Magnitude of Vibration *vis-a-vis* Charge per Delay and Total Charge

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The socio-eco-environmental constraints and increase of dwellings in and around the mine workings have very recently made the blasting activities to be of high risk in day-to-day excavation works. Vibration and noise having a geometric attenuation with respect to distance, sometimes poses problem in estimating its magnitude from the predicted best-fit propagation equation derived from wide range of data. Again, for same charge per delay, the attenuation characteristic varies with the change in total charge. This paper, explains that depending upon distance of concern, the magnitude of vibration depends not only on charge per delay (CD) but also on total charge (TC) and ratio between total charge and charge per delay (TCCD). Considering the widely accepted USBM square-root scaled distance predictor equation, the authors wanted to emphasize that after understanding the attenuation characteristics of blast induced vibration magnitudes, the data should be categorized into various suitable range of distances. Thereafter, predictor equations should be determined for each category of distance and with each charge parameter, namely, CD, TC and TCCD. The equation having least standard error of estimation (SEE) should be considered as the best-fit propagation equation for that range of distance. The best-fit propagation equation, thus derived, would enable the practicing mining engineers to have an optimum maximum allowable charge parameter to be blasted in a round and have a cost-effective and eco-friendly mining operation.

Keywords : Vibration characteristics; Charge per deley; Lease standard error or estimation

INTRODUCTION

Detonation of explosive generates a family of wave that has different characteristics and velocity. For same distance of concern and same charge per delay, the magnitude of vibration varies by changing the total charge to be fired in a round of blast. Vibration being a form of energy and one of the end effects of detonation of explosive, the characteristics of its attenuation varies with the variation of charge parameters, namely, charge per delay and total charge. Therefore, no single predictor equation can be used for estimating the magnitude of vibration for all distances of concern. However, if used, might result into an erratic estimation of both magnitude of vibration and charge parameter and thereby jeopardize the structure of concern or production of the mine. Considering the widely accepted USBM square root scaled distance predictor equation, the authors in this study emphasized that after understanding the attenuation characteristics of vibration wave, empirical equation should be derived for each nature of attenuation , that is, for each range of distance. The paper, thereafter, communicated that the measured magnitude of vibration, at a distance of concern, depends not only on charge per delay (CD) but also on total charge (TC) and/or the ratio between total charge and charge per delay (TCCD). Considering the above concept and the observations from three limestone quarries, the authors attempted to put forward the methodology for derivation of empirical equation for estimation of magnitude of vibration or maximum allowable charge parameters to be used for the protection of structures in that particular range of distance. The paper explains that firstly, the attenuation characteristics of the magnitude of vibration should carefully be studied for categorization of blast records into various range of distance. Thereafter, for each range of distance, in addition to maximum charge per delay (Q) in USBM general equation, the other charge parameters, such as, total charge (TC) and ratio between total charge and charge per delay (TCCD) should be used for determination of empirical equations. The equations, thus derived for each category of distance, should include CD or TC or TCCD for Q in the USBM equation. The equation having the least standard error of estimation (SEE) for a category of distance should be accepted as the best-fit equation for that range of distance.

