Tunnelling and Underground Space Technology 43 (2014) 113–122

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

An application of the modified Holmberg–Persson approach for tunnel blasting design

Ozgur Yilmaz [a,*], Tugrul Unlu [b,1]

[a] Department of Mining & Mineral Extraction, Zonguldak Vocational School, Bülent Ecevit University, Zonguldak 67500, Turkey
[b] Department of Mining Engineering, Engineering Faculty, Bülent Ecevit University, Zonguldak 67100, Turkey

ARTICLE INFO

Article history:
Received 6 February 2014
Received in revised form 7 April 2014
Accepted 28 April 2014
Available online 21 May 2014

Keywords:
Holmberg–Persson approach
Tunnel blasting
Blasting damage
Overbreak

ABSTRACT

In this study, the applicability of the modified Holmberg–Persson approach for a tunnel blast design was investigated. For this purpose, firstly, a detailed description of the modified Holmberg–Persson approach was made. After that, data collection program for the statistical analysis of the ground vibration parameters induced by the tunnel blasting was presented and then the determination of the critical peak particle velocity level associated with the rock damage was described. Finally, site-specific limiting peak particle velocity values obtained by measuring the overbreak after blasting were given. The results of the field investigations were discussed and a new equation to calculate the crushed zone radius was derived. The studies have shown that Holmberg–Persson approach which was originally suggested for perimeter control design technique, can also be applied for a full blasting round to select the proper explosive-hole combinations.

1. Introduction

Drilling and blasting application is generally inevitable for rock excavation activities in mining, quarrying and civil construction works. Therefore, the use of explosives is probably the most widely used means of crushing rock, as well as the most cost-effective rock excavation method in mining and construction operations. Predicting and limiting the blast induced damage zones are very important for the long term stability of underground openings which are excavated by drilling and blasting method. Perimeter control blasting techniques are commonly used in civil construction projects to overcome difficulties arising from drilling and blasting operations. In mining applications, however, these techniques are not so commonly used. Therefore, in underground mine galleries, poorly designed blasting operations may result in overbreak and unwanted structural damages.

In the late 1970s, Holmberg and Persson (H–P) introduced a perimeter control design technique based on the peak particle velocity (PPV) generated by the detonation of a charge (Holmberg and Persson, 1978, 1979). H–P approach gained quite wide acceptance due to the logical basis and the relative ease of the application. This method provides a unique practical methodology for blasting engineering applications which include the development of site specific indices for damage prediction and damage control. However, an error in the mathematics behind the H–P approach was discovered by Hustrulid and Lu (2002). Iverson et al. (2008) later introduced a modification in the H–P calculation procedure so as to mitigating the problem, at least partially.

H–P approach is one of the most widely used engineering methods to model the site specific attenuation of the blast waves in the rock mass. The main purpose of this study is to show the applicability of the modified H–P approach for a tunnel blast design. Even though this approach is a perimeter control design technique, it was used to design the whole blasting round in this work. In that regard, a limiting PPV value was obtained using the relationship between peak particle velocity, linear charge concentration, distance from the charge and the observed extent of damage, and then it was applied to the design curves for different linear charge concentrations to select explosive-hole combinations.

2. Description of the modified Holmberg–Persson approach

Since seismic waves decay with distance in a fairly regular manner, they are predictable with the acceptable accuracy (Nateghi, 2011). The H–P approach is based on the fact that rock damage due to blasting being related to the peak particle velocity associated with the blast produced seismic waves (Holmberg and

* Corresponding author. Tel.: +90 3722574010x1525; fax: +90 3722574023.
E-mail addresses: ozgyilmaz9@hotmail.com (O. Yilmaz), unlutugrul@hotmail.com (T. Unlu).
[1] Tel.:+90 3722574010x1197; fax: +90 3722574023.

http://dx.doi.org/10.1016/j.tust.2014.04.009
0886-7798/

Persson, 1978). The seismic wave energy associated with the blast induced ground vibration decreases with distances due to decay of both the amplitude and the frequency of vibration. The ground vibration recorded at a certain location depends principally on the amount of explosive charge per delay, the distance between source and measurement points and the elastic properties of the transmitting medium (Tripathy and Gupta, 2002). Many authors used the scaled distance concept to estimate peak particle velocity of the ground vibration (Duvall and Petkof, 1959; Langefors and Kihlstrom, 1963; Ambraseys and Hendron, 1968). The scaled distance is a normalized factor that combines the distance with the explosives energy to give a single number which can be used for further calculations. Holmberg and Persson (1978) does not take a particular charge symmetry into consideration to predict peak particle velocity and uses the following general equation:

$$\mathrm{PPV} = K \cdot W^{\alpha}/R^{\beta} \tag{1}$$

where PPV is peak particle velocity (mm/s), W is the maximum charge per delay (kg), R is the distance between blast location and vibration monitoring point (m), and K, α, β are site specific constants which can be determined by multiple regression analysis. The term K reflects the source energy and the coupling efficiency of the explosive to the blasthole wall. Higher values of K indicates high energy and well coupled explosives. The term β represents the loss of vibrational energy with distance. Higher values of β represents less competent rock mass which attenuates vibrational energy more quickly while lower values represents a competent rock mass with little fracture which transmits the vibrational energy with little attenuation (Scott, 2009).

