International Journal of Rock Mechanics & Mining Sciences 66 (2014) 30–40

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Design and optimization for bench blast based on Voronoi diagram

Jun Liu [a,*], Pinyu Sun [b], Fangxue Liu [c], Mingsheng Zhao [d]

[a] Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering, Hohai University, Nanjing, PR China
[b] Institute of Engineering Safety and Disaster Prevention, Hohai University, Nanjing, PR China
[c] College of Mechanics and Materials, Hohai University, Nanjing, PR China
[d] Guizhou Xinlian Blasting Engineering Limited Corp, Guizhou, PR China

ARTICLE INFO

Article history:
Received 15 March 2013
Received in revised form
5 September 2013
Accepted 20 November 2013
Available online 18 January 2014

Keywords:
Bench blast
Voronoi diagram
Hole-by-hole blast
Free surface
Blast design
Initiation sequence

ABSTRACT

A method is proposed for bench blasting in open pit mines that can automatically determine the blastholes positions, calculate the explosive charge mass, and identifies the initiation sequence in the case of the hole-by-hole initiation. An analytical solution of the blasthole and row spacing is first deduced based on the concept of the explosive charge maximization. Then for a specified blast area, the coordinates of the blastholes are determined by a cluster of reference polylines. A Voronoi diagram of the blast area is constructed by means of the reference points of the blasthole coordinates. Based on the Voronoi diagram, the explosive charge mass of a blasthole can be easily calculated by the volume formula of charge calculation. An algorithm that can identify the initiation sequence for the hole-by-hole blast is developed from the Voronoi diagram. A code for the bench blast design is developed in C++. The proposed method can automatically complete the whole bench blast design according to the blast area configuration and several parameters required by this method. The results of practical application show that the proposed method can greatly reduce the amount of the design work and validly improve the blast results.

1. Introduction

Bench blasting is the most common blasting technique in surface mines and quarries, and has been widely used in the fields such as civil, hydraulic, hydroelectric and transportation construction excavations. Therefore, an optimized bench blast design would be of significant benefit to the bench blast construction operators since the bench blast has been the most common rock blasting activity.

By definition, bench blast is blasting in a vertical or subvertical blasthole or a row of blastholes towards a free vertical surface. The boreholes are distributed row by row. In the traditional bench blast, more than one row of blastholes can be blasted in the same round. A time delay in the detonation between the rows creates new free surfaces for each row. In general, the millisecond delay initiation of the explosive charge is widely used in bench blast. However, there exist some limitations and shortages in the millisecond blasting method such as there are not enough compensation spaces during a blast blasthole detonating, the size distribution of fragments in muck pile is non-uniform, the strongly ground vibration induced by blasting would occur because of the large amount of explosive charge per delay, and tight bottom frequently appears in muckpile.

Due to the varying nature of rock properties and geology as well as free surface conditions, reliable theoretic formulae are still unavailable at present and in most cases blast design is carried out by personal experience. As efforts to find more scientific and the reliable method to improve or optimize bench blast design, various research studies were initiated. These works can be divided into four types from different viewpoints: (1) the empirical formulae based on field measurement (EFFM) and simplified analytical equation (SAE); (2) numerical modeling; (3) prevention hazard of bench blast; (4) the artificial neural network (ANN) and computer-aided design (CAD) of bench blast.

For the EFFM, the empirical relationships between design parameters and blast results were built by statistical analysis based on field measurements [1–3]. However, large amount of field test data are necessary in this method. Additionally, the methods have poor on-site applicability. For SAE, the simplified analytical equations between blasting conditions and blasting results were deduced based on simplification and assumptions of rock mass and explosives etc [4]. These equations can only reflect approximate relationships since some factors that influence the blasting results are neglected.

In recent decades, the numerical modeling methods have been employed to predict results of bench blast such as the Finite element Method (FEM) [5–8], the Discrete Element Method (DEM)

* Correspondence to: Key Laboratory of Ministry of Education for Geomechanics and Embankment Engineering 1 Xikang Road Nanjing, Jiangsu 210098 China. Tel.: +86 25 837 87172; fax: +86 25 837 13073.
E-mail address: ljun8@263.net (J. Liu).

1365-1609/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijrmms.2013.11.012

[9–11] and the Discontinuous Deformation Analysis (DDA) [12–15]. The blast design would be modified by the feedback from the simulated results. However, the optimum and selection of parameters of bench blast only aim at one or several factors instead of the complete blast design. Otherwise, the numerical method is difficult to apply in the routine production of bench blast since numerical modeling is a time consuming process and some parameters required by numerical modeling are difficult to determine. Therefore, the numerical method is difficult to be used to directly guide blast design, but it can well serve as a way of research.

A number of researches have optimized the bench blast from the perspectives of the hazard prevention of bench blast such as control of blast induced vibration [16–20] and flyrock [21–25]. However, it is biased to optimize a bench blast design only from the angle of hazard prevention. An ideal design should be a compromise between the lowest hazards and the best blast results. Therefore, the factors, which may affect the bench blast results, should be comprehensively considered between the hazards and the results of bench blast.