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LITERATURE REVIEW

Mining is at present an ever increasing challenge as work inevitably occurs in more populated areas. People being more environmental concern, the importance of cost-effective blasting coupled with high demand of mineral increases the concept of high risk management for blasting activities in day-to-day excavation work. Particle velocity, in comparison to acceleration and displacement is less sensitive to changes in geological condition and is, therefore, widely accepted as a measure of intensity of blasting[1]. Since, various parameters affect the magnitude of wave propagation and at the same time very difficult to include all the parameters for determination of propagation equation, the main parameters namely, charge per delay and distance are considered for determination of propagation equation. The other parameters that affect the magnitude of vibration, in addition to above, are blast geometry, type and amount of explosive, characteristics of stemming material and length, priming and initiation system, geo-mechanical characteristics of strata and direction of blast are included as constants, namely, the terms '*K*' and '*b*' in various predictor equations[2-7]. After the studies on particle acceleration and on energy ratio, by various researchers, Morris[7] characterized the wave propagation by suggesting a relationship between amplitude of a particle displacement, charge weight and distance of concern. Based on the works of Morris[7], Habberjam and Whetton[8] suggested a higher power for charge weight. Assuming cylindrical explosive geometry for long cylindrical charges, various researchers have commented on the vibration propagation equation in terms of peak particle velocity and have derived various empirical equations[9-18] The Swedish, in the process of evaluating the extent of rock damage, established a vibration propagation equation. They considered that summation of incremental charge quantity towards the magnitude of vibration should be considered, instead of one length, that is, total charge length for the determination of final impact of vibration[19-21]. Holmberg, in his recent study, for safety of structures, determined a correlation between the peak particle velocity and various types of geological ground condition[22-23] for designing blasts near the final pit wall treated explosive column as a single spherical charge. It is observed that except in the modifications of standards for safety of structures, no other equation or other parameters have been included for derivation of any new mathematical model for prediction of magnitude of vibration at any distance of concern[19,22,24,26].

ABOUT THE SITES

In this section, the detailed study of three mines have been in–corporated.

Mine A

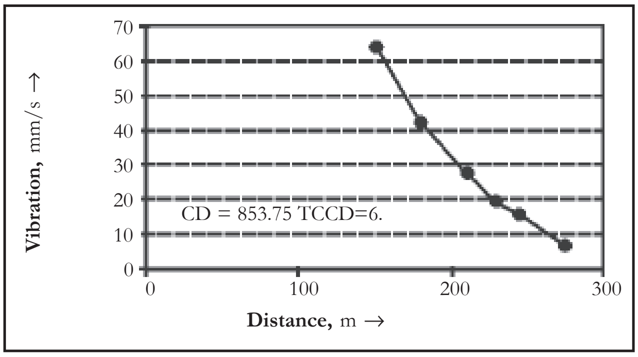
Kovaya Limestone Mine is a captive mine for 3.6 Mt/annum capacity cement plant. It is located at village Kovaya in Gujarat. The mine is operated by shovel-dumper combination with a bench height varying between 4-m and 8- m. The burden of 3-m-4.5m - 4-m -4.5-m spacing was used during the trial blasts. The explosive used was pentolite or acquadyne (83 mm dia or 125 mm dia) as booster and ANFO mixed with sawdust as column. The saw dust was mixed at a ratio of 10% by volume of ANFO used. The charge per hole varied between 31.25 kg and 62.79 kg and charge per delay varied between 85.3 kg and 853.6 kg.

Mine B Mine C

Jaypee Rewa cement has two captive mine, namely, Naubasta and Bela located at the district of Rewa in Madhya Pradesh. The deposit belongs to Bhander series of Upper Vindhyan system. Naubasta limestone mine was operated in three benches (between 5 m – 7 m bench height) and Bela in two benches (7m-10 m height). The charge consumption in these mines varied between 0.5 kg/m^3 and 0.6 kg/m^3. In both the mines charge per hole varied between 19 kg and 72 kg and fired with non-electric system of initiation.

ATTENUATION AND PROPAGATION CHARACTERISTICS OF BLAST WAVE

In nature, rock mass does not constitute an elastic, isotropic and a homogeneous medium for propagation of vibration. Therefore, non-elastic or non-dispersive rock characteristics provoke a loss of energy during wave propagation and add to the geometric attenuation. The interaction of seismic waves with time and space due to geometry of blasting face and topography of geological formation sometimes causes reflection or concentration of wave points to amplify the wave magnitudes [(Figures 1(b), 2(a), 2(d)-2(e) and 3(b)-3(c)]. Therefore, prior to any conclusive predictor equation it is essential to understand the attenuation characteristics of blast waves along the distances of concern. It has been observed that with



