Influence of initiation mode of explosives in opencast blasting on ground vibration

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The measurement and analysis of blast induced vibration is presently more state of the art than ever before. A modern understanding of the basic concepts behind vibration effects can help a beleaguered end user more confident about what their measurement really mean. It is reported that blast conducted with non-electric initiation system enhanced the efficiencies of Heavy Earth Moving Machinery (HEMM) machineries and reduced the reported nuisance of blasting. The developed countries are adopting the third generation of electronic detonators but in India the use of detonating fuse for blast initiation is still in practice. There are number of reasons stated by mine officials for this practice being still followed by mining industry. The one of the important reasons is the price ratio of Nonel tubes and detonating cords/fuse, which is comparatively very high in India in comparison with the other countries. A study was planned to investigate the influence of direction of initiation in the blasthole on ground vibration. The four opencast coal mines were selected for the study purpose. The two blasts at same bench were conducted while keeping all the blast design and explosives parameters such as, burden, spacing, hole depth, hole diameter, charge per hole, charge per delay, total charge in blast round, etc., identical. The explosive make for a set of two blasts were of same manufacture and both the blasts were conducted on same day to avoid the variation in explosive formulation. Blast induced vibrations were monitored at 6–11 locations. The experimental set of blasts includes single hole blasts, production blasts, as well as dragline blasts, performed by only changing mode of initiation, i.e. initiation of booster with detonating cord and with non-electric initiation in the bottom of the hole at floor level while maintaining all other parameters identical. The result indicated that former generated lower vibration levels compared with previous mode of initiation. The reductions in vibrations were observed up to 36·2% by for blastholes of depth >20 m. The minimum reduction of vibration was 8·2% for shorter blastholes depth of 7·5 m.

Keywords: Blasting, Initiation, Vibration, Explosives, Blast vibration

Introduction

Recent developments in blasting technology and accessories sprouted some new concept, which are anticipated to have considerable impacts on ground vibrations. The location of primed booster is important in ascertaining strain at particular location. The position along the hole at which the priming occurs changes the explosive performance and effect the resultant amplitude of vibration recorded at the structure concern. Kopp and Siskind (1986) reported that the orientation of blast and direction of initiation has a noticeable effect on the magnitude of vibration. Singh and Vogt (1998) reported that the peak particle velocity (PPV) measured in the flank opposite to the blast initiation was almost double the PPV measured in the flank at the initiation end. They used the down the hole initiation with short delay detonators which improved fragmentation while at the same time minimises ground vibrations.

Although researchers have tried to study and document the impact of blast design parameters on blast vibration and have reported in literatures (Fordyce *et al.*, 1993; Rodgers, 2003; Lucca, 2005; Singh *et al.*, 2005; Spathis and Brodbeck, 2005), but the impact of mode of explosives initiation sequences on generation of vibration has yet remain untouched. A study was planned to evaluate the impact of mode of initiation sequences of explosives in blasthole on the magnitude of blast vibration.

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Theoretical background

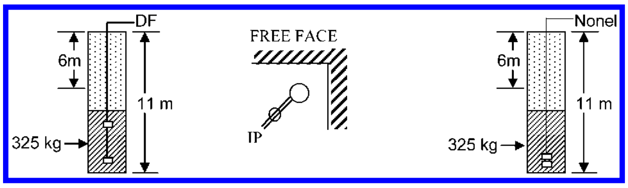
Rock breakage by explosives involves the action of an explosive and the response of the surrounding rock mass within the realms of energy, time and mass. As breakage at floor level is extremely important in bench blasts, the priming should be such as to produce maximum strain at that level. Bottom priming gives maximum utilisation of explosive energy, increasing fragmentation and displacement of the rock with minimum flyrocks. This is due to the fact that the detonation progresses upward towards the stemming while the gases of the explosion are entirely confined within the rock mass, until the stemming material is ejected and allows their escape. Just opposite to the bottom priming, in top priming a high strain wave is propagated towards the subdrilling zone where, of course, its energy is dissipated and therefore wasted. If the explosive is initiated with a primer at the highest point, the superposition of the strains generated by adjacent charge elements gives a lower result at any point of stemming.

