A CAREFUL BLASTING TECHNIQUE DURING CONSTRUCTION OF UNDERGROUND OPENINGS FOR NUCLEAR WASTE REPOSITORY

Zvonimir Ester, University of Zagreb, Mining, Geological & Oil Engineering Faculty, Croatia

Darko Vrkljan, University of Zagreb, Mining, Geological & Oil Engineering Faculty, Croatia

ABSTRACT

Underground nuclear waste repositories are constructed in natural rock formations, with heterogeneous compound and structure, and should be accommodated in design and construction according to rock conditions. The quality insurance of underground repository, during and after construction, is most demanding in view of contour and category of excavation. The technology of drilling and blasting, regarding the mechanical excavation, is accommodated in sense of response to cross section magnitude of underground openings, the rock conditions and category, the support performance and others design demands. The high level rock damage around underground openings, that is in opposition with reaching quality insurance. Conventional construction technology can be successful by implementation of controlled blasting technique avoiding extensive rock weakness.

1. INTRODUCTION

Drilling and blasting is the most flexible methods of excavation and can be easily adapted to changing drift sizes, ground conditions, ground support types or other design requirements. This method is versatile and applicable to any tunnel length. Disadvantages of drill and blast excavation compared to mechanical methods include:

- higher degree of disturbance to the rock surrounding the openings,
- because of this disturbance, drift conditions may be more difficult to assess for quality assurance or performance confirmation assessment.

The field tests taken during construction of highway tunnels provide the possibility of constructing underground openings by blasting in very complex surroundings without producing damage zone around. A design of safe blasthole patterns of underground opening to avoid rock damage demands test blast method, coupled with recording of seismic effect [12, 13]. Value of ground oscillation velocity is a standardized parameter for the evaluation of a damage capability. It is world-wide accepted and is included into most of world standards. The functional relationship of explosive quantity by one blasting cycle and peak velocity can be established depending of rock category excavated.

Investigations referring to effects of blast-induced vibrations on the stability of underground excavations have been undertaken by Langefors and Kihlstrom, Hoek and Bray, Bauer and Calder and Oriard. Langefors and Kihlstrom [5] predicted rock falls at peak particle velocities
exceeding 305 mm/s and rock fracturing at 610 mm/s. Bauer and Calker [6] predicted damage criteria of rock masses that are based on stresses produced by the peak particle velocity. They conclude that below 250 mm/s fracturing of rock will not occur, and vibration levels of 2500 mm/s are necessary to break the rock. Oriard [7] suggested the occurrence of same damage of rock masses at peak particle velocities over 635 mm. Hendron [8] summarised results of programme leaded by United States Corps. of Engineers Society, that investigate the dynamic stability of underlined tunnels in sandstone and granite. He shows that the minimum peak particle velocity associated with rockfala to be 457 mm/s.

Blasting operations in tunnels are carried out simultaneously with construction works. The various relevant studies agree that at 4 to 6 hours after casting, concrete is considered to be relatively insensitive to vibrations, and that the period between 6 to 24 hours has a great susceptibility to vibrations. Cured reinforced concrete can be readily subjected to vibration levels of 100 to 200 mm/s without any damage [9].

For the purpose of evaluation of possible damage of the rock burden above the tunnel, measuring of seismic effects of blasting on the surface was carried out with intention to define the safe mode of blasting.

2. TEST BLASTING

The several tunnels were drove on the road section Rijeka-Delnice of a new semi-highway Karlovac-Rijeka. In one of them a successful excavation was carried out on extremely problematic and demanding section (cca 60 m) where the tunnel goes only about 9.0 m below the motorway (figure 1). The tunnel excavation was carried out according to NATM with application of the drilling and blasting, while the quantity of explosive charge per one blasting cycle varied depending on the excavation category.

Before the work in critical zone started (the zone of thin overburden below the motorway) it was necessary to undertake test blasting and to record the seismic influence in order to define the safe way of blasting regarding the closeness of the mentioned objects and the safe working conditions.

The four empiric relationships of charge density, distance and peak particle velocity were known from investigations carried out elsewhere [3, 4, 5 i 10]:

\[ v = k* \left( \frac{D}{Q} \right)^n \]  

US Bureau of Mines \hspace{1cm} (1)

\[ v = k* \left( \sqrt[3]{\frac{Q}{D^2}} \right)^n \]  

Langefors and Kihlstrom \hspace{1cm} (2)

\[ v = k* \left( \frac{\frac{1}{2} L^2}{D} \right)^n \]  

Crandell \hspace{1cm} (3)
M.A. Sadovski

\[ v = k \left( \frac{3 \sqrt{Q}}{D} \right)^n \]  

(4)

where is

- \( v \) - peak particle velocity, mm/s
- \( Q \) - maximum weight of explosives per delay, kg
- \( D \) - distance between blast source and observation point, m
- \( k \) - parameter of blasting mode
- \( n \) - damping coefficient of seismic wave

In an earlier interpretation of the observed data the cube root scaling gave the best relationship with highest determination coefficient [2, 3, 4 and 10]. By each blasting \( Q \) and \( D \) values are known, while the calculation of readings gives resultant velocities of the particle velocity in observation points.