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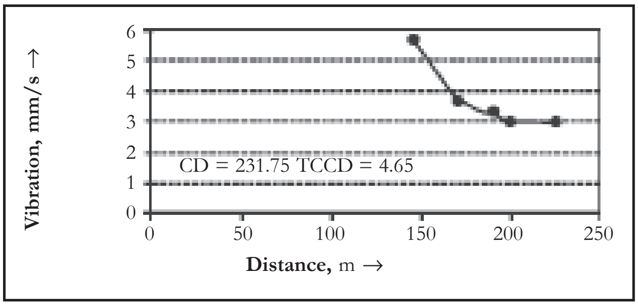

b

Figure 1 Attenuation characteristics of blast wave for Mine A

the difference in CD and TC, there is a change in the slope or the attenuation characteristics of vibration magnitudes and is not same throughout the distance of influence [Figures 1-3]. For single-hole firing it can be observed that magnitude of vibration increases with the increase in charge [Figures 1(a) and 1 (c)]. Use of excessive charge for single-hole firing, however, does not magnify the magnitude of vibration [(Figures 2 and Figure 3(a)]. The excess energy possibly adds to other environmental hazards like fly-rock, noise, etc. The difference in the attenuation characteristics of magnitude of vibration, between single and multi hole firing, indicated that TCCD plays an important role in quantifying the magnitude of vibration along the distances of concern [(Figures 2-3)]. Vibration being one of the resultant, developed on detonation of explosive, the decaying nature of blast wave, that is, the resultant force field varies with the intensity of force developed by individual delay and/or other interactive forces acting during that period, that is, TC and TCCD [(Figures 3 (a)-3(c)]. Therefore, non-linear attenuation characteristics of magnitude of vibration with respect to distance poses difficulty in estimating the magnitude of vibration or the maximum allowable charge parameter to be fired in a round from a single predictor empirical equation having wide range of data. The attenuation characteristics of magnitude of vibration, that is, the slope of the line at shorter distance is possibly affected by TCCD. Similarly at longer distance, the attenuation is affected by TC or TCCD and at intermediate distance by CD, TC or TCCD.

A wide difference between the measured and the calculated magnitude of vibration for same distance of concern will be observed, if estimated from an equation derived from a wide range of data. The propagation equation obtained from all data depends upon the density of measured magnitudes in a particular range of distance and might evolve an erratic estimation of both charge and vibration when used for other range of distances. Therefore, the quantum of deviation between the measured and the calculated

