323	0.827	0.7782
800	336	43.6435	2.0190	117.327	4.0766	0.854	0.7746	0.7568	0.8823	0.7844	0.7568
825	1600	20.625	4.3614	72.2926	19.0221	1.397	2.7284	6.1267	2.0449	2.6383	6.1267
850	1600	21.250	4.3186	74.4833	18.6510	1.27	2.5949	5.9649	1.9416	2.5085	5.9649
875	350	46.7707	2.0006	126.6093	4.0026	0.953	0.6896	0.7378	0.7731	0.6969	0.7378
900	490	40.6578	2.3452	116.5407	5.5004	1.015	0.8726	1.1361	0.8927	0.872839	1.1361
925	270	56.2937	1.7252	145.8115	2.9765	0.762	0.5051	0.4935	0.6050	0.5140	0.4935
950	270	57.8151	1.7101	149.7523	2.9245	0.462	0.4830	0.4818	0.5776	0.4914	0.4818
975	570	40.8382	2.4635	120.1063	6.0692	0.934	0.8661	1.2986	0.8472	0.8618	1.2986
1000	570	41.8853	2.4430	123.186	5.9686	0.731	0.8300	1.2694	0.8107	0.8257	1.2694
1025	450	48.3189	2.1531	136.5098	4.6359	0.589	0.6529	0.9007	0.6783	0.6538	0.9007
1050	450	49.4974	2.1360	139.839	4.5627	0.457	0.6270	0.8815	0.6506	0.6277	0.8815
1075	1700	26.0725	4.1196	92.333	16.9714	1.651	1.8404	5.2474	1.3372	1.7717	5.2474
1100	1700	26.6789	4.0885	94.4810	16.7158	1.397	1.7707	5.1404	1.2846	1.7042	5.1404

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1125	1600	28.125	3.9371	98.5809	15.5009	1.524	1.6205	4.6398	1.1936	1.5620	4.6398
1150	1600	28.750	3.9086	100.7716	15.2777	1.016	1.5618	4.549	1.1489	1.5050	4.549
1175	855	40.1841	2.8370	126.6161	8.0489	0.798	0.8899	1.9054	0.7730	0.8733	1.9054
1200	855	41.0391	2.8174	129.3101	7.9379	0.712	0.8590	1.8697	0.7452	0.8428	1.8697
1225	1520	31.4205	3.7311	109.1761	13.9211	0.691	1.3453	4.0096	0.9998	1.297	4.0096
1250	1520	32.0618	3.7063	111.4042	13.7367	0.635	1.3004	3.9376	0.9653	1.2540	3.9376

IV. RESULT AND DISCUSSION

A. Predicted by Duvall-Petkof

The equation (4) become complete to establish the relationship between PPV and SD values. The site constants **k = 440.25** and **b = 1.6797** are determined using regression analysis by plotting between SD and PPV on logarithmic scale as shown in figure (5). The value of Coefficient of Determinant $\mathbf{R^2}$ is **74.34%** as shown in figure (6).

$$V = 440.25(\mathbf{SD})^{-1.6797} \quad (4)$$

Predicted by Langfors-Kihlstrom

The equation (5) become complete to establish the relationship between PPV and SD values. The site constants **k = 0.1123** and **b = -2.716** are determined using regression analysis by plotting between SD and PPV on logarithmic scale as shown in figure (7). The value of Coefficient of Determinant $\mathbf{R^2}$ is **73.75%** as shown in figure (8).

$$\mathbf{V}= 0.1122(\mathbf{SD})^{2.716} \quad (5)$$

B. Predicted by General Predictor

The equation (6) become complete to establish the relationship between PPV and SD values. The site constants **k = 566.50** and **b = 1.69**, and **a = 0.8105** are determined using regression analysis by plotting between SD and PPV on logarithmic scale. The value of Coefficient of Determinant $\mathbf{R^2}$ is **74.26%** as shown in figure (9).

$$V = 566.50\ \mathbf{D}^{-1.69}\ \mathbf{Q}^{0.8105} \quad (6)$$

C. Predicted by Ambraseys-Hendron

The equation (7) become complete to establish the relationship between PPV and SD values. The site constants **k =3449.25** and **b= 1.7358** are determined using regression analysis by plotting between SD and PPV on logarithmic scale as shown in figure (10). The value of Coefficient of Determinant $\mathbf{R^2}$ is **74.28%** as shown in figure (11).

$$V = 3449.25\ (\mathbf{SD})^{-1.7358} \quad (7)$$

D. Predicted by Indian Standard DGMS

The equation (8) become complete to establish the relationship between PPV and SD values. The site constants **k = 0.1122** and **b = 1.358** are determined using regression analysis by plotting between SD and PPV on logarithmic scale as shown in figure (12). The value of Coefficient of Determinant $\mathbf{R^2}$ is **73.75%** as shown in figure (13).

$$V = 0.1122(\mathbf{SD})^{1.358} \quad (8)$$

A comparison of all datasets in respect of measured & predicted peak particle velocities by different model has been shown in figure (14). It has been observed that the Indian standard and Langefors- Kihlstron are in close proximity to measured one.