The elimination of premature escape of the gases into the atmosphere, with adequate stemming height, improves fragmentation and rock displacement by Bubble Energy. For elongated charges, the efficiency of the stemming with top priming is less because the inert stemming material as well as the rock itself at the top, start moving some milliseconds before detonation of the lower part of the explosive. The fall of the pressure of the gases is greater in long explosive columns with low detonation velocity and insufficient stemming. When the detonation reaches bench floor level, the pressure of the gases falls rapidly from its highest value due to their escape towards lower pressure zones. This phenomenon gives poor fragmentation in the bottom of the blasthole and especially a reduced displacement of the lower rock. If the priming takes place at floor level and not at bottom of the blasthole, an increase in peak strain is obtained owing to simultaneous detonation of the two parts of the charge that are equidistant from that point.

Brief geology of experimental sites

The study was conducted at four open pit mines in India. The Sonepur Bazari project of Eastern Coalfields Limited is located in the eastern part of Raniganj Coalfields. In the project area, four coal seams, namely, R-IV, R-V, R-VI and R-VII are mainly exposed. Presently, seams R-V and R-VI are being extracted by opencast method of mining. The mine produces $\sim$3·5 Mt of coal and overburden removal of about $11{\cdot}5\times10^6$ m^3 per annum. The average stripping ratio of the mine is 4·72 m^3 per tonne of coal produced. The total reserve of the coal is 188·26 Mt.

Jayant and Nigahi projects of Northern Coalfields Limited are 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 rocks are of Gondwana formation having coal bearings of Barakars within it. Three coal seams, namely, Purewa top, Purewa bottom and Turra are being mined out. The thickness of Purewa top, Purewa bottom and Turra seams are 5–9, 9–12 and 13–19 m respectively. The thickness of partings between Purewa bottom and Purewa top seams is 17–32 m whereas between Turra and Purewa bottom seams it is 52–59 m. The external overburden above Purewa top seam is 12–95 m. The mineable coal reserves are 348·9 and 491·8 Mt respectively. The average stripping ratio is 2·6 m^3 of overburden per tonne of coal. The direction of strike is towards E-W with broad swings. The dip of the coal seam is 1–3° in northerly direction. Both the mines produce $\sim$10 Mt of coal and $\sim 3\times10^7$ m^3 of overburden per annum.



1 Blast design layout with charging pattern for signature blast detonated by DF and Nonel initiation system at Jayant project

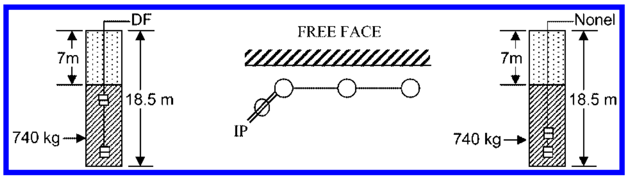
Kusmunda project is located on the western bank of Hasdeo River in the central part of Korba Coalfields in the district of Korba in Chhattisgarh State. The upper Kusmunda seam incrops below a cover of 6–31 m in an elliptical fashion and overlies lower Kusmunda seam after sandstone parting of 65 to 75 m. The lower Kusmunda seam is composite in western part of the property but the same splits into two sections, namely, lower Kusmunda (top split) and lower Kusmunda (bottom splits) 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 (one in 5·6 to one in 11·5). The mine produces $\sim$8 Mt of coal and overburden removal is of 10^7 m^3 annually.

Experimental details

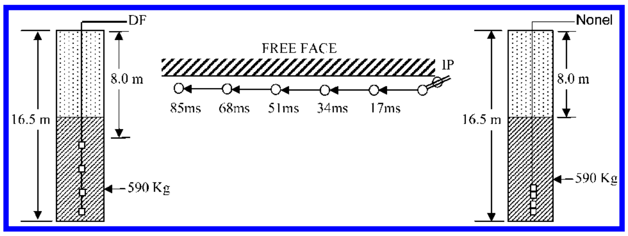
The set of experiments were planned in such a way that the two blasts are performed at same bench face and are blasted side by side. The blast design parameters, explosive parameters were kept identical. The variations were only in blast initiation systems, i.e. with detonating cords/fuse and Nonel tubes with bottom initiation at floor level. Blast vibrations were monitored by triaxial geophones in an array at 6–11 similar locations for each set of experiments.