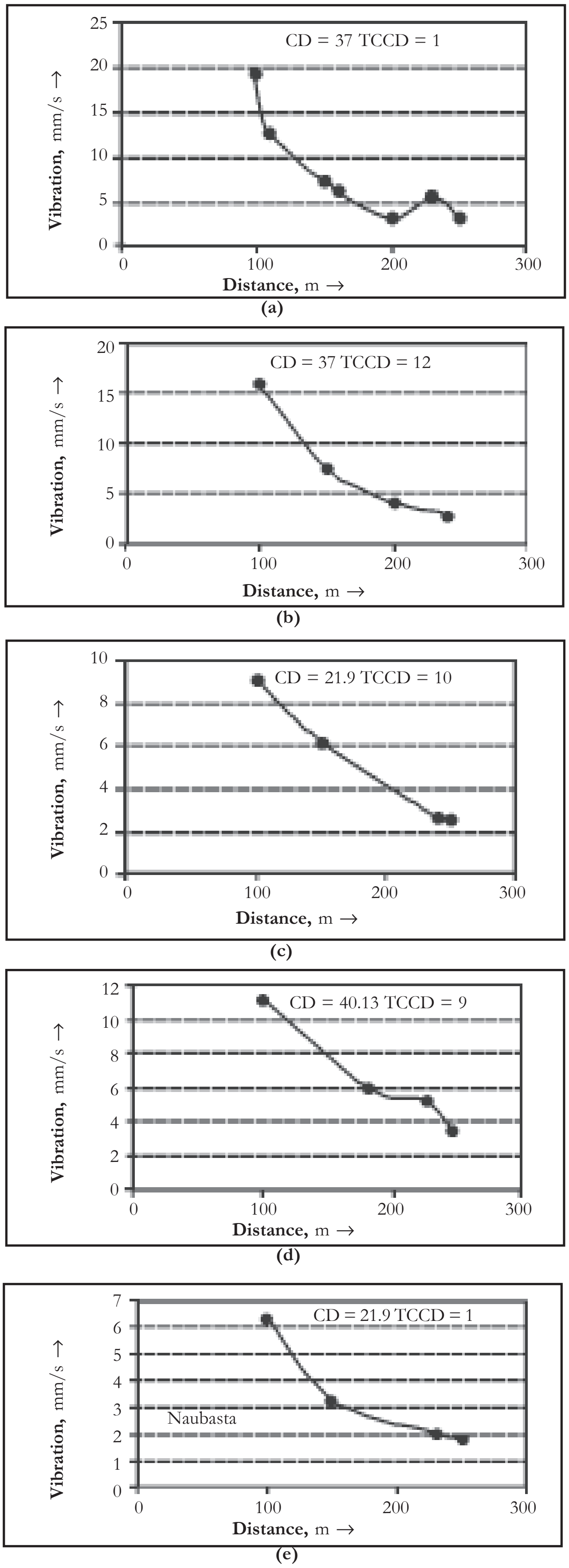

Figure 2 Attenuation characteristics of blast wave for Mine B.

