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Initiation mode of explosives vis-a-vis blast performance

Considerable progress has been achieved in recent years in the whole field of blasting science and technology. This applies to explosives formulation, initiation systems and blast simulation through advanced numerical codes. The commercial explosives in the market today are not only generally cheaper and safer than before, but also more flexible in their applications, and also geared for easy transport and delivery into the boreholes in very large volumes. The theoretical treatment of detonation process under both ideal and non-ideal conditions are noteworthy, but they are still based on somewhat hypothetical situations. The actual variables that are essential parts of normal blasting practice have not yet been taken into account in such treatments. These include the various initiation practices employed to detonate a column of explosive, from single point initiation to multi-point initiation in blastholes, and the effect on detonation characteristics of both detonators and explosives under multi-deck and multi-hole blasting conditions. The in-the-hole VOD of an industrial explosive is dependent on explosive's charge diameter and borehole diameter.

The in-the-hole VOD of explosives was measured at four experimental sites in India for different borehole diameters i.e. 150 mm to 311 mm, but the explosive composition being same particle size, density, viscosity and loaded into boreholes with the same degree of confinement. The results of the studies demonstrated that there is definite relationship in in-the-hole VOD of the explosive and the diameter of the blasthole. The study also confirmed that the explosives initiated with concentrated boosters yielded higher VOD in comparison with those explosives that were initiated with multi-point priming. The measured increase in VOD of explosives for increasing diameter of holes was up to 24%. The rate of change in in-the-hole VOD of explosives increases with increasing borehole diameter. It can be further stated that the in-the-hole VOD of the explosive reaches a fairly constant value after reaching a limiting/ threshold diameter of 311 mm.

1. Introduction

Explosives have been used for rock blasting for over a century; plausible scientific theories on rock fragmentation by blasting have emerged only during the last few decades. However, the rock breakage process is still not fully understood and controlled to the level now demanded by blasting customers. Computer modelling as an engineering tool has been extended to blasting to carry out extensive computations in blast simulations. Nevertheless, the validity of these models is dependent on knowledge of the explosive and rock interaction process (Leiper and Plessis, 2001; Cundall et al, 2001; Cunningham, 2001). Therefore, the prediction of explosive performance is crucial in understanding the explosive-rock interaction process and rock breakage.

There is now a very wide range of commercial explosive products available to the mining industry. Their performance is dependent upon their detonation properties in addition to the rock type and blasthole diameter. The selection of a suitable explosive for a given geotechnical environment in order to produce the desired blasting results has become more important and vital to the economics of mining operations. This means that the ability to understand explosive behaviour has become even more important than it has been. A pre-requisite to achieving this goal is an improved understanding of detonation science.

The methods available for determining explosive performance range from simple calculations to field tests. The essential objective in the use of explosives for rock breakage consists in having a chemically concentrated energy source, properly placed and in sufficient quantity so that when it is liberated in a controlled manner, in time and space, it can achieve the fragmentation of the rock material. Chemical explosives, depending upon the conditions to which they are exposed, can offer different behaviour than would be expected from their explosive matrix. To determine the suitability of an explosive substance for a particular use, its physical properties must be known first. The usefulness of an explosive can only be appreciated when the properties and the factors affecting them are fully understood. The decomposition processes of an explosive compound are: the actual combustion, the deflagration and lastly, the detonation.

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The nature of the compound itself as well as the initiation system and the external conditions govern the decomposition process. Detonation is a physico-chemical process characterised by its high speed of reaction and the formation of large quantities of gaseous products at an elevated temperature, which build up a great expansive force. In detonating explosives, the speed of the first gasified molecules is so large that they do not lose their heat through conductivity to the un-reacted zone of the charge but transmit it by shock, deforming it, provoking its heating and adiabatic explosion, generating new gases. The process repeats itself with undulating movements that affect the whole explosive mass and is called the shock wave (Chironis, 1985; Konya and Walther, 1990).

