Effect of Underground Blasting on Surface Slope Stability: A Numerical Approach

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Abstract  Stability of surface slope is a big challenge when underground excavation carried out just below the slope by the conventional drilling and blasting method. Blasting generates huge intensity of dynamic loading in the surrounding rock mass. If the intensity of dynamic loading is high, then it may be one of the reason for the triggering of instability in the surface structures. So, in the present paper, underground coal blast model has been developed using finite element method to understand the ill effects of underground blasting on the surface slope stability. Slope instability results have been represented by Peak Particle Velocity (PPV) of blast waves at varying time frames. Results have been computed on predefined specific target points which are crucial in terms of stability of surface slope. It has found that lowest bench has greater impact of blast loading and it can be dangerous from the stability point of view, whereas lower particle velocity monitored at the top most bench, compared to the other target points. It is all due to the attenuation of blast vibration energy with respect to the time and distance. From this study, it can be said that numerical modelling tool can be used to understand the phenomenon of dynamic blast vibration loading and its effects on the surface slope stability.

Keywords: underground blasting, surface slope, stability, peak particle velocity


1. Introduction

The stability of surface slope is an important issue for safety reasons. This becomes of more concern when these surface slopes are located above underground mine. These mines usually use blasting for rock fragmentation to desired size as well as to displace the fragments. Only a fraction of explosive energy is utilised in fragmentation and displacement of rock mass and rest of the energy is wasted in various blast nuisances, like, blast vibration, air blast, flyrock, noise, etc. Among these, blast vibration is a big threat for the stability of surrounding structures in the vicinity of the mining areas leading to their failure [3,4,9,24]. Several examples of pit slope failure due to underground rock blasting are reported in various published literature [2,22,23]. Many authors attributed such slope failures to blast vibration [12,20,26]. However, many researchers reported the difficulty of monitoring underground blast vibration intensity at various locations of surface slope. This was attributed to the fact that monitoring of blast vibration is carried out using seismographs. This procedure has many disadvantages among which is time consuming, and large number of needed seismographs in addition to its high cost. Therefore, numerical modelling was considered as an alternative technique for this purpose. Besides its low cost, it is easy to use and has the capability to deal with dynamic loading conditions. Where, this dynamic loading is usually expressed in peak particle velocity (PPV) which reflects slope stability with respect to the intensity of blast vibration waves [5,24,25]. In this paper, surface slope stability at Indian coal mine will be investigated as a function of PPV resulted from underground mine blasting. In this regard, two dimensional finite element numerical modelling will be used.

2. Numerical Model

Figure 1 shows geometry of 2D model reflecting the geological column of the investigated Indian area. The deposit has three coal seams of approximately three meter impeded within shale and sandstone rocks. The first and the second coal seams are economically excavated using surface mining techniques. The first and the second coal seams are economically excavated using surface mining techniques. On the other hand, the third seam is 57 meter below surface and it is exploited using underground mining. The model also illustrates that the underground mine have galleries with 3 m (wide)*1.2 m (height) separated by 19 m pillars. However, properties of coal and the different surrounding rock masses are shown in Table 1. In this study, mine working is starting from the central gallery due to its nearness from the surface and thus considered as blast dynamic loading source. Central underground gallery has been denoted as the source of dynamic explosion.
Several numerical tools are available to investigate the slope instability due to PPV (Preece and Thorne 1996; Jia et al. 1998; Wang et al. 2009). This model will investigated using commercial software Abaqus/explicit. In the model, the peak particle velocity will be predicted in different bench crest (1 to 4) as denoted in Figure 1.

Results of finite element models are elaborated in terms of PPV with time frame. The model analyzed for a total duration of 100 millisecond to reduce computational cost. Table 2 demonstrates the explosive properties used in this model.

### Table 1. Rock Mass Properties

<table>
<thead>
<tr>
<th>Property (units)</th>
<th>Soil</th>
<th>Shale</th>
<th>Sandstone</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (kg/m³)</td>
<td>1800</td>
<td>2100</td>
<td>2000</td>
<td>1840</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
<td>0.25</td>
<td>0.27</td>
<td>0.3</td>
</tr>
<tr>
<td>Elastic modulus (MPa)</td>
<td>560</td>
<td>1000</td>
<td>2200</td>
<td>1950</td>
</tr>
<tr>
<td>Cohesion (MPa)</td>
<td>0.01</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Friction Angle (degree)</td>
<td>32</td>
<td>33</td>
<td>35</td>
<td>40</td>
</tr>
</tbody>
</table>