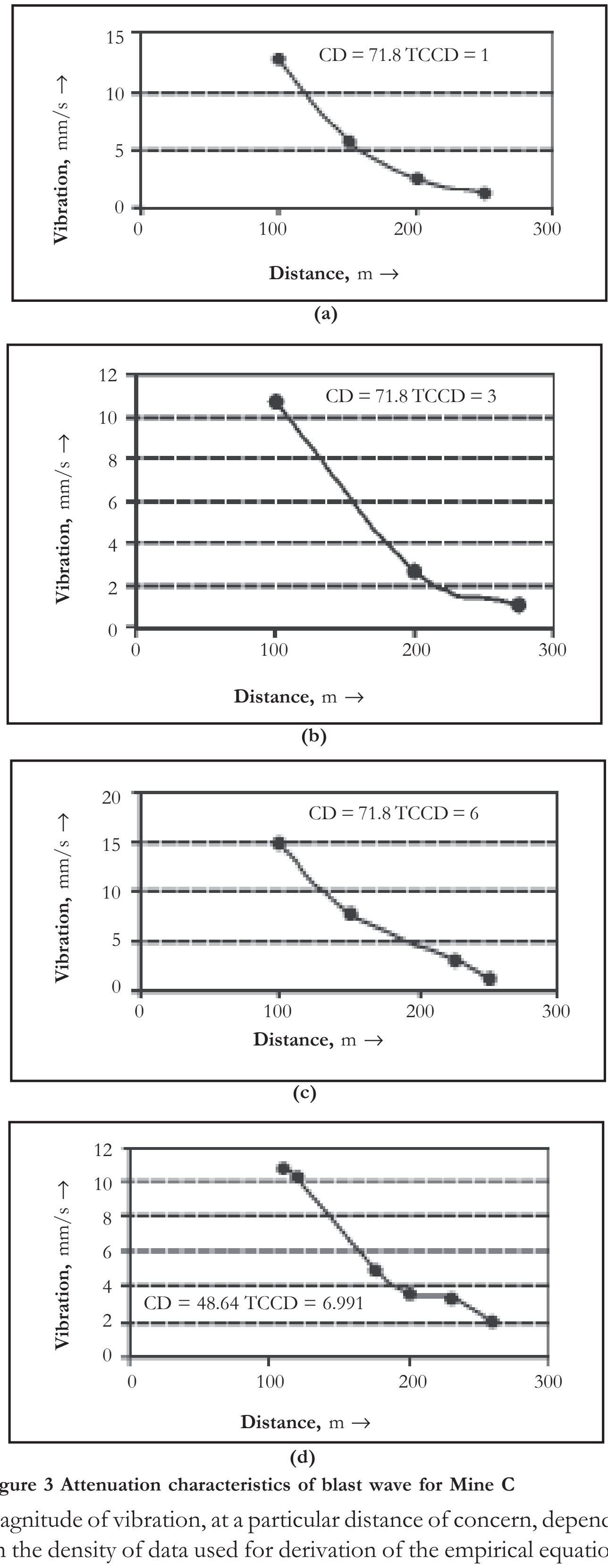

Figure 3 Attenuation characteristics of blast wave for Mine C

magnitude of vibration, at a particular distance of concern, depends on the density of data used for derivation of the empirical equation for that particular range of distance, that is, the deviation will be maximum if the magnitude of vibration, for shorter distance, is estimated from the propagation equation derived from the data of longer distances and vice-versa. Depending upon the equation derived from a range of data, an increase of solid angle or arc length