Once the explosive has been initiated, the first effect produced is the generation of a shock or pressure wave that propagates through its own mass. This wave is the carrier of the energy necessary to activate the molecules of the explosive mass that are around the initial energised focus which then starts a chain reaction. At the same time that this wave is produced, the reacting explosive mass produces a large quantity of high temperature gases. If this secondary pressure acts upon the rest of the mass that is un-detonated, its effect is added to that of the primary pressure wave, passing from the process of deflagration to that of detonation. If the gas pressure wave performs to the contrary in the un-reacted explosive mass, a system of slow deflagration takes place, slowing down the explosive reaction and causing a loss of energy in the primary detonation wave that can even result in the wave becoming incapable of energising the rest of the explosive mass, thereby stopping detonation.

In-the-hole VOD of explosives is one of the important parameters that affect the blast results. The detonation wave starts at the point of initiation in the explosives column and travels at supersonic speed, in relation to the sonic velocity of the explosive material itself. This velocity remains fairly constant for a given explosive matrix but varies from one explosive matrix to another depending primarily on the composition, particle size, density, charge diameter and degree of confinement. Cast boosters are used as priming systems to initiate or activate the detonation of the explosive column in the blasthole so that there should be sufficient run-off of the VOD in the blasthole. In order to understand the role of concentrated or distributed cast boosters in the blasthole loading configuration on energy release and release rate characteristics, the field experiments were carried out at Kusmunda opencast mine, Sonepur Bazari opencast mine, Jayant opencast mine and Umrer opencast mine in India.

2. Geological details of experimental sites

2.1 Sonepur Bazari opencast mine

Sonepur Bazari opencast mine of Eastern Coalfields Limited is located in the eastern part of Raniganj coalfields. Four coal seams viz. R-IV, R-V, R-VI and R-VII are mainly exposed in the mine. Presently, seams R-V and R-VI are being extracted by opencast method of mining. The total reserve of the project is 188.26 Mt.

2.2 Kusmunda opencast mine

Kusmunda opencast mine is located on the western bank of Hasdeo river in the central part of Korba coalfields. The upper Kusmunda seam in-crops below a cover of 6-31 m in an elliptical fashion and overlies lower Kusmunda seam after sandstone parting of 65 to 75 m. The area constitutes a doubly plunging anticlinal trend. The lower Kusmunda seam is composite in the western part of the property but the same splits into two section viz. lower Kusmunda (top split) and lower Kusmunda (bottom split) eastwards. One oblique set of faults strike across the anticlinal axis, while the other set of faults appear to strike parallel to the anticlinal axis. The seam generally has a dip ranging from 50 to 100 (1 in 5.6 to 1 in 11.5) and the overall grade of coal is Grade 'F'.

2.3 Jayant opencast mine

Jayant opencast mine of Northern Coalfields Limited is located in the Singrauli coalfields. The area geographically lies between latitudes 24°6'45"to 24°11'15" and longitudes 82°36'40" to 82°41'15". The project is situated on a high plateau ranging from 300 m to 500 m above MSL. The rocks are of Lower Gondwana formation. There are three coal seams namely Turra, Purewa bottom and Purewa top. The thicknesses of the coal seams are 13-19 m, 9-12 m and 5-9 m respectively. The direction of strike is towards E-W with broad swings. The dip of the coal seam is 10-30 in northerly direction. The total leasehold area is 2,464 hectares. The average stripping ratio is 2.6 m^3 of overburden per tonne of coal. The overview of the mine is depicted in Fig.1.

Fig.1 The overview of the Jayant opencast mine

2.4 Umrer opencast mine

Umrer project of Western Coalfields Limited is located in the Umrer coalfields. Three coal seams viz. seam IV, seam III and seam II are mainly exposed in the mine. Presently, production is going on in all three seams. The average stripping ratio of the mine is 2.7 m^3 per tonne coal produced. The dip of the mine is 1 in 10.