It was decided to first conduct six sets of single hole blasts to eliminate the scatter of delay interval and their impact on generation of blast vibration. Figure 1 depicts the details of single hole blasts performed at Jayant project with top (detonating fuse (DF)) as well as with bottom initiations by non-electric initiation. Vibrations were monitored at 10 locations in both the blasts.

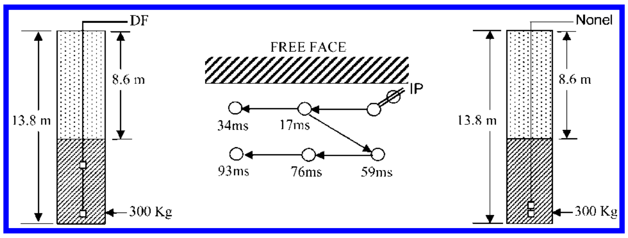
The impact of initiation sequences were also studied by detonating three holes instantaneously at Nigahi project. Two rounds of experiments were performed by only varying the mode of initiation. The blast lay out is depicted in Fig. 2. Vibrations were monitored at nine locations in both the blasts. Similarly, the experiments were conducted with six holes at Sonepur Bazari and Nigahi projects. The experiments conducted with blast layouts for Nigahi and Sonepur Bazari projects are depicted in Figs. 3 and 4. The blasts performed with seven holes for the same purpose at Kusmunda project are shown in Fig. 5. The experiments were further extended and performed with production blasting too.



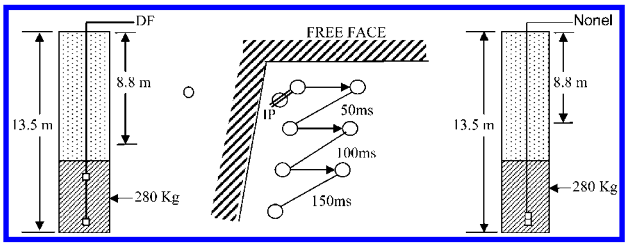
2 Blast layout and charging pattern for three holes detonated by detonating cord as well as by Nonel initiation system at Nigahi project



3 Typical blast layout conducted at Nigahi project for both initiation systems



4 Typical blast layout conducted at Sonepur Bazari project with both initiation systems

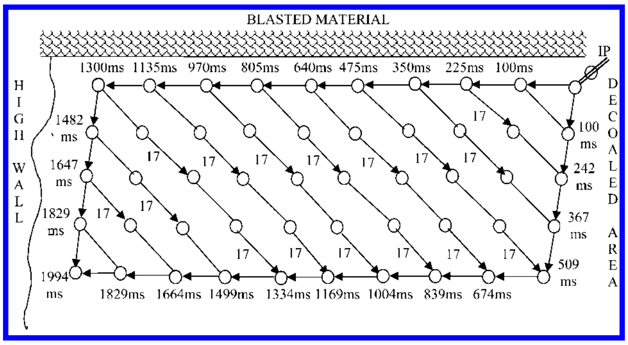


5 Typical blast layout conducted at Kusmunda project with both initiation systems

The layout of dragline experimental blast conducted at Jayant project is depicted in Fig. 6. The hole depths were 33 m. Burden and spacing were 10 and 12·5 m respectively. Two rounds with similar blast design were conducted. The explosive detonated in both the blasts were 114·387 kg and the number of holes were 50. The charge per delay was 4680 kg. The blast conducted with DF and similar successive blast with only change in initiating mode (Nonel) was performed on the same bench. The typical blast waveforms recorded at 800 m from the blast face is presented in Figs. 7 and 8.