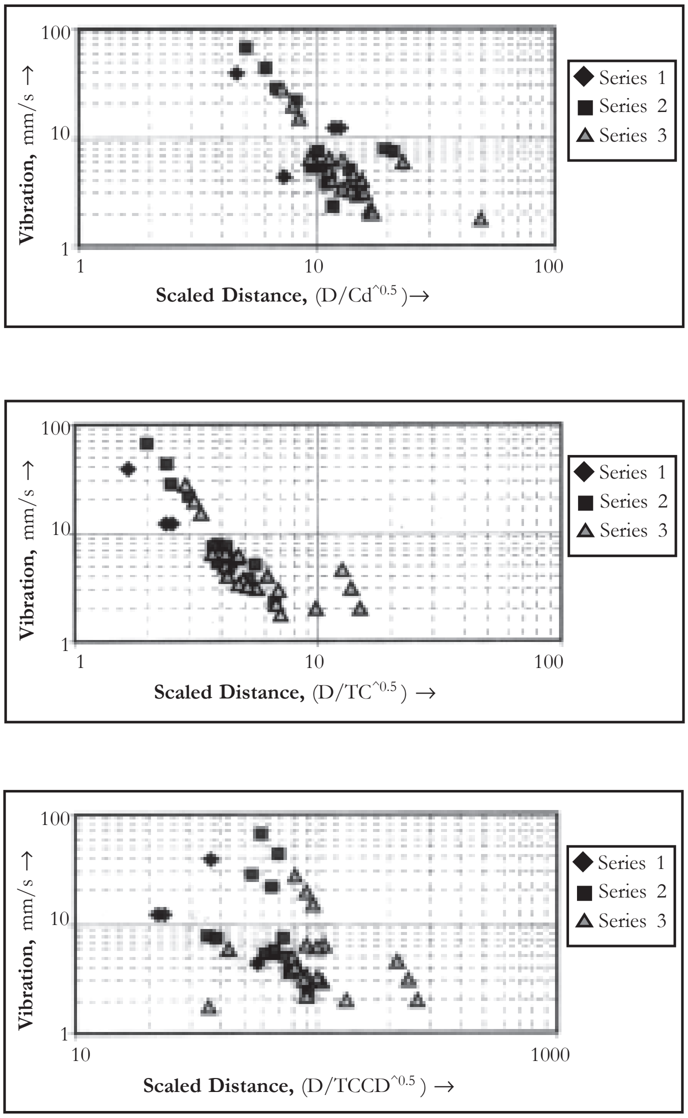

Figure 4 Scatter plots of vibration for different charge parameters for Mine A

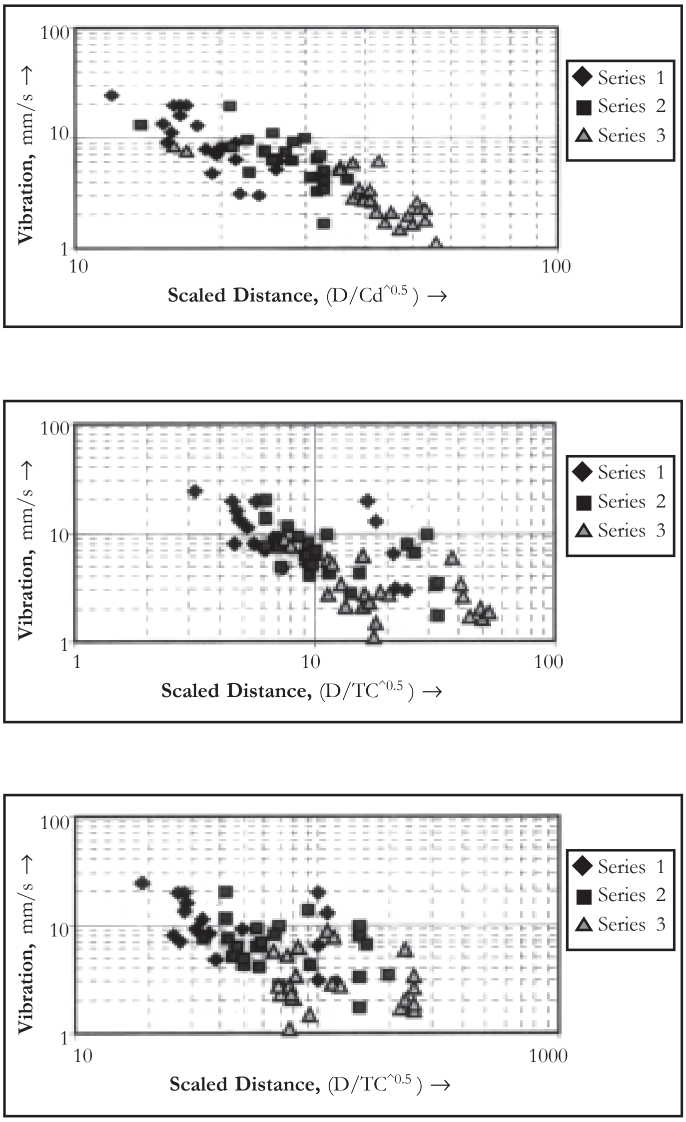

Figure 5 Scatter plots of vibration for different charge parameters for Mine B

will be observed with the increase or decrease of magnitude of scaled distance or with different range of data or range of data having different attenuation characteristics. Therefore, estimation of charge from empirical equation obtained from wide range of data might jeopardize the mining operation by unknowingly enhancing the vibration impact on the concerned structures or increase the operation cost by lowering the charge parameter. The authors, therefore, specifically illustrate that only after understanding the attenuation characteristics of magnitude of vibration and categorizing the data with respect to attenuation or distance, derivation of best-fit propagation equation for that range of distance should be predicted. The close range of scaled distance would provide less solid angle or arc length between measured and estimated magnitude and have a higher accuracy of vibration and charge parameters. This would also facilitate to have a cost-effective operation with greater safety of structures. Therefore, observing the attenuation characteristics, the authors categorized the blast records into three broad categories, nemely, less than 130 m, between 130 m and 200 m and greater than 200 m for derivation of best-fit empirical equation. Considering the USBM equation, the authors have modified the equation by only replacing magnitude of Q, maximum charge per delay. The authors used all the possible charge parameters, namely, CD, TC and TCCD for Q for determining the three propagation equations for each range of distance. The log-log scatter plot of vibration against scaled distance for each mine and for various charge parameters, namely, CD, TC, and TCCD is given in Figures 4-6. In Figures 4-6, series I, II and III represents distances of measurement less than 130-m, between 130-m and 200-m and more than 200-m, respectively. The authors, after determining the empirical equation for each charge parameter and for each category of distance, calculated the standard error of estimation [see Table 1] and the equation having least value of standard error of estimation (SEE) was selected as the best-fit predictor equation for that range of distance. The predictor equation having least SEE would, therefore, minimize the error in determining the maximum allowable charge parameter to be fired in a round of blast and contain the magnitude of vibration well within the safe limit and facilitates the practicing mining engineers to have an eco-friendly mining operation, that is, cost-effective production without hampering the safety of concerned structures.