3. Experimental details

Industrial chemical explosives are classified in two large groups, according to their shock wave velocity. They are rapid detonating explosives and slow deflagrating explosives. The detonating explosives are divided into primary and secondary, depending upon their applications. The primary have high energy and sensitivity and are used as initiators for the secondary, among which we can mention the compounds used in blasting caps and cast primers (mercury fulminate, PETN, Pentolite, etc.). The secondary explosives are those that are applied to the breakage of rocks and although less sensitive than the primary, they do more useful work (Du Pont, 1980; Mohanty, 1981). The most common industrial explosives for civilian use are ANFO, ALANFO, slurries or watergel, emulsions and heavy ANFO. It is well recognised that commercial explosives exhibit non-ideal detonation behaviour since their performance is influenced by blasthole diameter and confinement. Byers Brown (2002) noted the fact that although the basic physico-chemical nature of non-ideal detonation and the law governing it in mathematical form have been known for over 55 years, there is still a lot of work is to be done. However, a number of mathematical codes are available to solve the problem with some degree of accuracy.

The energy calculations are based on single point initiation and steady state detonation of the explosive column in the blasthole, the former is rarely employed in actual practice in deep hole coal mining because the length of explosives column is sometimes 35-40 m. A common practice is to employ two boosters located at two locations in the blasthole, which may or may not have the same delays. The explosive column may also be traced with detonating cords of specific strengths and connected to these boosters (Mohanty, 2009). Pentolite was used as cast boosters and the explosives used were emulsion in the experimental studies. An attempt was made to maintain the prill size of AN as identical in the study because the prill size of AN has influence upon the density of the explosives. In Indian context the imported prill size of AN is different than those of indigenous AN prill.

3.1 Details of blast performed at Sonepur Bazari opencast mine

Field experiments with varying blast designs were conducted at Sonepur Bazari opencast mine. In each experiment, one blasthole with concentrated boosters and another blasthole on the same bench with distributed boosters as shown in Fig.2 were detonated. The in-the-hole VOD of both the holes were recorded while keeping the drilling pattern, blast design parameters and explosives matrix and loading practice identical. The blasthole loading configuration and the recorded in-the-hole VOD of explosives at Sonepur Bazari opencast mine is presented in Table1.

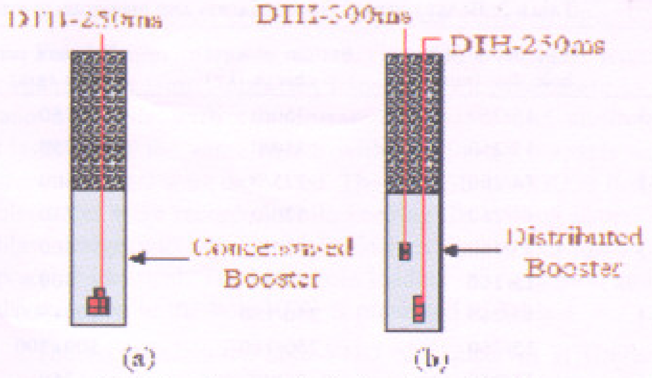

Fig.2 Cast boosters distribution in the blasthole

The recorded in-the-hole VOD of explosives at Sonepur Bazari opencast mine due to variation in the placement of boosters locations (concentrated and distributed) is shown in Fig.3. The other blast design parameters viz. length of explosives, explosives column in bottom deck, density of explosives, drill diameter, percentage of cast booster etc. in each experiment (two holes) were kept identical in both the holes.

3.2 Details of blast performed at Kusmunda opencast mine

The field experiments with varying blast designs were conducted at Kusmunda opencast mine. In each experiment i.e. one blasthole with concentrated boosters and another blasthole on the same bench with distributed boosters as shown in Fig.2 were detonated. The in-the-hole VOD of both the holes were recorded while keeping the drilling pattern, blast design parameters and explosives matrix and loading practice identical. The blasthole loading configuration and the recorded in-the-hole VOD of explosives at Kusmunda opencast mine is presented in Table 2.

