Reduction of Blast Induced Ground Vibrations with Open Trenches in Surface Mines

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ABSTRACT: Problems due to ground vibrations are a matter of serious concern for the users of explosives. It is not possible to eliminate vibrations completely or to contain them at the source. Efforts need to be made in controlling them within safe levels, without affecting the production schedule and economic viability of the project. When predicted or monitored vibrations exceed the statutory limits, ground vibrations are generally controlled by modifying the blast design parameters. In critical situations, digging a trench has reduced ground vibrations. The extent to which it can reduce ground vibration has been examined by field experiments at a surface coal mine in India and through computer simulation using 3DEC. The results show that the percentage of reduction depends on the trench depth to blasthole depth ratio and the horizon of the blast. It was also observed that the reduction in vibration is independent of the width of the trench.

1 Introduction

Opencast mines are currently using more than 200 tons of explosives in a single blast. Mines which were once far away from the villages/townships find themselves surrounded by settlements. Apart from mining, blasting has become an integral part of many allied industrial activities. In recent times, problems due to blasting in general, and ground vibrations in particular, have increased. For all practical purposes, restricting the maximum charge per delay seems to be the panacea for controlling ground vibrations. In many cases, the reduced maximum charge per delay means a reduction in hole diameter, a reduction in the bench height, or dividing the charge per hole into different decks, resulting in cost escalation and compromised production targets. Discontinuities like faults, pre-split planes, joints, etc. are known to reduce ground vibrations. Sometimes, a trench is created between the blast site and the structures to be protected, to minimise the effect of ground vibrations on the structures of importance.

Devine et al. (1965) studied the influence of fracture planes on the transmission of ground vibrations due to blasting. Berzal (1976) observed that pre-split planes reduced vibration levels and that interposing double pre-split fracture planes reduced ground vibrations considerably. Similarly, Gupta et al. (1990) recorded a reduction in vibration level of about 30 per cent due to pre-splitting, as compared with normal production blasting in an opencast coal mine in the Jharia coalfields of India. However, experiments conducted by Worsey et al. (1996) revealed that pre-split planes were ineffective in reducing blast vibrations. This was found to be the case for both blasting on the same bench of the pre-split plane and also for blasting in lower benches. Venkatesh et al. (1999) observed in the data from Sasti Opencast Coal Mine in India that the vibration levels were attenuated by a fault plane by up to 39 per cent. Even at Durgapur Opencast Coal mine in India, Venkatesh et al. (1999) found that the fault plane reduced vibration levels by about 45 per cent. Prakash et al. (2004) observed significant reduction in the magnitudes of vibration during their field experiments with a) trench and b) a pre-split plane dug between the blast site and the critical structure. It can be deduced that discontinuities have contributed in reducing ground vibrations and, keeping this in view, detailed investigations were carried out by the authors to exclusively study the extent of reduction in vibration levels by man-made trenches. Field experiments were conducted in an opencast coal mine in India and the simulation studies were done using 3DEC, a distinct element code.
2 Field experiment

2.1 Mine details

In order to study the reduction of ground vibrations due to blasting by a trench, Venkatesh (2002) conducted field experiments in a surface coal mine with an annual production of 1.7 Mt of coal and 5.3 Mcu. m of overburden. The topsoil in this mine is about 6 m to 8 m thick comprising of Morrum/Sandy soil. The immediate formation below the topsoil consists of weathered medium grained sandstone to a depth of 12 m, below which it is medium grained sandstone. The sandstone has a density of 2.2 g/cc and an unconfined compressive strength of 25 MPa. Thickness of the coal seam is about 17 m and it is excavated in two benches. The average bench height in the overburden is 12 m. A blasthole diameter of 250 mm is used in the overburden benches. Rope shovels of 4.6 cu. m bucket capacity are used in conjunction with 35 t and 50 t dumpers to remove the overburden.

2.2 Experiment details

A trench 16 m deep, 20 m wide and 200 m long was created at a distance of 300 m from the top bench for carrying out the experiments. The trench excavated is shown in Figure 1. In total seven blasts were conducted and the ground vibrations generated from these blasts were monitored on either side of the trench. Several types of mounting methods and their effect on the measured vibration level are discussed by various researchers (Dowding, 1992; Anderson, 1993; Blair, 1995; Richard et al., 1999; Armstrong and Sen, 1999; Adhikari et al., 2005). The suggested methods are clear for external geophones and suggest burial while measuring in soil. The geophones were buried at a distance of 3 m from the edge of the trench on either side (Figure 2). SINCO-6, a microprocessor based seismograph having two external tri-axial geophones, was used to monitor ground vibrations. For burying the geophones, pits of 30 cm x 30 cm x 30 cm dimension were made. The measured vibrations are given in Table 1.

Figure 1. View of the trench.

