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# PREDICTION OF OVERBREAK IN UNDERGROUND TUNNEL BLASTING A CASE STUDY

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**ABSTRACT:** Tunnels are required to be constructed for meeting different human needs such as power generation, transportation, underground storage, sewages etc. Irrespective of the purpose for which the tunnels are driven, all are plagued by overbreak problems. Tunnels driven for water conveyance, in hydroelectric projects, in particular, need to be excavated with minimum overbreak so that the cost of permanent concrete lining is kept to minimum.

Predicting overbreak assumes significant importance to design site-specific blasts for minimizing the same. This paper presents a brief review of existing peak particle velocity (PPV) based overbreak estimation models and discusses the influence of PPV on overbreak in a lake tap horizontal tunnel of Koyna Hydro-electric Project, India. Koyna Lake Tap Tunnel is a water feeder tunnel for a fully underground hydroelectric power project. The tunnel had to be driven through hard compact basalt under a shallow cover of 15m beneath a fully charged water body. The rock parting is also compact basalt. Water injection and subsequently grout injection tests confirmed that the rock is intact and there is no evidence of major joints or cavities.

Blasting was completed in two rounds: First the lower part (up to spring level) and then the upper part (arch shape) in a controlled manner i.e., by limiting the maximum charge per delay. Vibration studies were conducted for both the rounds using Minimate Plus) 077 Seismographs, placed on the sidewall. The threshold limits of PPV for different degrees of rock damage are proposed from extrapolated vibration predictor equation. The actual overbreak in the tunnel was measured from the tunnel profiles using a Planimeter. It was found that the percentage overbreak varied from 2.45 to 16.07. The predicted overbreak from extrapolated PPV measurements is compared against the measured overbreak to validate the proposed blast-induced rock damage (BIRD) assessment model. The PPV threshold level, for incipient crack growth was found to vary from 1300 to 2000 mm/s; for crack widening from 2000 to 2800 mm/s and for overbreak from 2800 to 5200 mm/s.

## 1. INTRODUCTION

Drilling and blasting is the most popular excavation technique adopted for tunneling due to its acceptability in a wide range of geo-mining conditions. Faster tunneling rates are possible with the recent developments in explosives, initiating devices and drilling systems. Longer pulls to the tune of 5 to 6 m per blast are common today. However, longer pulls are associated with higher explosive charge per hole and per delay as well, thus, leading to roof rock damages. These are costly in terms of higher support requirement apart from time loss in unproductive work.

In order to control and reduce blast-induced rock damage, assessment of the extent of damage is important. Most of the existing criteria relate damage to ground vibrations resulting from dynamic stresses induced by the blasting process. This paper discusses a case from Koyna Hydro-electric project where tunneling was done below a fully charged water body.

In one of the tunnels known as Lake Tap tunnel, excavation was required under a fully charged water body. In this context it is important to review the blast-induced rock damage prediction techniques and correlate the extrapolated blast vibration data with actual overbreak. All this exercise is aimed at fixing the maximum permissible charge that can be exploded keeping ground vibration within 50mm/s at the critical point, the rock plug.

## 2. OVERBREAK ASSESSMENT

Overbreak assessment in tunnels assumes greater importance to minimize the same adopting suitable site-specific blast designs. A host of geo-technical, explosive, blast design and operational parameters influence it. However, estimation of overbreak from the ground vibration, in terms of peak particle velocity, is found to have increased application in recent times as discussed in Table 1. This is due to the fact that peak particle velocity (PPV) has been accepted as a parameter to assess the structural/rock damage world over today. The proposed PPV estimation models and the damage levels for overbreak are discussed in Table 1. It is understood that before the rock fails as overbreak it must pass through two stages namely, the blast-induced crack growth and crack widening due to expanding gases. It is thus necessary to identify the threshold levels for these two stages.

## 3. FIELD INVESTIGATIONS

Blast optimization trials along with roof/side vibration measurements were conducted in Lake Tap Tunnel of Koyna Hydro Electric Project[7,8]. The important project features are given in Table 2. Data generated included rock characteristics, blast design, performance parameters, PPV and overbreak. A schematic diagram of the lake tap tunnel is shown in Fig.1[9].