Interpretation of vibration waveforms

The analyses of blast waveforms recorded from bottom initiation systems indicated that persistence of vibration is comparatively lower than top initiation system (Figs. 7 and 8). The recorded vibration data indicated that the bottom initiation generated lower vibration magnitude in comparison with top initiation. Vibration



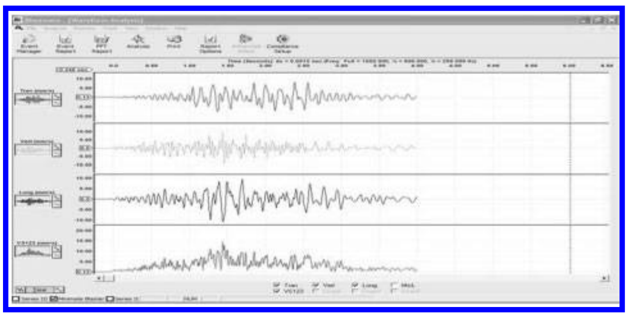
6 Blast layout of dragline blast performed with top and bottom initiation system at Jayant project

owing to bottom initiation is further reduced with increase in depth of holes. In case of signature blasts, the reduction in peak particle velocity varied 11·7–15·6% when the depths of holes were 11 m. Similarly, the reductions in vibrations were 9·3–30%, when depths of holes were up to 20 m. At dragline blast of Jayant project, the reductions in vibrations were 12·7–36·2%. The high speed camera was deployed for motion analysis of the blasts. The premature escape of gaseous energy was observed with top initiation of blasts (Fig. 9). The bottom initiation resulted into lower level of vibration, airblast, control over flyrocks and the muck pile was also optimum for shovel loading. Figures 9 and 10 depict the rock movement owing to blasting with top and bottom initiations at Kusmunda project.

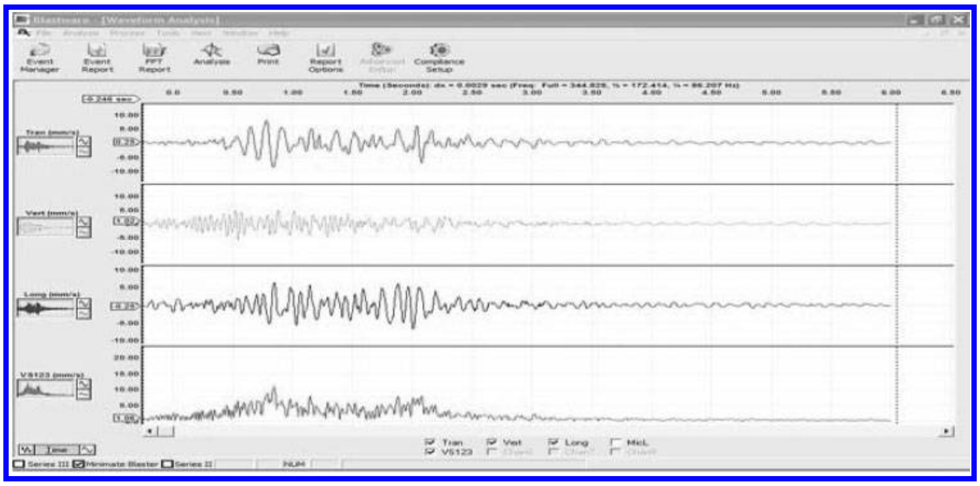
Analyses of vibration data

The vibration data recorded by detonation of blasts with DF (top initiation) and Nonel (bottom initiation) systems were plotted for their respective scaled distances for each mine separately (Figs. 11–14). The combined vibration data from detonation of blasts at all the experimental sites with DF and Nonel are plotted for their respective scaled distances and presented in Fig. 15.

The vibrations recorded at various locations for each sets of experiments were 144. The blast vibrations recorded owing to top and bottom initiation at all the projects are grouped together for statistical analyses and best fit empirical equations were established for each site of the study (Table 1). The vibrations data of all the four mines were combined separetly and are also plotted for their respective scaled distances (Figs. 16 and 17).



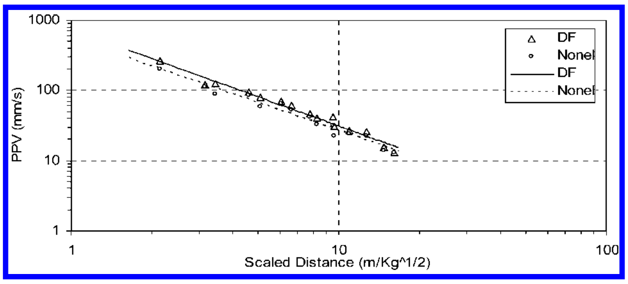
7 Blast wave signature recorded at 800 m from dragline blast performed with top initiation system (DF) at Jayant project