The coefficients \( k \) and \( n \) are precisely calculated from the series of equations which can be set when particle velocities are measured in two observation points at single blasting

\[ v_{r1} = k \rho_1^n ; \]
\[ v_{r2} = k \rho_2^n ; \]

(6)

(7)

the equation \( \sqrt[3]{Q} = \rho \) represents scaled distance, where follows

\[ n = \frac{\log \frac{v_{r1}}{v_{r2}}}{\log \frac{\rho_1}{\rho_2}} \]  

(8)

\[ k = \frac{v_{r1}}{\rho_1^n} = \frac{v_{r2}}{\rho_2^n} \]  

(9)

Values of the coefficients \( k \) and \( n \) represent constant values only for the direction of measuring. In other directions, due to variable geological structure, value of damping coefficient \( n \) changes; therefore for each direction that is of interest for construction, it is necessary to undertake particular measuring on two observation points. Coefficient \( k \) represent the cumulative influence of various blasting parameters like type of explosive, initiation mode, relation between diameter of explosive cartridge and blasthole, etc. The assumption is that these parameters can be kept constant in a single construction area.

Ten test blastholes were drilled 1.0 m deep and 45 mm in diameter. The quantity of explosive charge was increased from initial 0.535 kg per hole to finally 1.070 kg. The distance between observation point and blastholes was always 10 m. Thus, the direct proportionality between the quantity of explosive charge \( Q \), and the particle velocity \( v \) was achieved. The values of \( k, n \) and \( D \) were kept constant during blasting of the whole test blast field.
The figure 1 illustrates the test blasting field and the location of the observation point.

![Image of tunnel cross-section with observation point and blastholes](image1.png)

**Figure 1.** *Tunnel cross-section with position of observation point and test blastholes*

The figure 2 illustrates the test blasthole, which was filled with 0.735 kg of explosive charge.

![Image of blasthole geometry](image2.png)

**Figure 2.** *The geometry of explosive charge of the blasthole*
The figure 3. illustrates the particle velocity graph, achieved by blasting of the test blasthole.

![Graph of particle velocity](image)

**Figure 3.** Particle velocity caused by blasting of the test blasthole

3. RESULTS OF TEST BLASTING

The table 1 shows the data on explosive charges of test blastholes and corresponding readings of peak particle velocities.

<table>
<thead>
<tr>
<th>No. of test blasthole</th>
<th>explosive charge Q (kg)</th>
<th>peak particle velocity v (mm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.535</td>
<td>2.175</td>
</tr>
<tr>
<td>2</td>
<td>0.535</td>
<td>2.492</td>
</tr>
<tr>
<td>3</td>
<td>0.535</td>
<td>2.429</td>
</tr>
<tr>
<td>4</td>
<td>0.535</td>
<td>1.905</td>
</tr>
<tr>
<td>5</td>
<td>0.735</td>
<td>2.826</td>
</tr>
<tr>
<td>6</td>
<td>0.735</td>
<td>4.890</td>
</tr>
<tr>
<td>7</td>
<td>0.835</td>
<td>6.969</td>
</tr>
<tr>
<td>8</td>
<td>0.835</td>
<td>6.969</td>
</tr>
<tr>
<td>9</td>
<td>0.970</td>
<td>7.398</td>
</tr>
<tr>
<td>10</td>
<td>1.070</td>
<td>10.176</td>
</tr>
</tbody>
</table>

These results were used to construct a graph of functional relationship between the explosive quantity and peak particle velocity (figure 4). This graph allows calculation of peak particle velocities for any quantity of explosive charge.
\[ v = (9.842238)Q^2 + (-1.078778)Q \]

\[ R = 0.96 \]

**Figure 4.** The functional relationship of explosive quantity and peak particle velocity

4. CONCLUSIONS

1. Test blasting proved that it is possible to construct a tunnel by classical means, by drilling blastholes and blasting, in a very complex setting. The closest object was located just 1.2 m from the blast location.

2. This case study indicates the need for test blasts, coupled with recording of seismic effects. It is possible to assert possible damage of the surrounding rock only after the measured data.

3. Herein, we illustrate the model which allows assertion of a safe blasting regime based on a single observation point.

4. It is necessary to stress once more, that the measured values are applicable only in the direction of the measurement. For each of the preferred directions it is necessary to determine the blasting parameters by additional measurement.

REFERENCES


2. Hendron A.J.(Jr.): 'Engineering of Rock Blasting on Civil Projects' Structural and


