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# BLAST-INDUCED DAMAGE ASSESSMENT FOR INCREASED ROADWAY STABILITY IN UNDERGROUND COAL DRIVAGES

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## ABSTRACT

Importance of blast-induced rock damage (BIRD) assessment for increased roadway stability is discussed. Near-field PPV estimated has been utilized to fix up damage threshold levels for categorizing the degree of rock damage. Influence of roof RMR(Rock mass rating), PPV and maximum charge per delay on blast-induced rock damage (BIRD) is also analysed. Limiting maximum charge per delay is computed for controlling roof stability problems.

This paper synthesizes the blast vibration studies conducted in four underground coal mines of CIL, India, namely, Tandsi, Bhandewada, Dobari and Saonar mines. The PPV measurements have been used to decipher the damage zone in the roof. The roof vibration predictor equations developed have been extrapolated for establishing the damage threshold levels. The PPV level for incipient crack growth, crack widening and overbreak are worked out. It was found that the gallery size, roof RMR, coal strength, presence of hard bands, charge density in the periphery holes and the distance of periphery holes from the roof have significant influence on the roof damage. The PPV levels arrived at have been conversely utilized for fixing up the maximum charge per delay for minimizing roof damage.

## 1.0 INTRODUCTION

The predominant problem in underground coal mining in India is roof stability. Most of the coal roofs in India are fragile consisting of shale, shaly coal and sandstone. Assessment of rock load and support design are based on empirical approaches such as CMRI-ISM Geomechanical classification, RMR (Bieniawski, 1974) and Q index (Barton, 1974) etc. In spite of having well established RMR based support design guidelines, still coal mine development headings often encounter roof stability problems for various reasons such as, delay in supporting, improper support practices, defective capsules apart from the excess roof vibrations due to **solid blasting**. It has been found that the solid blasting technique, followed extensively in bord and pillar development, generates high PPV's (Peak particle velocity) due to absence of free face thus, possibly acting as a potential trigger for roof falls. There is scarce data related to coal mine roof vibrations (PPV) due to solid blasting in different geo-mining conditions to analyse the impact of the same on roadway stability.

The blast-induced roof- rock damage can be predicted through different approaches viz peak particle velocity (PPV), P-wave velocity and correlating the same with observed roof fall data. This paper presents a systematic study on the roof vibration measurements conducted in different underground coal mines in India. The PPV levels near the blast face are arrived at by extrapolation of far-field measurement to categorise the roof damage threshold levels for the purpose of controlling the same and providing a sound basis for optimum blast design and roof support design.

It will be judicious to design blast pattern such that there is a balance between the pull achieved and the blast-induced rock damage. The decision with regards to the blast optimization should be made on the basis of overall cost. It is required to understand the damage threshold levels and use the same to determine the safe maximum charge per delay. Thus, a modified blast design can be done based on the roof vibration measurements for meeting this dual objective.

## 2.0 METHODS OF DAMAGE PREDICTION

The exact physics behind the roof - rock damage due to blasting is not yet known completely. Numerous methods were proposed by different leading researchers to predict blast-induced rock damage (BIRD). The following are some of the important methods, on which, prediction can be based:

1.Amplitude concept
2.Energy ratio concept
3.Scaled distance concept
4.Particle velocity concept
5.Permeability test
6. Modulii test
7. Rock modulus
8. Half cast factor
9. Frequency and surface condition
10. Drift condition rating
11. Geophysical methods
12. Acoustic emission technique
13. Empirical damage index
14. Accelerometers
15. Dynamic finite element model
16. P-wave velocity measurement

In this study, PPV based damage estimation has been done for arriving at damage threshold levels.

## 3.0 FIELD INVESTIGATIONS

Blasting trials and roof vibration (PPV) monitoring carried out in four underground coal mines namely, Dobari, Bhandewada, Saonar and Tandsi have been included in this study. Some of the investigations were done when the second author was associated with CMRI. The geo- mining conditions of these mines are detailed in **Table 1**. From the table it appears that Tandsi Mine is having a more fragile roof in comparison to other mine roofs. The shale roof of Bhandewara was posing roof stability problems due to weathering. The details of blast design and performance parameters of the four mines are discussed in **Table 2**. The improvement in pull obtained in Saonar Mine was 0.65 m. This is due to the longer hole (2m) used and better charge and delay distribution. Improvements in other mines are in the range of 0.2 to 0.4 m depending on the strength of the coal and the blast design. similar improvements are seen in yield, powder factor and detonation factor. Sockets and misfires have considerably reduced. The blast patterns adopted in these four mine are given in **Fig.1**. Both the existing and modified blast patterns are shown in this illustration. The geological cross section of the seam is depicted in **Fig.2**.

The support system used in the galleries and the height of roof falls observed in these mines are pictorially shown in this figure. The PPV measurement in the roof was carried out using a suitable sensor fixing gadget. The measurements were essentially far-field in nature using Minimate and Blastmate seismographs of M/s Instantel Inc. Canada.