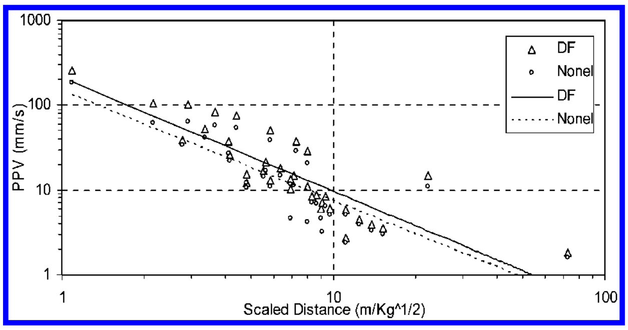
8 Blast wave signature recorded at 800 m from dragline blast performed with bottom initiation system (non-electric initiation) at Jayant project

9 Rock movement and venting of gases in top initiation (DF) at Kusmunda project

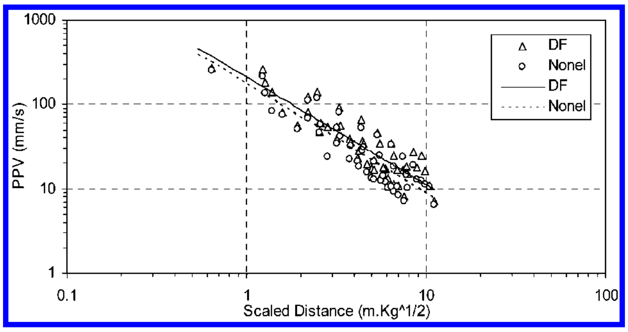
10 Rock movement and excellent fragmentation due to bottom initiation (Nonel tubes) at Kusmunda project



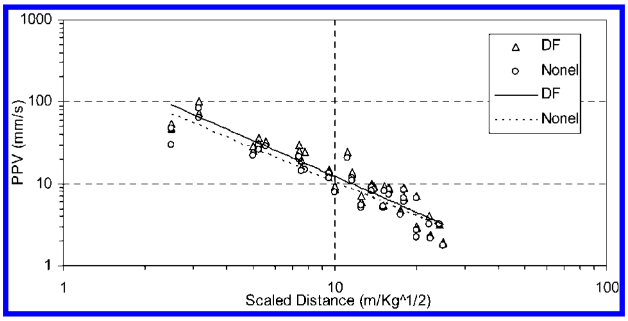
11 Propagation plots of vibration data recorded due to DF and Nonel initiation systems at Sonepur Bazari project



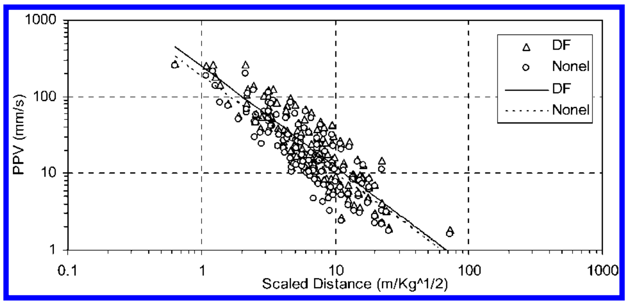
12 Propagation plots of vibration data recorded due to DF and Nonel initiation systems at Jayant project



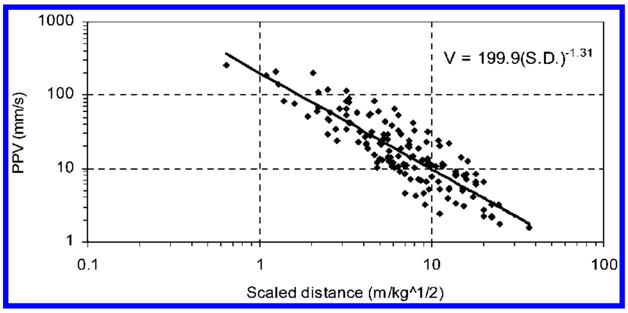
13 Propagation plots of vibration data recorded due to DF and Nonel initiation systems at Nigahi project