Figure 2. Placement of sensors with reference to trench.
Apart from studying the role of the trench in attenuating the vibrations, blasts were conducted to ascertain the efficacy of the trench with respect to the horizon of the blast. Of the seven experiments, three blasts were conducted in the first bench, two in the second bench and two in the fourth bench. The maximum charge per delay varied from 378 kg to 1,200 kg while the distances of the monitoring stations before the trench varied from 312 m to 498 m. As the width of the trench is relatively large, the monitored values before the trench and after the trench cannot be directly compared as the attenuation of the vibrations due to distance must also be considered. In order to exclusively establish the influence of the trench in attenuating the vibration levels, the data before the trench and the data after the trench were regressed separately and the following predictor equations were established:

\[
V = 435\frac{D}{\sqrt{W}} - 1.67 \quad (1)\\
\]

\[
V = 278\frac{D}{\sqrt{W}} - 1.57 \quad (2)\\
\]

where \( V \) is peak particle velocity in mm/s, \( D \) is the distance between the blast site and instrument station in m, \( W \) is the maximum charge per delay in kg and \( r \) is the coefficient of correlation.

From equations 1 and 2 vibration levels were computed for each blast for the distances beyond the trench. The computed values are at the same distances but those predicted from equation 1 correspond to the values in the absence of trench while those predicted with equation 2 correspond to the values with the trench. The computed values are given in Table 2. From Figure 3 it can be observed that the trench attenuates the vibration level and is a practical solution for controlling them.

The extent of reduction in the vibration levels due to trench in different blasts is shown in Figure 4. The minimum and the maximum reduction in vibration levels due to the trench were 11 and 19 per cent respectively. The field results are not indicative of any relationship between the horizon of the blast and the efficacy of the trench in attenuating ground vibrations. This may be due to the large distance of 300 m between the trench and the blast site and also because of the relatively shallow depth of blast location.

As can be seen, in order to know the effect of trenches they need to be practically dug and experiments conducted in the field. In many situations, digging of trenches may not be economical for mere study purpose. Computer simulations happen to be the most cost effective, can provide realistic indications of PPVs when calibrated with real-world data and are non destructive in nature.
3 Computer simulation

3DEC, a distinct element code was used to simulate opencast blasting to establish the extent of reduction in vibration intensity due to varying trench depth (Berzal, 1976; Adhikari et al., 2005). Chen et al. (2000) had carried out a small-scale field explosion test in granite to investigate the dynamic response of jointed rock mass under explosion loads. The test was modeled using 3 DEC, an extension of the Universal Distinct Element Code (UDEC) from two dimensional to three dimensional analysis. It has been mostly used to model static problems in jointed rock masses (Anon, 1998).

3.1 Calibration of the model

A computational model of dimensions 400 m x 40 m x 100 m size was created. A free face was created with a bench height of 7 m. A blast hole of 150 mm diameter was created at a distance of 4 m (burden) from the free face. These parameters are of those full-scale single hole blast conducted at an opencast coal mine in India (Adhikari et al., 2005). A set of vertical joints with a spacing of 20 m and horizontal joints with a spacing of 10 m was generated. Energy absorbing viscous boundaries were applied on all sides except on the top, which is a free boundary. Once the basic geometry was created, the next step was to apply the blasting load on the blasthole walls. As such 3DEC cannot simulate the explosion process and the explosion load should be provided to the 3DEC model. The explosion load is very difficult to determine for actual explosion events (Chen et al., 2000). In many other studies, the representation of explosion load is often empirically assumed as a triangular pulse (Francois et al., 1993). In the present case also, velocity time history was applied as triangular pulse to the blasthole walls by developing a FISH function for this purpose. The boundary logic in the 3DEC code had to be modified to provide a more general command structure. Here, the memory location of block grid points, where loading is to be applied, was stored in an array. The blast loading was applied as functions of time at these block vertices. The loading history is shown in Figure 5. The velocity monitoring was carried out at two locations, at 146 m (Location A) and at 188 m (Location B) behind the hole parallel to the X-axis. The developed model was calibrated by repeated runs by altering the input velocity and adjusting the material and joint properties (Figure 6). The model output is close to the actual field test at both the monitoring locations (Table 3). This shows that the attenuation characteristic of the rock mass has been simulated in the model. This calibrated model was used to study the extent of reduction in ground vibrations due to a trench.

Table 3. Comparison of 3DEC modeling results with field test.

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Velocity (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field test</td>
<td>3DEC modeling</td>
</tr>
<tr>
<td>146</td>
<td>4.19</td>
</tr>
<tr>
<td>188</td>
<td>3.68</td>
</tr>
</tbody>
</table>
3.2 Computation of vibration for different trench conditions

In order to establish the extent of reduction in ground vibration due to trench, model studies were carried out for trench depths of 3.5 m, 7 m, 10.5 m and 14 m. They represent the trench depths (T) equal to 0.5, 1.0, 1.5 and 2.0 times the blasthole depth (H). To start with, a trench 1 m wide was created in the calibrated model at a distance of 66 m behind the blasthole and two monitoring locations (A & B) as per actual field stations were identified at 146 m and at 188 m from the blasthole in the model to generate the vibration histories (Figure 7). Figure 8 shows the generated vibration histories at two monitoring locations A and B for a trench depth to hole depth ratio of 0.5. Figure 9 shows the generated vibration histories at two monitoring locations A and B for a trench depth to hole depth ratio of 1.0. Figure 10 shows the generated vibration histories at two monitoring locations A and B for a trench depth to hole depth ratio of 1.5. Figure 11 shows the generated vibration histories at two monitoring locations A and B for a trench depth to hole depth ratio of 2.0.
4 Results and discussions