The Eq. (1) above is based upon the assumption that the detonation occurs at a single point and hence it is only valid when the distance R is large compared to the length of the charge. When the point under consideration is close to a long charge, like the case in the tunnel blasting, the peak particle velocity must be obtained by integration over the charge length (Hoek and Brown, 1980). Holmberg and Persson (1978) divided the long charge into a number (n) of small elemental charges of equal length ΔL. Assuming that the charge concentration per unit length is q, the charge weight for each element can be expressed as:

$$\Delta W = q\Delta L \tag{2}$$

where ΔW is the charge weight of each elemental charge, ΔL is the length of each elemental charge and q is the charge concentration per unit length. Consequently, the peak particle velocity at a given observation point due to the arrival of a particular elemental charge denoted by the subscript i may be expressed by the following equation:

$$\Delta \mathrm{PPV}_i = K(\Delta W)^{\alpha}/R_i^{\beta} = K(q\Delta L)^{\alpha}/R_i^{\beta} \tag{3}$$

Assumed problem geometry to simplify the discussion is shown in Fig. 1. As can be seen, the charge lies along the z axis with the r axis passing through the mid-point of the charge. The total PPV due

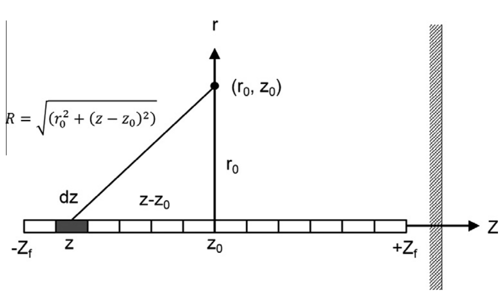

Fig. 1. Schematic representation of the simplified charge geometry.

to the arrival of the seismic waves from the different elemental charges is to be determined at an observation point (r_0–z_0) located along the r axis. Since the waves from the elemental charges travel different distances to reach the observation point, their amplitudes will be distance dependent. Also, in general, the arrival times and wave orientation will vary depending on the velocity of detonation of the explosive and the wave velocity through the rock mass. Holmberg and Persson assumed that the entire charge detonates instantaneously, the amplitudes are simply summed without considering arrival direction and PPV is proportional to the dynamic strain experienced by the rock mass. It was also assumed in this approach that the peak particle velocity due to each small element of charge within the blast hole is numerically additive. Besides, the effect of free face boundaries and the velocity of detonation of the explosive charge have been neglected for practical purposes (Holmberg and Persson, 1978, 1979). This simplifies the situation considerably and the resulting PPV is obtained by summing the contributions from the different elemental charges:

$$\mathrm{PPV} = \sum_{1}^{n} \Delta \mathrm{PPV}_i = Kq^{\alpha} \sum_{1}^{n} \Delta L^{\alpha} R_i^{\beta} \tag{4}$$

The above assumptions allowed the derivation of a simple non-linear relationship to describe the peak particle velocity attenuation in the near field. Under these conditions Holmberg and Persson replaced the summation by the following integral expression:

$$\mathrm{PPV} = K\left[q\int_{z_i}^{z_f} \frac{dz}{\left[(r_0)^2 + (z - z_0)^2\right]^{\beta/2\alpha}}\right]^{\alpha} \tag{5}$$

However Hustrulid and Lu (2002) pointed out that the step from PPV which was expressed as a summation in Eq. (4) to PPV which was expressed by the integral in Eq. (5) is not correct. The exponent α was moved from inside the summation sign to outside of the integral sign. This error can be corrected by simply reverting back to Eq. (4). Since ΔL is the same for all of the elemental charges at the summation expression, this term can be removed from under the summation sign to yield (Iverson et al., 2008; Tesarik and Hustrulid, 2009):

$$\mathrm{PPV} = \sum_{1}^{n} \Delta \mathrm{PPV}_i = Kq^{\alpha} \Delta L^{\alpha} \sum_{1}^{n} 1/R_i^{\beta} \tag{6}$$

It is clearly seen in Eq. (6) that the PPV depends on the length of the elemental charge raised to the power α. Only for the very special case, $\alpha = 1$, the equation is stable. For the case $\alpha > 1$, the PPV decreases to zero as the elemental length decreases. For the case of $\alpha < 1$, the PPV increases to infinity as the elemental length decreases. Thus, this procedure cannot be followed. NIOSH (The National Institute for Occupational Safety and Health) has revisited the basic concepts that Holmberg–Persson approach involved and correct the mathematical problems. The new solution involves determining the average travel distance to the observation position for all of the elemental charges. In this approach, the PPV is given by Iverson et al. (2008):

$$\mathrm{PPV} = KW^{\alpha}/\bar{R}^{\beta} = K(qL)^{\alpha}/\bar{R}^{\beta} \tag{7}$$

where $\bar{R}$ is the average travel distance. According to Martin (2007) the average travel distance can be defined by the following indefinite integral expression (Iverson et al., 2008):

$$\bar{R} = \frac{1}{z_f - z_i}\int_{z_i}^{z_f} \sqrt{(z - z_0)^2 + (r - r_0)^2}\, dz \tag{8}$$

The value of the indefinite integral may be written as (Weast, (1983), from Iverson et al. (2008):