Artificial Neural Networks (ANN) is a type of intelligent tool to understand the complex problems. Once the network has been trained, with sufficient number of sample data sets such as the previous bench blast parameters and blast results, it can make predictions, on the basis of its previous learning, about the output related to new input data set of similar pattern [26–30]. Nevertheless, a large number of sample data sets with respect to bench blast are required to train the network. Additionally, the CAD technique has been developed to optimize bench blast design in recent decades [31]. In general, a computer-aided blast design system consists of two modules: one uses theoretical and empirical formulae and procedures to design a blast based on user supplied geological and mechanical data, while the other is an expert system that analyses some factors that influence on blast results and recommends remedial action using knowledge based rules [32–34]. The CAD method has the same limitation as that of ANN in terms of bench blast design.

To overcome the limitations and the shortages of the millisecond blasting in which the blastholes are initiated row by row, the hole-by-holy initiation techniques were proposed as the emergence of Orica's high-precision delay detonator [35] and have been widely used in the bench blast. In the hole-by-holy initiation pattern, the blastholes in a blast area are initiated one by one, i.e., each blasthole is independently initiated according to a certain sequence of time and space. Thus, there exists a time delay between the blastholes, which can create more new free surfaces for the blastholes blasted subsequently. The advantages of the hole-by-hole blast include: the number of free surfaces for a blasthole would increase as its neighboring blastholes are gradually initiated; the boulder frequency is reduced since the rock mass is well fragmented; and the blast induced vibration is also significantly reduced. Nevertheless, the precise and accurate timing delays are required in the holy-by-hole initiation pattern and an automatic design method is also required when a large number of blastholes need to be initiated. The ShotPlus software [35] developed by Orica is a blast initiation sequencing program according to survey data detailing blasthole coordinates and identifiers, geological boundaries, pit design information. The ShotPlus allows the evaluation and optimization of blast design with Orica products. However, the ShotPlus cannot automatically implement the whole bench blast design, for example, the blasthole coordinates are input manually.

In this work, a design method of hole-by-hole bench blast is developed based on the Voronoi diagram. This method can automatically determine the blastholes positions, the initiation sequence, explosive charge mass and other parameters required in blasting construction. The detailed algorithm was designed and the corresponding code was also developed on the platform of VC++.

In the following sections, the determination of blastholes positions is first presented. Then the Voronoi diagram of blast area is introduced. Furthermore, the methods of determining explosive charge mass and the initiation sequence of the blastholes are illustrated. Finally, an example of practical application is introduced to demonstrate the performance of the proposed method.

2. Blasthole positions determination

Determining the blasthole positions is the first step in the bench blast design. The distribution of blastholes was empirically determined in the bench blast design according to the blastability of rock, bench height and blasthole diameter. In this work, an adaptive scheme is proposed by which blasthole spacing (defined as the distance between two neighboring blastholes in a same row) and row spacing (defined as the distance between two neighboring rows) can be automatically calculated based on the known conditions such as the specific charge, the bench height, the blasthole depth and the blasthole diameter. Then a series of polylines, which serve to calculate the coordinates of the blasthole centers, are generated by moving the bench crest back towards to the inner blast area. Furthermore, the blasthole positions can be obtained by means of reference circles that are forwarded along the polylines at equal intervals (the blasthole spacing).

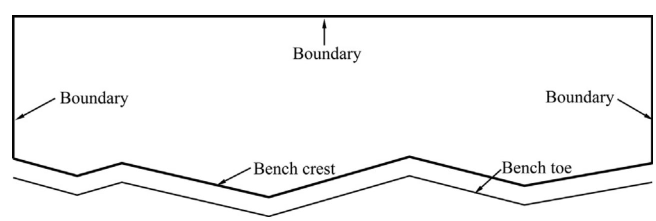

Fig. 1. The description method of the blast area configuration.

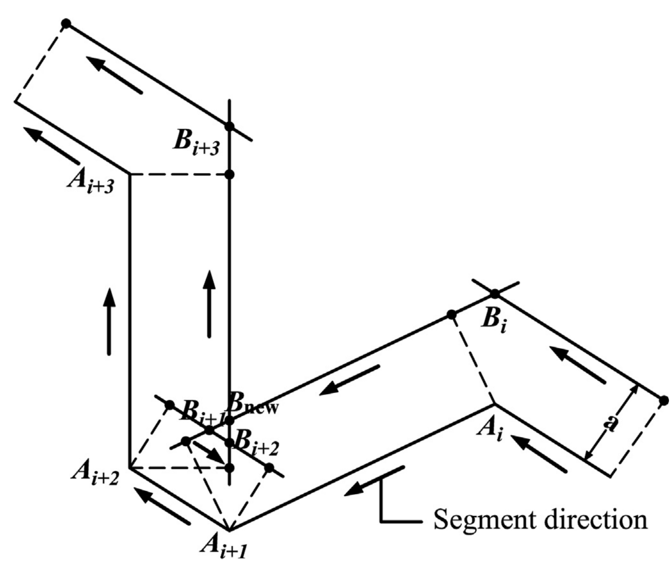

Fig. 2. The schematic of removing a segment whose direction vector is opposite to that of the corresponding segment in the previous polyline in the process of the reference polyline generation.