4.1 Effect of trench depth on the intensity of ground vibration

The model studies reinforce that trenches do reduce the vibration levels. Table 4 summarises the results from the model studies. It can be concluded that the reduction in vibration level is related to the depth of a trench and that the maximum efficiency of the trench is for the T/H ratio between 1 and 1.5. Cutting to a 2 T/H ratio seems to be redundant as the reduction in vibration from 1 to 2 T/H ratio is only 13% as compared to that at T/H ratio of 1 which is about 55%. It is better to dig a parallel trench than deepening it to twice the blasthole depth.

Table 4. Summary of the results from the model study.

<table>
<thead>
<tr>
<th>Depth of trench (T) [m]</th>
<th>Hole depth (H) [m]</th>
<th>Ratio T/H</th>
<th>Velocity at 146 m from blast (point A) [mm/s]</th>
<th>Velocity at 188 m from blast (point B) [mm/s]</th>
<th>Percentage reduction at point A</th>
<th>Percentage reduction at point B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>4.26</td>
<td>3.51</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3.5</td>
<td>7</td>
<td>0.5</td>
<td>3.55</td>
<td>2.53</td>
<td>16</td>
<td>27</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>1.0</td>
<td>1.91</td>
<td>1.40</td>
<td>55</td>
<td>60</td>
</tr>
<tr>
<td>10.5</td>
<td>7</td>
<td>1.5</td>
<td>1.57</td>
<td>1.14</td>
<td>63</td>
<td>67</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>2</td>
<td>1.34</td>
<td>0.76</td>
<td>68</td>
<td>78</td>
</tr>
</tbody>
</table>

Prakash et al. (2004) measured vibrations on two sides of a trench and varied the trench depth for each experiment. The ratios of trench depth to blastholes were 0.3, 1.0 and 1.125 and the damping varied from 16.6 to 55 per cent. In these cases, the blast locations and trench location was the top overburden bench. The results from the model studies are in accordance with the field experiments and hence prove to be a reliable and cost effective tool to decide the vibration isolation parameters.

4.2 Effect of trench width on the intensity of ground vibration

In order to establish the influence of trench width on the intensity of ground vibration, model studies for trench depth equal to the hole depth (7 m) were extended. The study had concluded that for a trench depth to hole depth ratio of 1, the reduction in vibration level was most economical and effective. The width of the trench studied in the model was 1 m and this was taken as the base level for comparison. The result with trench width of 3 m and 6 m is given in Table 5. From Table 5 it can be concluded that the width of the trench has an insignificant influence in reducing the intensity of ground vibration.
Table 5. Results from simulation study – to establish the effect of trench width on vibration level.

<table>
<thead>
<tr>
<th>Trench width [m]</th>
<th>Velocity from the model [mm/s]</th>
<th>Reduction in vibration level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.91</td>
<td>Base level</td>
</tr>
<tr>
<td>3</td>
<td>1.87</td>
<td>2%</td>
</tr>
<tr>
<td>6</td>
<td>1.84</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

5 Estimation of vibration with a trench between the blast and target structure

From the study it could be established that the trench affects the intensity of ground vibrations. In order to estimate the probable vibration levels with a trench, the following equation can be used:

\[ V = K \times R \times (D/\sqrt{W})^b \]  

(3)

where \( V \) is peak particle velocity in mm/s, \( D \) is the distance between the blast site and instrument station in m, \( W \) is the maximum charge per delay in kg, \( K \) & \( b \) are site specific constants and \( R \) is the attenuation constant for variable trench characteristics:

(a) \( R \) is 0.15 in the case of trench depth equal to \( \frac{1}{2} \) the hole depth with the blast is at the same bench and in the case of trench depth equal to or greater than hole depth with the blast in the benches below the trench floor level.
(b) \( R \) is 0.50 in the case of a trench from 1 to 1.5 times the hole depth with the blast is located in the same bench as the trench.

The above equation can be fine tuned with more field studies.

6 Conclusions

Reducing the maximum charge per delay alone need not be the solution to control the intensity of ground vibrations. Alternatives like digging a trench has been shown to be effective in reducing the vibration levels. Numerical analysis indicated that a trench between the blast and the monitoring location could substantially reduce ground vibration. It was the trench depth (T) to blasthole depth (H) ratio that was crucial for the percentage of vibration reduction. At T/H ratio equal to 1.0, vibration could be reduced by 55-60 per cent. The results of the model studies were comparable to those of field measurements. It can be concluded that the width of the trench has an insignificant influence in reducing the intensity of ground vibration. To start with, the suggested equations can be used as a guide to estimate the probable vibration levels with a trench.

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8 References


Anon. 1998. Itasca user manual – 3DEC.


Blair D.P. 1995. Blast vibrations in soil and on large resonant structures. EXPLO 95, Brisbane, 317-322.