Table 1. PPV based damage estimation models proposed by different researchers

| Model(s) | PPV estimation | Merits and demerits |
|---|---|---|
| Scaled distance | $V = K (R/\sqrt{W})^{\alpha}$<br>Where, V = PPV (mm/s)<br>R = Distance of point of interest from blast hole (m)<br>W = Maximum charge per delay (kg)<br>K, $\alpha$ = Site specific constant. | Easy to establish site-specific predictor.<br>Unable to cover all the factors, like bench stiffness etc. Not applicable to near-field blast zone |
| Near-field PPV Holmberg & Persson [1] | $V = K\rho^{\alpha} [{}_0\int^{D-H} dx / \{R_0^2 + (D-x)^2\}^{\alpha/2\beta}]^{\alpha}$<br>Holmberg and Persson considered $\beta = 2\alpha$ and arrived at the following result by normal integration:<br>$V=K (\rho / R_0^{\alpha}[\tan^{-1}(D/R_0)-\tan^{-1}(H/R_0)]^{\alpha}$ | Applicable to rock near to blast hole as it consider the charge as a cylindrical charge. |
| Near-field PPV Rustan et al [2] | | The PPV range was 300-900 mm/s for smooth blasting. An extrapolation for 0.5 m range gives PPVs in the range of 1000 - 3000 mm/s. This is considerably higher than the often-referred range of damage, i.e., 700 - 1000 mm /s. The damage with 700 mm/s extends to 0.1 m range. The observed damage range by direct methods is 0.5 m, which suggests that PPV for damages can be higher than 700 - 1000 mm/ s. |
| Yang [3] | Queen's University blast test - site | The actual damage data from the field related closely with theoretically estimated values. |
| Meyer and Dunn[4] | Used Holmbe<br>Perseverance Nickel mine in Australia | Critical PPV for damage was found to be 600-mm/s while minor damage occurring above 300 -mm/ s |
| Blair et.al [5] | Developed a Dynamic finite element model to assess the damage zone | Argued Holmber<br>incorporating any time lag for the arrival of vibration peaks. Thus the model is unable to provide correct near-field analysis |
| Holmberg and Persson [6] | Modified their previous concept | Effective parts of elemental waves arrive at a point almost simultaneously; hence, difference in time of arrival of elemental waves from different parts of charge can be neglected. |