The recorded in-the-hole VOD of explosives at Kusmunda mine for various booster placement locations (concentrated and distributed) is shown in Fig.4. The recorded in-the-hole

Table 1: Blast loading configuration and recorded in-the-hole VOD of explosives at Sonepur Bazari opencast mine

	Hole depth (m)/ hole dia. (mm)	Bottom charge/ top charge (kg)	Boosters per hole (gm)	In-the-hole VOD of explosives (m/s)	Boosters loading configuration	% change in VOD
SBP- 1	12.5/270	300/0	750	4729	Concentrated	3.20
	12.5/270	300/0	750	4582	Distributed	
SBP- 2	26/ 270	275/0	750	4938	Concentrated	10.40
	26/270	320/0	750	4473	Distributed	

TABLE 2: BLAST LOADING CONFIGURATION AND RECORDED IN-THE-HOLE VOD OF EXPLOSIVES AT KUSMUNDA OPENCAST MINE

	Hole depth (m)/ hole dia. (mm)	Bottom charge/ top charge (kg)	Boosters per hole (gm)	In-the-hole VOD of explosives (m/s)	Boosters loading configuration	% change in VOD
KUS-1	15/260	350/0	750	5535	Concentrated	7.87
	15/260	350/0	750	5131	Distributed	
KUS-2	14/260	275/0	600	5168	Concentrated	6.51
	14/260	320/0	750	4852	Distributed	
KUS-3	15/160	175/0	400	5334	Concentrated	13.63
	15/160	175/0	400	4694	Distributed	
KUS-4	15/260	250/180	500+300	4853	Concentrated	10.47
	15/260	250/180	500+300	4393	Distributed	
KUS-5	15/260	380/0	750	5069	Concentrated	15.44
	15/260	380/0	750	4391	Distributed	
KUS-6	15/260	175/0	500	4939	Concentrated	6.95
	15/260	190/0	500	4618	Distributed	

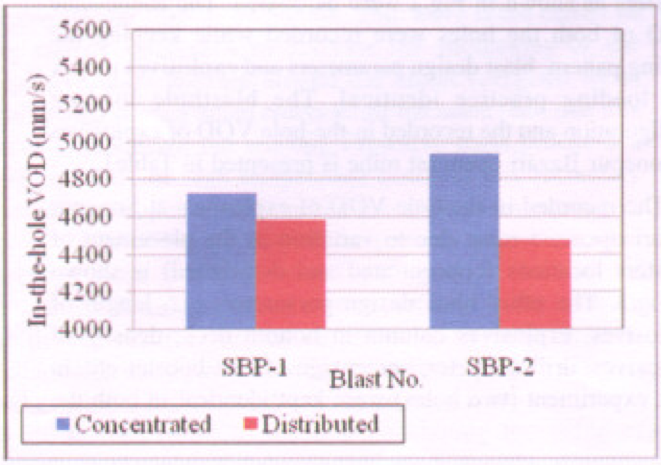

Fig.3 A comparison of the measured in-the-hole VOD of explosives with varying placement of boosters in the blastholes at Sonepur Bazari opencast mine.

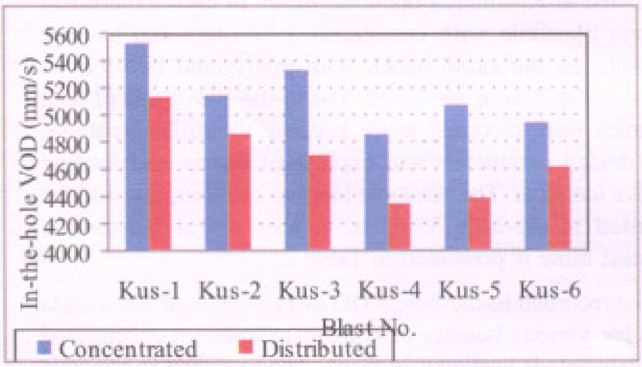

Fig.4 Measured in-the-hole VOD for various booster placements at Kusmunda opencast mine