Table 1 Details of empirical equations for all the mines

	Charge Parametre	Number of Data	USBM Equation	Index of Determination	Standard Error of Estimation (SEE)
	CD		$V = 297.641(D/\sqrt{Q})^{-1.55398}$	–0.74	0.849
Mine A	TC	48	$V = 56.0664 (D/\sqrt{Q})^{-1.46217}$	–0.82	0.841
	TCCD		$V = 362.044(D/\sqrt{Q})^{-0.9193}$	–0.40	1.056
			Distance (< 130 m)		
	CD	4	$V = 74.9158(D/\sqrt{Q})^{-0.8368}$	–0.45	2.251
	TC	4	$V = 55.0688(D/\sqrt{Q})^{-1.8318}$	–0.78	2.049
	TCCD	2	——-	—-	—-
			Distance (130 m – 200 m)		
	CD	14	$V = 563.55(D/\sqrt{Q})^{-1.7822}$	–0.71	1.035
	TC	17	$V = 121.023(D/\sqrt{Q})^{-2.077}$	–0.83	1.057
	TCCD	12	—-	—-	—-
	D		**Distance (> 200 m)**		
	CD	21	$V = 155.615(D/\sqrt{Q})^{-1.34439}$	–0.75	0.552
	TC	20	$V = 30.315(D/\sqrt{Q})^{-1.1033}$	–0.71	0.561
	TCCD	20	$V = 11.1533(D/\sqrt{Q})^{-0.1973}$	–0.12	0.583
	CD	50	$V = 163.869 (D/\sqrt{Q})^{-1.0381}$	–0.68	4.97
Mine B	TC	49	$V = 117.117(D/\sqrt{Q})^{-1.3509}$	–0.86	3.78
	TCCD	18	$V = 22.03(D/\sqrt{Q})^{-0.2972}$	–0.17	3.61
			Distance (< 130 m)		
	CD	15	$V = 74.1782(D/\sqrt{Q})^{-0.71}$	–0.46	5.36
	TC	15	$V = 119.718(D/\sqrt{Q})^{-1.4081}$	–0.81	3.85
	TCCD	15	$V = 689.55(D/\sqrt{Q})^{-1.2292}$	–0.65	1.85
			Distance (130 m – 200 m)		
	CD	19	$V = 74.19(D/\sqrt{Q})^{-0.75}$	–0.53	3.17
	TC	18	$V = 102.688(D/\sqrt{Q})^{-1.2355}$	–0.68	3.11
	TCCD	18	$V = 22.0295(D/\sqrt{Q})^{-0.2972}$	–0.17	1.21
			Distance (> 200 m)		
	CD	16	$V = 34.2073 (D/\sqrt{Q})^{-0.6834}$	0.51	4.41
	TC	16	$V = 149.699 (D/\sqrt{Q})^{-1.4688}$	0.74	4.35
	TCCD	16	$V = 0.1152 (D/\sqrt{Q})^{-0.74}$	—-	2.26
	CD	32	$V = 1722.19 (D/\sqrt{Q})^{-1.857}$	–0.82	4.89
MINE C	TC		$V = 322.01(D/\sqrt{Q})^{-1.938}$	–0.90	4.11
	TCCD		$V = 14605.6(D/\sqrt{Q})^{-1.91}$	–0.86	4.28
			Distance (< 130 m)		
	CD	9	$V = 31.0087 (D/\sqrt{Q})^{-.358346}$	–0.23	7.55
	TC	11	$V = 37.7325 (D/\sqrt{Q})^{-.677082}$	–0.46	7.65
	TCCD	12	$V = 446.457(D/\sqrt{Q})^{-.99}$	–0.68	6.03
			Distance (130 m – 200 m)		
	CD	9	$V = 609.231(D/\sqrt{Q})^{-1.466}$	–0.63	5.77
	TC	11	$V = 222.978(D/\sqrt{Q})^{-1.691}$	–0.89	3.10
	TCCD	12	$V = 43690.4(D/\sqrt{Q})^{-2.122}$	–0.69	5.60
			Distance (> 200 m)		
	CD	9	$V = 77.3344 (D/\sqrt{Q})^{-1.024}$	–0.32	1.42
	TC	11	$V = 196.565 (D/\sqrt{Q})^{-1.7987}$	–0.70	1.07
	TCCD	12	$V = 5755.06 (D/\sqrt{Q})^{-1.752}$	–0.69	1.18