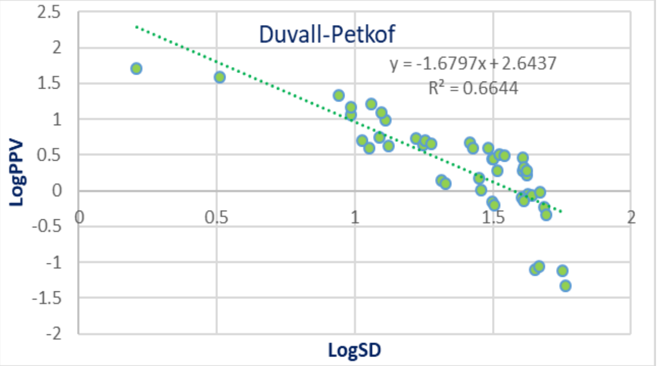

Fig. 5. Logarithmic plot between SD & PPV by Duvall-Petkof

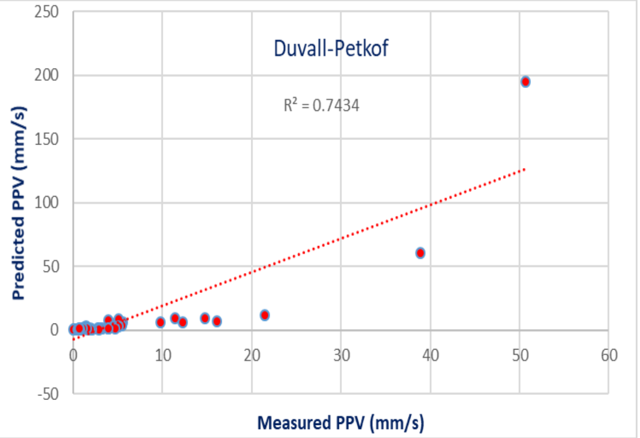

Fig. 6. Measured and predicted PPV's correlation by Duvall-Petkof

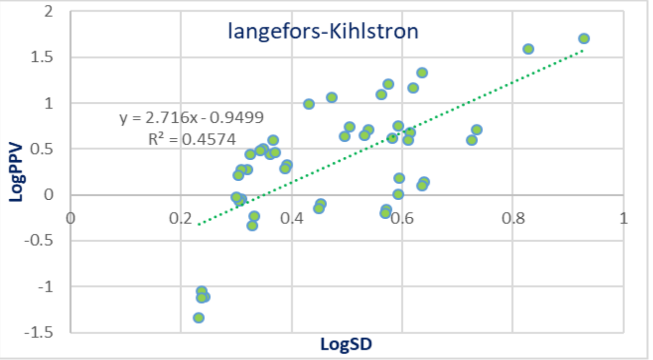

Fig. 7. Logarithmic plot between SD & PPV by Langefors-Kihlstron

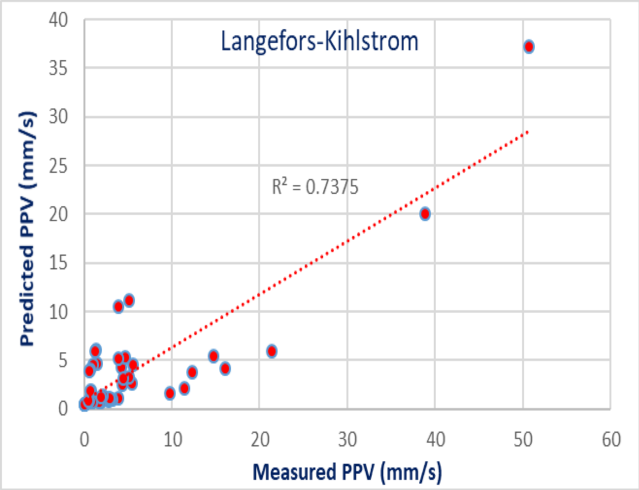

Fig. 8. Measured and predicted PPV's correlation by Langefors- Kihlstron

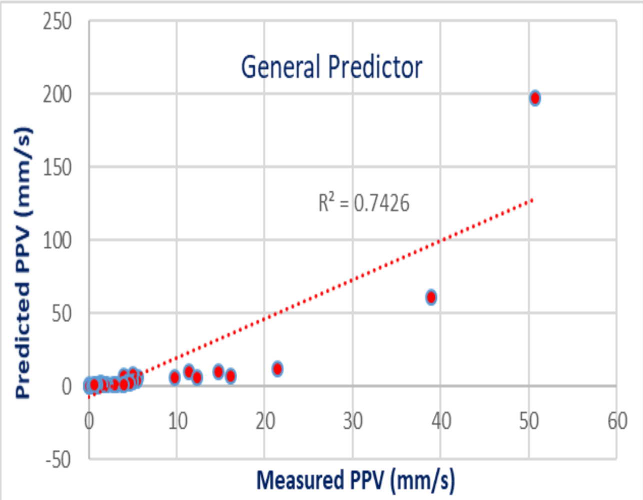

Fig. 9. Measured and predicted PPV's correlation by General Predictor

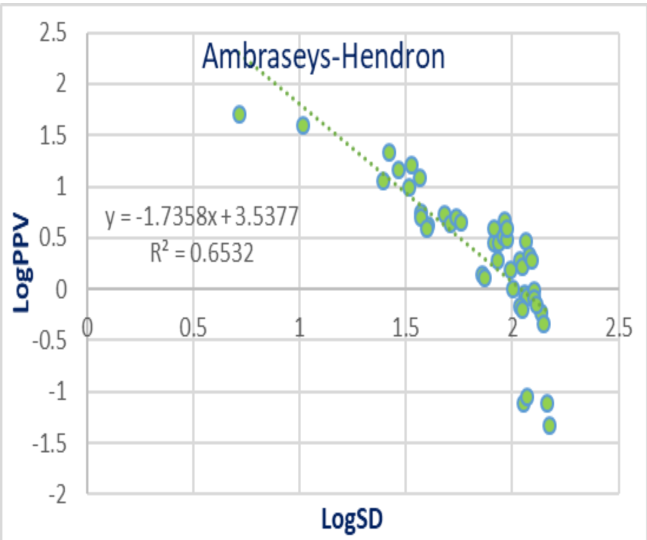