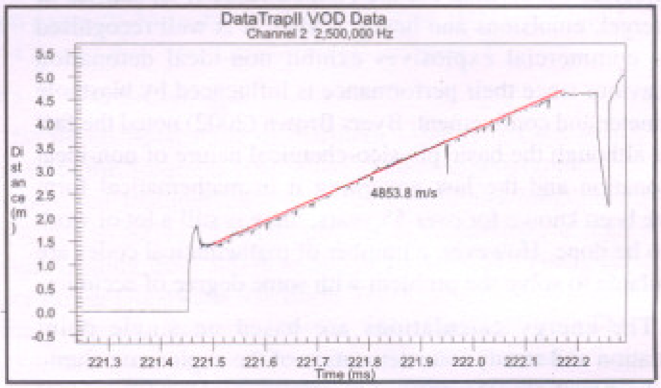

Fig.5 In-the-hole VOD trace where boosters are at one location at Kusmunda opencast mine

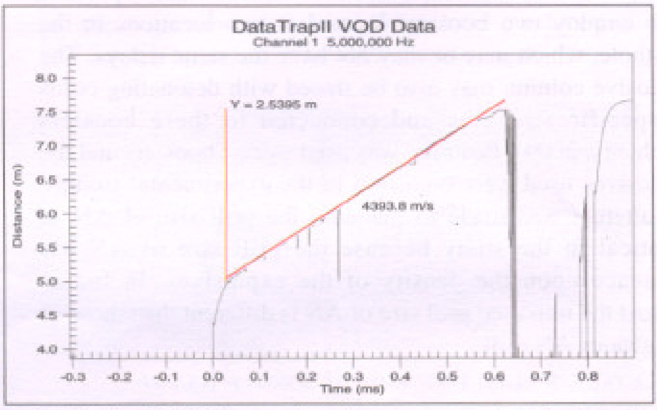

Fig.6 In-the-hole VOD trace where boosters are at two locations at Kusmunda opencast mine

VOD traces for concentrated and distributed booster placements are presented in Figs.5 and 6.

3.3 DETAILS OF BLAST PERFORMED AT JAYANT OPENCAST MINE

Field experiments with varying blast designs were conducted at Jayant opencast mine. In each experiment i.e. one blasthole with concentrated boosters and another blasthole on the same bench with distributed boosters as shown in Fig.2 were detonated. The in-the-hole VOD of both blastholes were recorded while keeping the drilling pattern, blast design parameters and explosives matrix and loading practice identical. The blast hole loading configuration and the recorded in-the-hole VOD of explosives at Jayant opencast mine is presented in Table 3. The recorded in-the-hole VOD of explosives at Jayant opencast mine for various booster placement locations (concentrated and distributed) is shown in Fig.7.

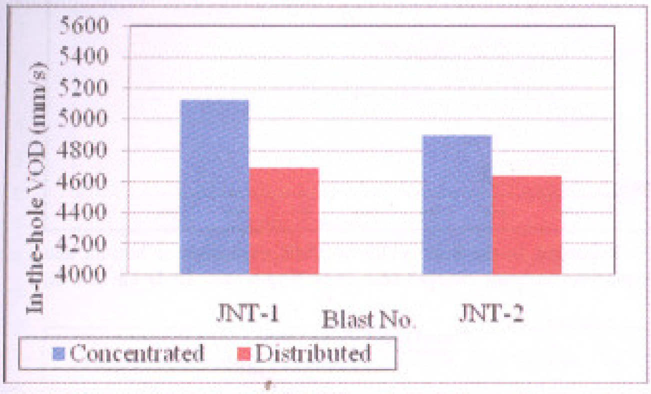

Fig.7 Measured in-the-hole VOD for various booster placements at Jayant opencast mine

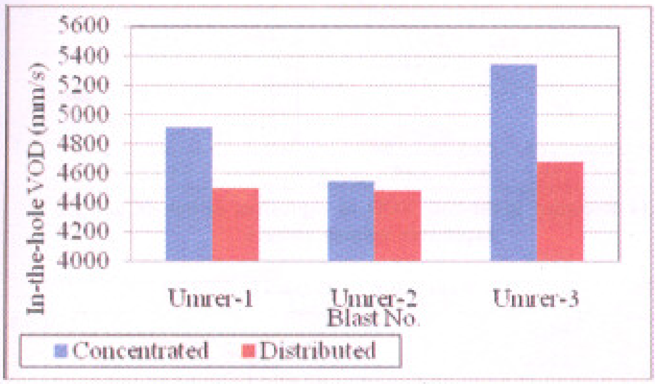

Fig.8 Measured in-the-hole VOD of explosives for various booster placements at Umrer opencast mine