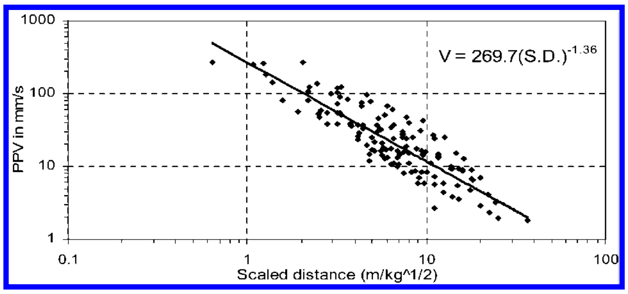
14 Propagation plots of vibration data recorded due to DF and Nonel initiation systems at Kusmunda project



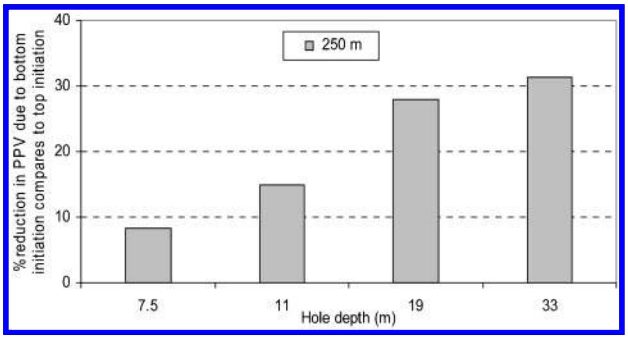
15 Propagation plots of vibration data recorded at all the sites due to DF and Nonel initiation systems



17 Propagation plots of vibration data recorded at all sites by Nonel initiation system



16 Propagation plots of vibration data recorded at all sites by DF initiation system



18 Reduction in PPV owing to bottom initiation to that of top initiation for different depths of holes (vibrations were monitored at 250 m for each sets of experiments)

Results and discussion

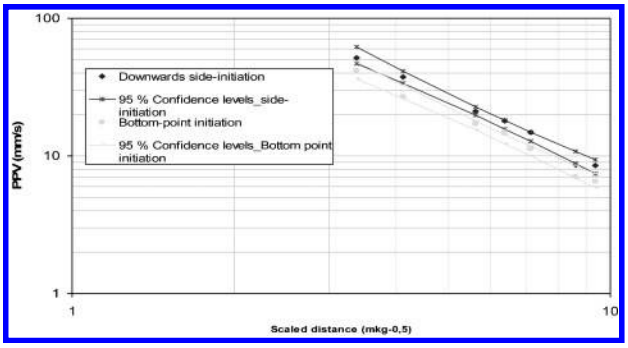
It is evident from the Figs. 11–15 that blasts performed with bottom (Nonel) initiation system generated lower vibrations in comparision with those blasts which were performed with top (DF) initiation system. The reduction of vibration were 8·2–36·2% in case of bottom initiation system to those of top initiation system. It was also observed that as the depth of holes were longer, the reduction in vibration amplitude were more with bottom initiation system to that of top initiation system. The prediction of vibration for identical charge per delay at particular location with the help of predictor equations established for the mines are also in agreement with the recorded data.

To quantify the reduction of vibration in respect to variation in depth of blastholes, the blastholes depth were separated in two groups. In one group vibrations data from blastholes of depth up to 20 m and in other group for >20 m, were studied. The similar excerise were carried out for a group with vibration data from blastholes up to 12 m and other group of hole depths 12–20 m were taken and analysed. On analyses it was observed that the reduction of vibration from bottom initiation was in the range of 8·2–30% for blastholes up to 20 m depth whereas for holes >20 m, the reduction was up to 36·2%. Similar trends was observed with blastholes up to 12 m and 12–20 m depth. The reduction of vibration in case of the former was up to 15·6% and in the latter, it was up to 30%.

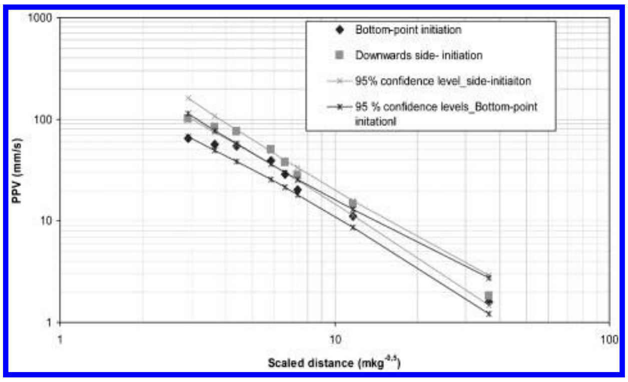
Blast vibrations were monitored for four set of experiments at 250 m. The blasthole depths were 7·5, 11, 19 and 33 m. The recorded vibration data clearly demonstrated that as the depth of blast hole increases the vibration reduction owing to bottom initiation also increases (Fig. 18).