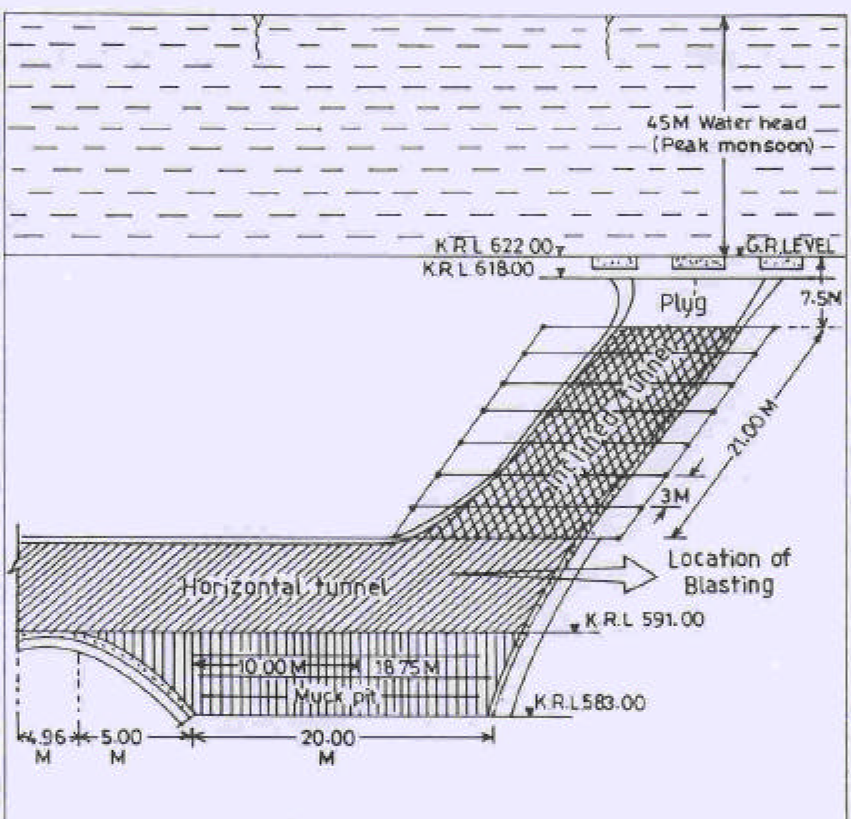

Fig. 1 Schemc for excavation of lake tappings, KHEP, stage IV works.

(Not to scale)

Table 2. Important features of Koyna Lake Tap Tunnel, KHEP Stage IV

| | |
|---|---|
| Location and Project purpose | Western Maharashtra, India. Underground hydroelectric project. |
| Geology of the area | Different formations, namely, compact basalt, amygdaloidal basalt and volcanic breccia belonging to Deccan Traps, India |
| Rock characteristics | |
| [7] | For compact basalt: 15 21<br>For amygdaloidal basalt and volcanic breccia: 10 1.25 |
| Schmidt hammer testing | Schmidt hammer tests were conducted to characterize the rock mass and the values varied from 35 to 56 with an average Schmidt number of 48. |
| Geological disturbances | Vertical to sub vertical joint sets spaced at 0.4m, at angles of 60-150 degrees with the excavation wall in basalts. The joints are tight and no seepage was observed. |
| Water and grout injection tests | The results of the water and grout injection tests indicated the massive nature of rock. The grout and water consumed were nil. |
| Special features | Excavation was carried out just 15 m under a fully charged water body. It is a D-shaped 35m long horizontal tunnel and is passing under a shallow cover of 15 to 21 m rock parting with 45m water head above it. |

Considering the stability of working and timely completion of work a controlled blasting methodology was designed. Continuous monitoring of excavation work for controlling the blast vibration within permissible limits and improving pull were the main objectives of the work.

### *3.1 Blast Design and Vibration Monitoring*

Trial blasts were conducted and vibration monitoring was done for establishing the ground vibration propagation equation. For minimizing the blast-induced vibration and related rock damage the blast design was done in two rounds (Figure 2). In round I holes up to spring level were blasted and in round II remaining holes were blasted.

Data was collected regarding peak particle PPV and scaled distance (SD), where SD is given by the following relation:

$$SD = D/(Q)^{1/3} \qquad (1)$$

Velocity for several blasts carried out in two rounds. For both the rounds, PPV was measured for different maximum charge per delay (Q) and at varying distance (D). Using the monitoring data, presented in Table 3, for each round ground vibration predictor equations were plotted between PPV and scaled distance

*3.2 Determination of Max. Charge/Delay*

Blast vibration monitoring was done for both the rounds. The data has been analysed and the ground vibration predictor was computed as shown in Fig 3 and Fig 4 for both Round-I and Round-II respectively. Using the predictor equation the maximum charge per delay was fixed for an allowable vibration level of 50 mm/sec as shown in Table 4.

Table 4. Maximum permissible charge per delay

| Distance (m) | Max. charge/delay (kg) |
|---|---|
| 10 | 1.15 |
| 20 | 4.60 |
| 30 | 10.36 |
| 40 | 18.41 |
| 50 | 28.77 |