**Table 1 - Geo-mining characteristics of the mines under investigation**

| Mines / Parameters | Dobari | Bhandewada | Saonar | Tandsi |
|---|---|---|---|---|
| **Area & Subsidiary** | Bastacolla Area<br>BCCL | Wani (N) Area<br>WCL | Nagpur Area<br>WCL | Kanhan Area<br>WCL |
| **Roof Condition** | The immediate roof is shale of 0.6m and above this is strong sandstone. Roof RMR is 67.1. Slips are observed. | The roof rock is shale and occasionally slips are observed. | Mine has a fairly strong roof of RMR varies between 64 to 67. Roof rock is free from any predominant geological disturbances. | This mine has sandstone roof. But presence of cross bedding planes reduce the stability of the roof with roof fall extending upto 4 to 5 m. |
| **Coal Type** | Soft cocking coal. | Soft bituminous coal | Soft bituminous coal | Soft bituminous coal |
| **Coal compressive strength (MPa)** | Not Available | 24 MPa | 38MPa | 35MPa |
| **Method of mining** | Bord and pillar | Bord and pillar | Bord and pillar | Bord and pillar |
| **Problems faced** | Joint sets unfavourable to gallery axis. pull obtained is less. | Shale roof limits the max. charge per delay to reduce blast induced roof damage | Reluctance of drillers to drill holes of full length i.e., 2m. | Severe roof strata control problems due to presence of cross bedding planes and joints. |

**Table 2: Performance of blast trials conducted in different mines**

| **Sl. No.** | **Parameters** | **Saonar** | | **Bhandewara** | | **Tandsi** | | **Dobari** | |
|---|---|---|---|---|---|---|---|---|---|
| | | Existing | Modified | Existing | Modified | Existing | Modified | Existing | Modified |
| 1 | Size of gallery (m × m) | 4.2 × 2.8 | | 4.2 × 2.2 | | 3.9 × 3.0 | 3.9 × 2.5 | 4.2 × 2.6 | |
| 2 | No. of holes | 14 | 17 | 15 | 18 | 16 | 16 | 15 | 17 |
| 3 | No. of delays | 3 | 5 | 5 | 6 | 5 | 5 | 3 | 4 |
| 4 | Total charge (kg) | 6.67 | 11 | 6.75 | 9.02 | 6.74 | 6.74 | 9.6 | 11 |
| 5 | Max. charge /delay (kg) | 2.25 | 2.8 | 1.8 | 2.26 | 1.8 | 1.8 | 3.6 | 3.6 |
| 6 | Max. charge/hole (g) | 525 | 700 | 450 | 500 | 450 | 450 | 750 | 750 |
| 7 | Depth of hole (m) | 1.5 | 2 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| 8 | Total drilling (m) | 21 | 34 | 22.5 | 27 | 24 | 24 | 22.5 | 25.5 |
| 9 | Specific drilling (m/t) | 1.2 – 1.4 | 1.2 – 1.4 | 2.25 | 1.93 | 1.22 | 1.17 | 0.97 | 0.98 |
| 10 | Cycle time (min) | 35 | 55 | 60 | 70 | 30 | 30 | 40 | 50 |
| 11 | Average pull (m) | 0.85 | 1.4 – 1.6 | 0.78 | 1.1 | 1.2 | 1.5 | 1.3 | 1.45 |
| 12 | Average yield (ton) | 15-18 | 24 – 28 | 10 | 14 | 19.6 | 20.5 | 21-25 | 25-26 |
| 13 | Average powder factor (t/kg) | 2.0 | 2.3 | 1.1 | 1.35 | 2.08 | 3.1 | 2.4 | 2.4 |
| 14 | Average detonator factor (t/no.) | 0.85 | 1.4 | 0.51 | 0.75 | 0.88 | 1.3 | 1.53 | 1.52 |
| 15 | Sockets | Not significant | | 0.3 – 0.5 | Not significant | 0.3 – 0.5 | Not significant | Not significant | |
| 16 | Special features | Strong roof | | Pyrite bands | | Cross bedding plane | | Strong roof | |

## 4.0 ANALYSIS OF FIELD INVESTIGATIONS

Predictor equation for the roof vibration assessment, relating scaled distance and PPV observed, have been developed by regression analysis. Subsequently, the predictor equation has been used to arrive at near-field PPV values by extrapolation. The influence of PPV on the damage distance into the roof for the sites has been estimated and is shown in **Fig.3** through **Fig.6**. The threshold values of blast-induced rock damage are tabulated in **Table 3**.