3.4 Details of blast performed at Umrer opencast mine

Field experiments with varying blast designs were conducted at Umrer opencast mine. In each experiment i.e. one blasthole with concentrated boosters and another blasthole on the same bench with distributed boosters as shown in Fig.2 were detonated. The in-the-hole VOD of both blastholes were recorded while keeping the drilling pattern, blast design parameters and explosives matrix and loading practice identical. The blast hole loading configuration and the recorded in-the-hole VOD is presented in Table 4.

The recorded in-the-hole VOD of explosives at Umrer opencast mine for various booster placement locations (concentrated and distributed) is shown in Fig.8. The recorded in-the-hole VOD traces for concentrated and distributed booster placements are presented in Figs.9 and 10.

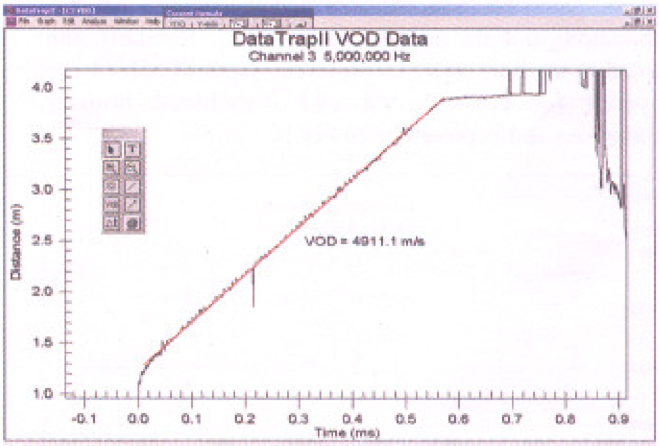

Fig.9 In-the-hole VOD trace when boosters are at one location at Umrer opencast mine

Table 3: Blast loading configuration and recorded in-the-hole VOD at Jayant opencast mine

	Hole depth (m)/ hole dia. (mm)	Bottom charge/ top charge (kg)	Boosters per hole (gm)	In-the-hole VOD of explosives (m/s)	Boosters loading configuration	% change in VOD
JNT-1	13/160	210/0	250	5125	Concentrated	9.41
	13/160	210/0	250	4684	Distributed	
JNT-2	22/270	630/ 420	1200+800	4895	Concentrated	5.56
	22/270	630/ 420	1200+800	4637	Distributed	

Table 4: Blast loading configuration and recorded in-the-hole VOD at Umrer opencast mine

	Hole depth (m)/ hole dia. (mm)	Bottom charge/ top charge (kg)	Boosters per hole (gm)	In-the-hole VOD of explosives (m/s)	Boosters loading configuration	% change in VOD
UMR-1	7.5/270	250/0	500	4911	Concentrated	10.63
	7.5/270	250/0	500	4439	Distributed	
UMR-2	7.5/160	90/0	200	4547	Concentrated	1.49
	7.5/160	90/0	200	4480	Distributed	
UMR-3	7.5/270	200/0	400	5539	Concentrated	18.48
	7.5/270	200/0	400	4675	Distributed	

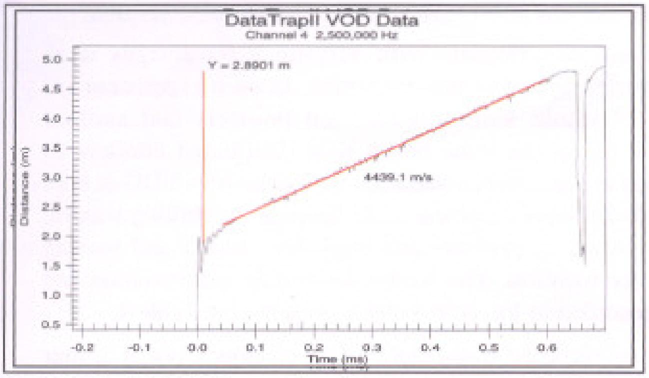

Fig.10 In-the-hole VOD trace when boosters are at two locations at Umrer opencast mine

4. Discussion

The recorded in-the-hole VOD at different drill hole diameters were compared for concentrated and distributed booster combinations and are reproduced in Fig.11. Similarly, the recorded in-the-hole VOD for different depth of holes were compared for concentrated and distributed booster combinations and is presented in Fig.12.