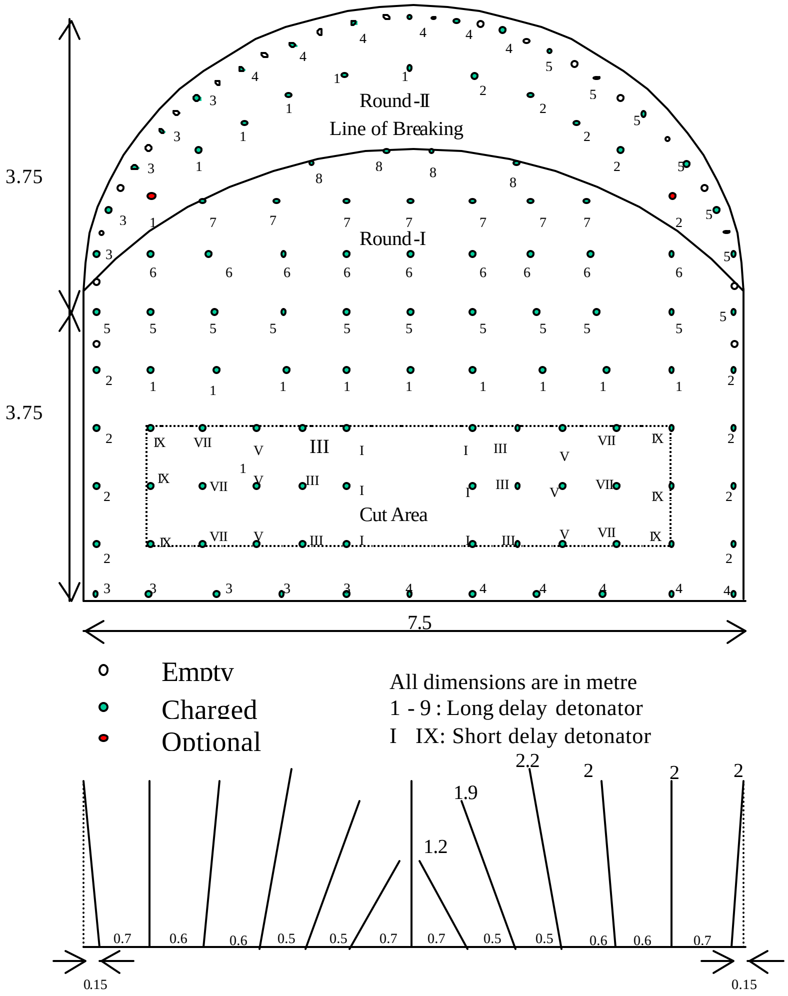

Fig 2: Blast pattern for Lake Tap Tunnel, Koyna

Table 3. Ground vibration monitoring details (Round I and Round II)

| Sl. No. | Distance (m) | Overbreak (%) | Q (kg) | | V (mm/s) | |
|---|---|---|---|---|---|---|
| | | | Round -I | Round - II | Round -I | Round - II |
| 1 | 43.1 | | 18.75 | - | 20.78 | - |
| 2 | 44.5 | | 12.75 | - | 13.30 | - |
| 3 | 45.9 | 15.14 | 6 | 7.7 | 11.50 | 8.2 |
| 4 | 47.3 | 14.32 | - | 7.2 | - | 7.78 |
| 5 | 48.7 | 14.45 | - | 5.25 | - | 6.22 |
| 6 | 50.5 | | 10.8 | - | 12.22 | - |
| 7 | 52.3 | | 6.6 | - | 8.86 | - |
| 8 | 53.7 | 7.23 | 9 | 4.8 | 12.76 | 6.65 |
| 9 | 55.1 | 17.75 | 16.8 | 9 | 11.73 | 5.86 |
| 10 | 57.1 | 2.45 | 13.65 | 3.6 | 11.13 | 1.83 |

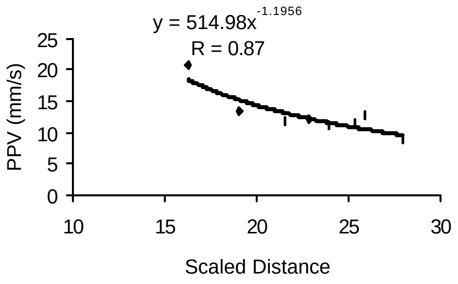

**Fig 3. Vibration Predictor for Round-I**

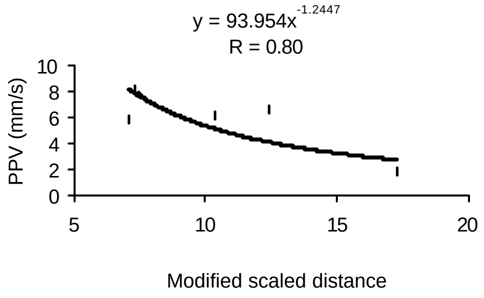

**Fig 4- Vibration Predictor for Round-II**

### 3.3 Near-Field PPV

Estimation of near-field PPV is required for fixing up the damage threshold values for crack initiation, crack widening and overbreak as proposed in Section 2[10]. Thus, an attempt has been made to assess the damage threshold levels by extrapolating the far-field PPV predictor equation. Fig.5 shows the extrapolated values for the damage threshold limits of peak particle velocity for three zones namely, crack growth, crack widening and overbreak.