**Table 3 – Threshold levels for different categories rock damage**

| Mines / Parameters | Dobari | Bhandewada | Saonar | Tandsi |
|---|---|---|---|---|
| **Roof RMR** | 67.1 | 50 | 64-67 | 44 – 64 (wide variation) |
| **Bolted length used** | 1.5 m | 1.5 m | 1.5 m | 1.5 m |
| **Threshold PPV levels for crushed zone** | 1010 mm/s and above | 1667 mm/s and above | 2060 mm/s and above | 1200 mm/s and above |
| **Threshold PPV levels for overbreak zone** | 920 – 1010 mm/s | 1400 – 1667 mm/s | 1890 – 2060 mm/s | 980 – 1200 mm/s |
| **Threshold PPV levels cracked zone** | 640 – 920 mm/s PPV level | 960 – 1400 mm/s PPV level | 1030 – 1890 mm/s PPV level | 650 – 980 mm/s PPV level |
| **Estimated roof damage distance** | 0.2 m overbreak observed. Due to crack widening time dependent failure is upto 0.82m because of unfavourable joint sets towards the gallery. Bolting of 1.5 m may be adequate to support. | 0.2 m overbreak was observed immediately and cracked zone is upto 0.85m height. Rock bolting with 1.5 m bolt may be adequate. | 0.15 m overbreak observed. Roof cracked upto 0.66m. Rock bolting with 1.5 m long bolt seems to be adequate. | 0.3 m overbreak zone is observed and the cracked zone extends upto 1.0 m. But due to presence of cross bedding planes roof fall upto 4.5m was observed. Bolting of 1.5m is inadequate. |
| **Observed roof damage distance** | Upto 0.56 m | Upto 1.0 m | Upto 0.5 m | 4 m to 5 m |
| **Modification proposed** | From the study of the PPV levels the maximum charge may be used upto 2.2 kg/delay. | Introducing stab holes to get better pull and proposed to used varying delay for better charge distribution. | To get the maximum drilling efficiency, roof height must be reduced. | Reduction of charge in the periphery holes. To get 3 m coal extraction first the top2.5 m then the 0.5 m from floor may be extracted. |

Note : The observed roof damage distance is arrived at from the average height of roof fall collected from the mine.

Comparing the estimated and observed roof damage distance it appears that the suggested blast-induced rock damage is rational. However, a planned monitoring of roof convergence with single point borehole extensometer or multi point borehole extensometer would confirm more precisely the extent of roof damage (bed separation) and the validity of the hypothesis used in this research work.

The influence of RMR, PPV and maximum charge per delay on blast-induced rock damage is discussed below:

### 4.1 INFLUENCE OF RMR

The mines, where the study has been done, have different roof RMR ranging from 44 to 67. It is observed from the graph that RMR has significant role to play in determining the degree of damage to the roof rock. The overbreak/ height of roof fall immediately after the blast is seen to reduce with increasing RMR as shown in **Fig.7**. The estimated bed separation zone for these mines has also been shown in **Fig.7**. The trend appears to be same. However, the rate of decrease is much steeper, thus indicating sharp decline in thickness of bed separation zone for higher roof RMR values.

### 4.2 INFLUENCE OF PPV THRESHOLD LEVELS

The PPV limits for three zones viz overbreak zone, cracked zone and intact zone are shown in **Fig.8** against RMR. The threshold limits for three categories of rock damage namely, crushed zone (very close to hole), overbreak zone and crack zone (consisting crack initiation and crack widening) are given in **Table 3**. The degree of rock damage is dependent on the PPV values. Threshold value of PPV ranges between 1200 –2060 mm/s for crushed zone, 980 – 1890 mm/s for overbreak zone and 650-1030 mm/s for cracked zone.

### 4.3 SELECTION OF MAXIMUM CHARGE/DELAY BASED ON PPV THRESHOLD VALUES

The face production of development headings is largely dependent on pull obtained. Higher pull necessitates higher amount of charge/hole and charge per delay as well. This will lead to more roof vibration during blasting and may result in large overbreaks. The selection methodology for maximum charge per delay (Q) must be based on roof RMR and PPV Threshold limits discussed above for different degrees of rock damage. The ‘Q’ selected for these investigations is arrived at from the relationship shown in **Fig.9**. Such methodology would obviously optimize the pull without compromising the roof stability.

## 5.0 CONCLUSION

Roof vibration predictor equations were developed using scaled distance and PPV data for the four underground coal mines having different geo-mining set up. The threshold limits of

PPV for the three proposed zones of rock damage namely, crushed zone (very close to periphery blast hole), overbreak zone and crack zone (consisting crack initiation and crack widening) are identified. The PPV limit for crushed zone varies from 1200- 2060 mm/s. For overbreak zone the PPV limit varies from 980 to 1890 mm/s, where as for cracked zone this value ranges from 650 to 1030 mm/s. The PPV range for crushed zone, overbreak zone and cracked zone is found to vary from mine to mine due to the change in RMR. The maximum charge per delay is determined based on RMR values for increased production and safety. However, more case studies would help in consolidating the suggested methodology.

It has been observed that though the overbreak and significant visible damage due to blast is less immediately after the blast but with time the height of roof fall has seen to increase considerably. At times gross failure of bolted roof has been observed. Thus it is rational to calculate the required bolt length for supporting roof based on the possible damage estimated from roof vibration data.

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