Fig. 10. Logarithmic plot between SD & PPV by Ambraseys-Hendron

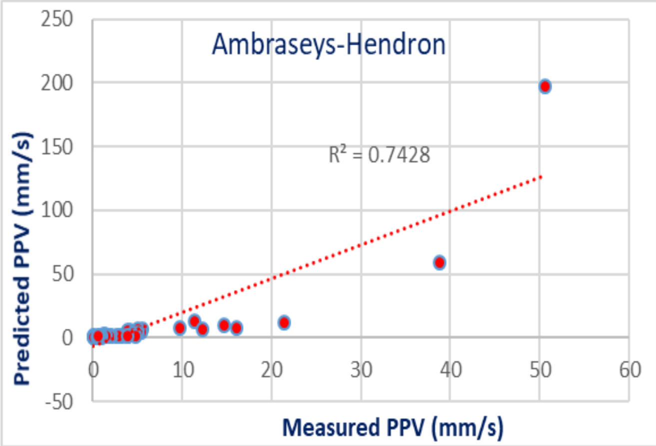

Fig. 11. Measured and predicted PPV's correlation by Ambraseys-Hendron

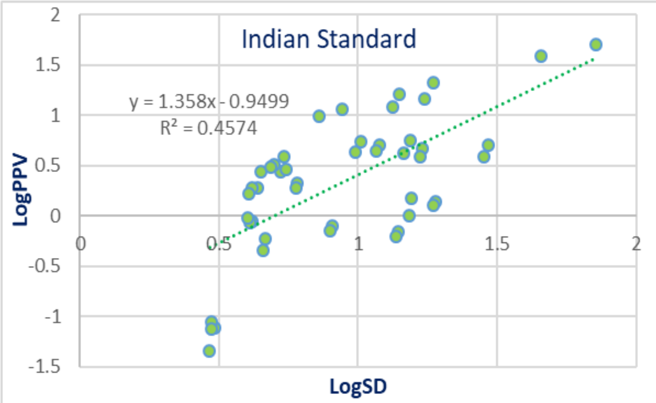

Fig. 12. Logarithmic plot between SD & PPV by Indian Standard

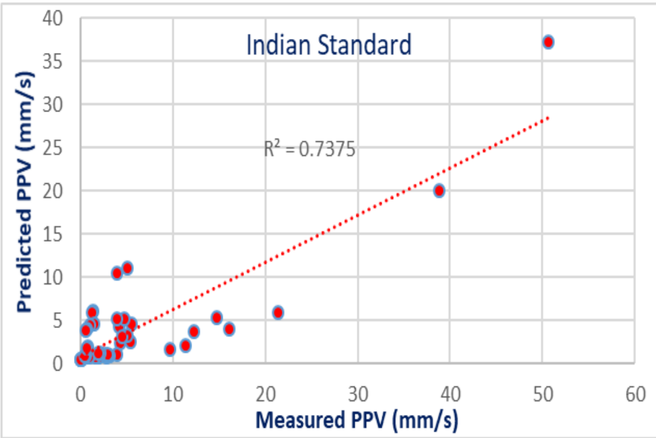

Fig. 13. Measured and predicted PPV's correlation by Indian Standard

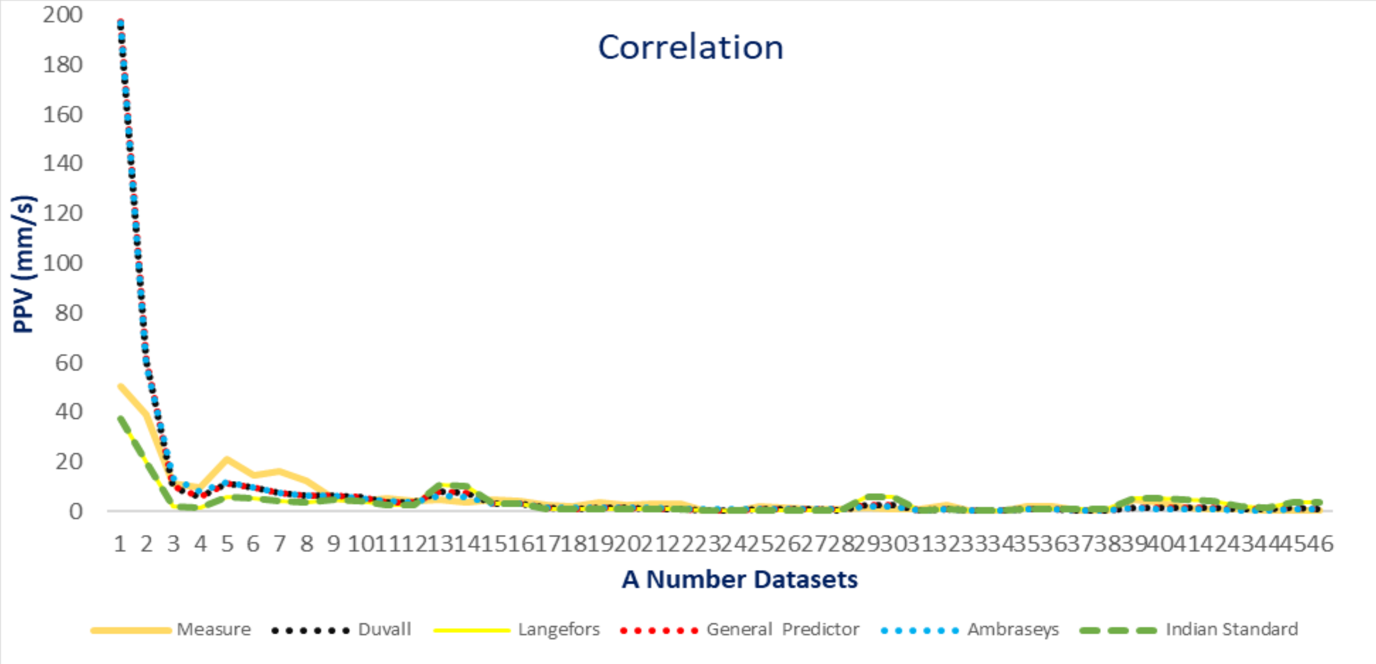

Fig. 14. Comparison between measured and predicted PPV

V. CONCLUSION

All the establish attenuation equation given by various researchers are accepted and validate for the prediction of peak particle velocity. They are not much better but good enough to make the optimization of blast design parameters for safe, smooth, and eco-environmentally blasting operation. The site constants various from one site to another site due to anisotropic behavior of rock medium. They can be only apply particular mine 'B' not the other mines. The Coefficient of Determinant (CoD), 74.34%, 73.75%, 74.26%, 74.28%, and 73.75% by Duvall-Petkof, Langefors-Kihlstrom, General predictor, Ambraseys-Hendron, and Indian Standard,respectively.

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