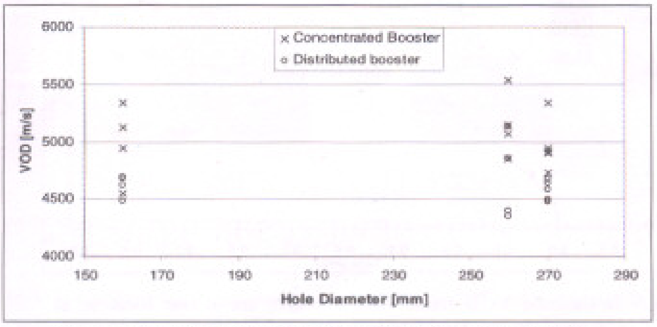

Fig.11 Plot of recorded VODs against hole diameters for concentrated and distributed booster locations

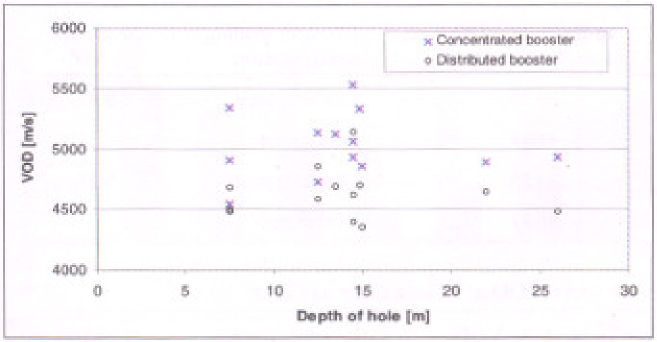

Fig.12 Plot of recorded VODs against depth of hole for concentrated and distributed booster locations

The recorded in-the-hole VOD of explosives of 26 blast holes for different diameter and depth of holes are plotted and are presented in Figs.11 and 12 respectively. At number of instances the recorded VOD in bottom deck was higher than the recorded VOD on top deck (Figs. 13, 14 and 15).The in-the-hole VOD of explosives from various drill diameters were recorded at Umrer and Kusmunda projects for a number of experimental set up. The recorded data are given in Tables 5 and 6 respectively.

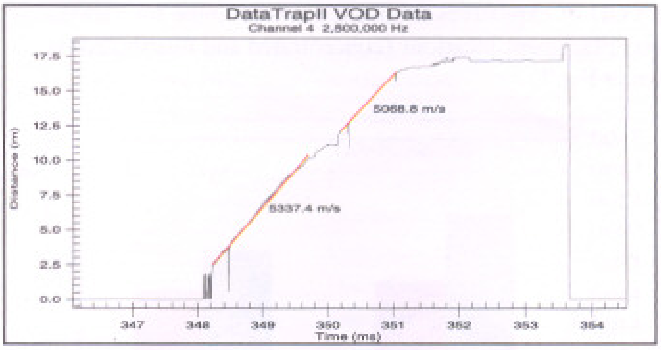

Fig.13 Recorded In-the-hole VOD of SME explosive at bottom and top explosives column charges (the deck length was 10 D i.e. 2.7 m)