Table 1 Predictor equations derived from vibration data recorded by detonation of blasts with DF and Nonel initiation system

Name of the project	Mode of initiation	Predictor equation
Sonepur Bazari	DF	$v=742{\cdot}46\times(R/Q_{\max}^{1/2})^{-1{\cdot}38}$
	Nonel	$v=597{\cdot}89\times(R/Q_{\max}^{1/2})^{-1{\cdot}348}$
Jayant	DF	$v=342{\cdot}75\times(R/Q_{\max}^{1/2})^{-1{\cdot}631}$
	Nonel	$v=232{\cdot}98\times(R/Q_{\max}^{1/2})^{-1{\cdot}576}$
Nigahi	DF	$v=211{\cdot}12\times(R/Q_{\max}^{1/2})^{-1{\cdot}278}$
	Nonel	$v=174{\cdot}86\times(R/Q_{\max}^{1/2})^{-1{\cdot}297}$
Kusmunda	DF	$v=330{\cdot}82\times(R/Q_{\max}^{1/2})^{-1{\cdot}418}$
	Nonel	$v=249{\cdot}9\times(R/Q_{\max}^{1/2})^{-1{\cdot}38}$
Combined data of all the four projects	DF	$v=269{\cdot}7\times(R/Q_{\max}^{1/2})^{-1{\cdot}36}$
	Nonel	$v=199{\cdot}9\times(R/Q_{\max}^{1/2})^{-1{\cdot}31}$



19 Attenuation laws of seismic field radiated by two blasts initiated with DF and with booster in bottom (non-electric detonator) at the third bench of Jayant project together with their respective upper and lower 95% confidence levels



20 Attenuation laws of seismic field radiated by two blasts initiated with DF and with booster in bottom (non-electric detonator) at dragline bench of Jayant project together with their respective upper and lower 95% confidence levels

Validation of attenuation law

Statistical analyses were carried out to validate the blast wave attenuation law in order to validate the conclusion drawn on influence of mode of initiation of explosives on blast vibration. Figure 19 shows that the attenuation law for bottom point initiation is lower than that for side initiation (initiation from top) tests in the blast conducted at third bench of Jayant project, the trend lines slightly overlap at the lower extreme of the scaled distance range. This becomes more evident for the tests carried out at a dragline bench of Jayant project (Fig. 20). Hence, there are evidences with a probability of 95% that both attenuations laws for side and bottom point initiation are different. Similar, results were obtained for all the set of the recorded vibrations.

The T test shows, that the means of all the vibration records at a mean scaled distance of 8·9 m $kg^{-0\cdot5}$ at Sonepur Bazari, Jayant, Kusmunda and Nigahi sites generated by blasts with top initiation are different at 95% confidence level than the mean of blasts in which the explosive is bottom initiated. The predicted PPV is 34·7 and 26·9 mm s^{-1} respectively for top and bottom initiation indicting higher PPV owing to top initiation with 95% confidence level.

Conclusions

It is concluded based on the recorded vibration data and analyses thereof that bottom (Nonel) initiation system generates less vibration in comparison with top (detonating cord/fuse) initiation system. The reductions in vibrations were observed up to 36·2% by changing only the mode of initiation of blastholes from top initiation to bottom initiation for blastholes of depth >20 m. The minimum reduction of vibration was 8·2% for shorter blastholes depth of 7·5 m. The fragmentations got improved and the efficiencies of the operating heavy machineries were also enhanced in handling the blasted materials where bottom initiations were practiced. Noise generations were also comparatively low with bottom initiation system. The statistical analyses for blast wave attenuation law also confirmed that by only change from DF detonation (top initiation) to non-electric initiation at bottom at floor level will reduce vibration by mean value of 21·25%. If the charge length is high, reduction in vibration will be more.

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