### 3.4 Overbreak

The overbreak profiles were prepared before and after each blast. The area of the overbreak profiles was measured by planimeter. The planimeter is an instrument for determining the areas of figures on a plane surface having either straight or irregular boundaries. The area was measured with pole outside the area of the figure. The tracer arm was moved in a clockwise direction. It was right hand side type. The overbreak calculated for the blasts has been tabulated in Table 3**.**

The maximum charge per delay and measured overbreak for the blasts has been statistically analysed. A best-fit curve was plotted between them as shown in Fig. 6 and the following relation was obtained from the regression analysis:

$$Y = 0.2867\ X^{1.999} \qquad (2)$$

Where, Y is overbreak ( % )
X is max. charge per delay (in kg)

The regression coefficient (R) for the best-fit curve was 0.88. The higher values of R indicate a greater dependability of the above equation for future overbreak predictions and charge control.

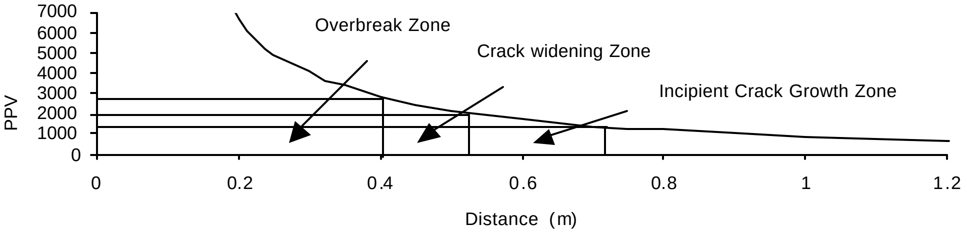

**Fig 5 - Proposed PPV threshold levels for damage estimation**

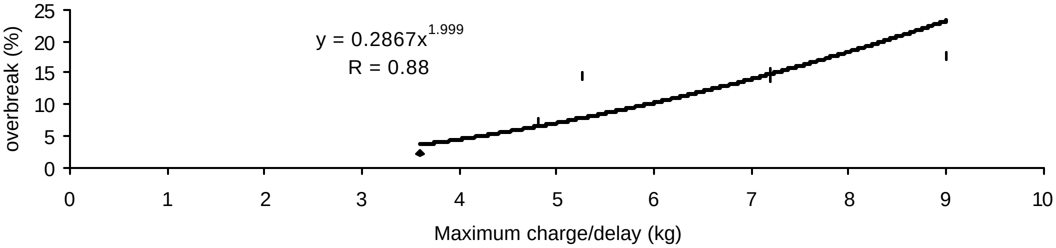

**Fig 6- Influence of maximum charge per delay on overbreak**

## 4. CONCLUSION

Different overbreak/blast damage assessment techniques are reviewed. Trial blasts suggested the safe charge per delay and the suitable blast pattern. Blast vibrations were monitored for all the blasts and it was seen that the values obtained were within allowable limits. Considering the water body above the tunnel and low cover it was advised to continue with 1.5m pattern only using the required number of delays. It is also advised that any change in strata or increased seepage, if observed, should be considered for possible redesign of blasting pattern. Far-field PPV has been extrapolated to near-field for assessing damage threshold levels. Overbreak measured in the tunnel has been related with maximum charge per delay to suggest safe charges for controlling both peak particle velocity and overbreak. The proposed controlled blasting methodology has helped in completing the tunnel safely with reduced overbreak. It is possible now to estimate the likely overbreak in such similar formations and design blast patterns to minimize the overbreak.

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