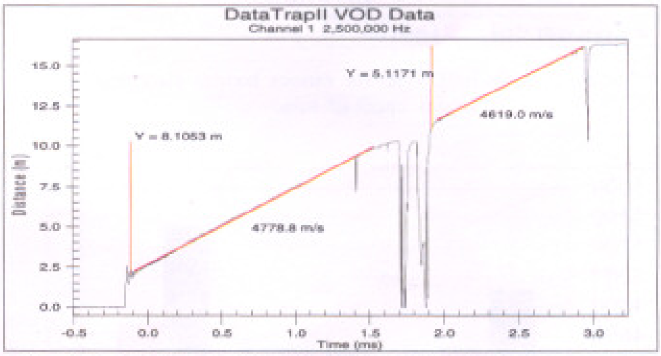

Fig.14 Recorded in-the-hole VOD of explosives in bottom and top explosives column charges

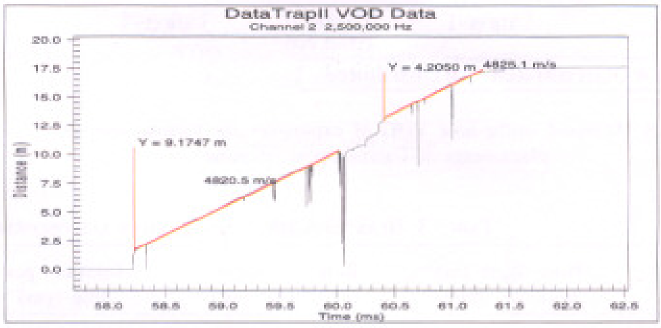

Fig.15 Recorded in-the-hole VOD of explosives in bottom and top explosives column charges

5. Results and conclusions

The recorded in-the-hole VOD of explosives data from 26 holes i.e. 13 sets of experiments with varying hole depths and drill hole diameters shows that when the boosters are placed at one location (concentrated) e.g. at sub-grade levels, higher VODs were recorded in all the mines. There was drop in the VOD when the boosters were distributed at two locations (distributed). Concentrated boosters in a blasthole always yielded higher in-the-hole VOD when compared to the distributed booster charging configuration. Thus, it may be

TABLE 5: RECORDED IN-THE-HOLE VOD OF EXPLOSIVES AT DIFFERENT BOREHOLE DIAMETERS AT UMRER PROJECT

	Hole diameter (mm)	In-the-hole VOD of explosives (m/s)
1	160	4480
2	160	4494
3	160	4565
4	160	4638
5	250	4778
6	250	4820
7	270	4835
8	270	4840
9	270	4911
10	270	5019
11	270	5148
12	270	5155
13	270	5339

TABLE 6: RECORDED IN-THE-HOLE VOD OF EXPLOSIVES AT DIFFERENT BOREHOLE DIAMETERS AT KUSMUNDA PROJECT

	Hole diameter (mm)	In-the-hole VOD (m/s)
1	160	4498
2	160	4503
3	160	4538
4	160	4599
5	160	4642
6	160	4694
7	260	4778
8	260	4819
9	260	4854
10	260	5058
11	260	5069
12	260	5128
13	260	5138
14	260	5140

stated that velocity of detonation are always higher with the concentrated booster loading configuration as compared to the distributed booster loading configuration.

The explosive energy released for non-decked blasts have been shown to be sensitive to the mode of initiation, especially the common practice of using various combinations of detonating cords and boosters in the same hole. It has been experimentally shown that the performance of the explosives at the bottom and top of the explosive column is different (Fig.13). It appears that the VOD and the pressure at the hole bottom is higher than that at the top of the explosive column due to the higher density explosive product. The recorded in-the-hole VOD also confirmed that when the length of explosives column is more, the increase in the VOD with a concentrated booster configuration is more (Figs. 5, 6, 9 and 10). The run-off of VOD was very smooth when boosters were concentrated at one location.

There exists a positive and significant relationship between in-the-hole velocity of detonation and borehole diameter (Tables 5 and 6). The relationship between in-the-hole VOD and blasthole diameter may be approximated for different geo-mining scenarios. The in-the-hole VOD for the product tested reaches a fairly constant value at a limiting/threshold diameter of 311mm. The measured increase in VOD for increasing blasthole diameter of holes was up to 24% in experimental studies. However, it was difficult to draw a definite conclusion that there is a significant increase in the in-the-hole VOD with an increase in the diameter of the blasthole or depth of holes.

6. Acknowledgements

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