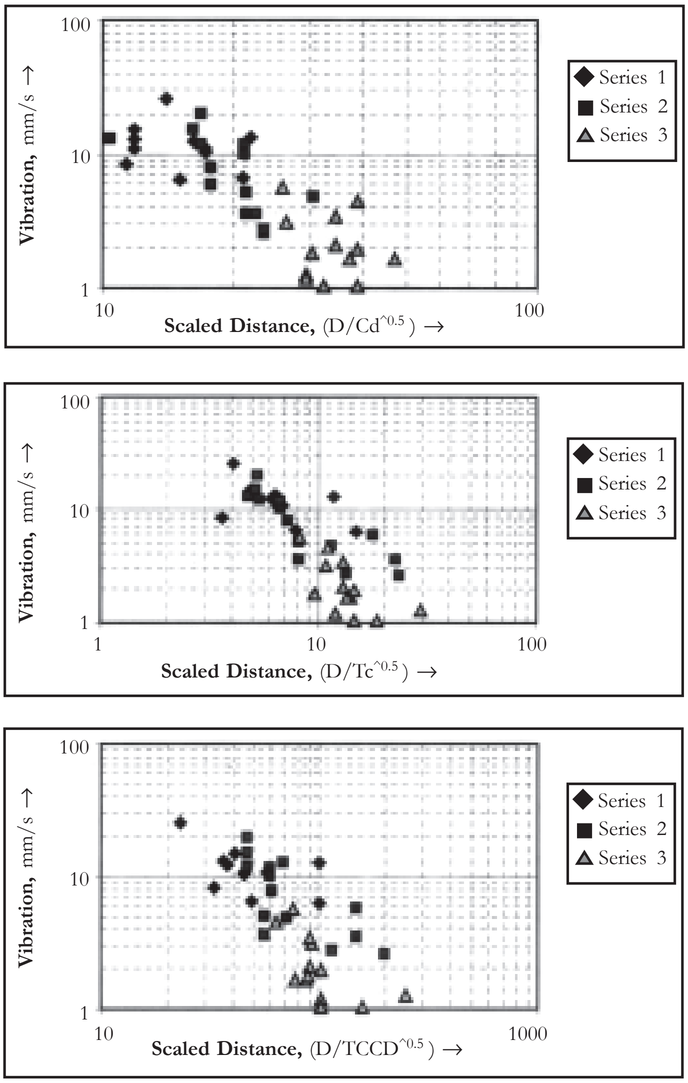

Figure 6 Scatter plots of vibration for different charge parameters for Mine C

CONCLUSION

It is very difficult to predict the actual magnitude of vibration from the predictor equation derived from wide range of data. It is observed that the attenuation of magnitude of vibration, along the distance of concern, varies with the variation of charge parameters. The attenuation characteristics, at closer distance, depends on TCCD and at longer distances TCCD or TC plays an important role in determination of magnitude of vibration. At intermediate distance, the magnitude of vibration is guided by the ratio of TCCD or the charge parameters, namely, CD or TC. Therefore, considering the attenuation characteristics of magnitude of vibration against distance of measurement, vibration data should be categorized into different range of distances. Thereafter, for each category of distance, empirical equation should be derived for each charge parameter, CD, TC and TCCD. After determining the correlation coefficient and standard error of estimation (SEE) for each category and for each empirical equation, the empirical equation having the lowest standard error of estimation should be selected as the best-fit equation for that range of distance. The best-fit empirical equation derived for that range of distance should not be used for estimation of magnitude of vibration for other range of distance. For regular blasting, the charge parameter obtained from the derived best-fit empirical equation, for that range of distance, should be implemented for the safety of concerned structures.

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