### Table 2. Explosive properties

<table>
<thead>
<tr>
<th>Explosive property (Units)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detonation velocity (m/s)</td>
<td>5000</td>
</tr>
<tr>
<td>Detonation pressure (A) (GPa)</td>
<td>70</td>
</tr>
<tr>
<td>Borehole pressure (B) (GPa)</td>
<td>3</td>
</tr>
<tr>
<td>$\rho_0$</td>
<td>$0.24$</td>
</tr>
<tr>
<td>$R_1$</td>
<td>5.5</td>
</tr>
<tr>
<td>$R_2$</td>
<td>0.9</td>
</tr>
<tr>
<td>Density (Kg/m³)</td>
<td>1900</td>
</tr>
<tr>
<td>$E_{m0}$ (Jule)</td>
<td>$3*10^6$</td>
</tr>
</tbody>
</table>

Detonation energy products has defined by JWL (Jones Wilkins Lee) equation of state [6,7,10,11]. JWL equation is most versatile and widely used to assign the explosive material properties for pressure generation as given in equation 1.

\[
P = A \left(1 - \frac{\rho_0}{R_1\rho_0}\right) e^{-\frac{R_1\rho_0}{\rho}} + B \left(1 - \frac{\rho_0}{R_2\rho_0}\right) e^{-\frac{R_2\rho_0}{\rho}} + \frac{\rho_0^2}{\rho} E_{m0}
\]

Where, A, B, R1, R2, $E_{m0}$ and $\omega$ are constants, P is the pressure (depended variable), $E_{m0}$ internal energy per unit mass, $\rho_0$ user defined density of explosive and $\rho$ density of the detonation product. In addition, $\omega$ is the Grüneisen coefficient and A, B, R1, R2 are parameters. The parameters A and B have dimensions of pressure, while R1, R2 and $\omega$ are dimensionless. They are subject to the constraints that $R_1>R_2>0$ and $\omega>0$. Moreover, for explosive products $A>B>0$. But, when used for reagents $A<−B>0$.

### 3. Results and Discussion

Figure 2 (a-j) shows the total different frames used to represent the PPV with time. It can be seen from this figure that PPV started to propagate around the blasting area. The maximum value of PPV is 114.5 m/s at 3 millisecond after the blast, which is very high (Figure 2a). However, this PPV has still existing in surrounding blast gallery but could not reach to the surface. At around, 25 millisecond, the PPV become affects the surface and at 35 millisecond it started to affect the first bench of mines. It took nearly 100 millisecond to reach at the upper most bench of the mine. Figure 2 (a-j) clearly demonstrates the velocity vector at different time frames and its impact on the surrounding rock mass.

It also indicates that as the time and distance passed, velocity vector scale is substantially decreased and it is all due to the attenuation of blasting energy. The peak particle velocity curve of target points with time frame are shown in Figure 3. It can observed that the first bench of mine is severely affected by blasting, whereas the top most bench of mine is less affected due to the attenuation of blasting energy. The measured peak particle velocity at target points 1 and 4 are 0.55 m/sec and 0.08 m/sec, respectively.

The purpose of blasting is to fracture the rock mass and it should be exceed the strength of the rock or exceed the elastic limit of the rock mass. When this limit crosses, fracturing occurs. As fracturing continues, the energy is used up and eventually falls to a level less than the strength of the rock and fracturing diminishes. The remaining energy travels through the surrounding rock mass, and deform it but could not able to fracture the rock mass due to elastic limit. This will result in the generation of ground vibration and it could damage the nearby structures. If there is any rock slope situated nearby to the blasting source, it stability would be effected by ground vibration.
Figure 2. (a-h) Underground blasting released velocity vector at various time frame
Table 3. PPV for slope target nodes

<table>
<thead>
<tr>
<th>Bench Number</th>
<th>PPV (mm/sec)</th>
<th>Approx. vertical distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>550</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>320</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>140</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>58</td>
</tr>
</tbody>
</table>

The PPV damage criteria has been widely used for blast-induced damage. Therefore, in the present study, slope target nodes were analyzed (Table 3) to understand the damage on each bench with respect to blast vibration. It can be observed that first target point is heavily affected due to high PPV (550 mm/sec), whereas target node of the uppermost bench shows the lowest value of PPV (80 mm/sec). As per the damage criteria suggested by the Adhikari et al., [1] for medium rocks, first target slope node can be considered under induced cracking categories, second denoted the falling of loose pieces, third and fourth can be represented the no damage categories. Therefore, first target point can be considered as most vulnerable slope under the condition of underground blast loading.

4. Conclusions

The instability of slope due to underground blast loading was investigated through numerical simulation using Abaqus/explicit finite element. Slope instability was identified by peak particle velocity (PPV) at previously marked target points at various bench slope using numerical model. Different velocity vectors were studied on each bench slope to find out the influence of PPV on the slope instability. Nearest target point from blasting represented the more vulnerable slope and its effect attenuated with respect to time and distance. This numerical study provides useful information of blast energy propagation in the rock mass which can be understood and visible during blasting operation in the field. Therefore, numerical modelling can be considered as a useful tool to understand the complex processes of blast wave propagation, which is very difficult to study at the field or mine site.

References


