

Application of "the optimization method" (golden section law) in blasting engineering

Yu Shu-bao^{1,2}, Wang Xu-guang³, Wang Bo-yin², Fu Zhan-hua², Yu Yong-hai²

¹School of Mechanics and Civil Engineering, China University of Mining and Technology, Beijing 100083, China;

²Tangshan Jinyu Blasting Engineering Co., Ltd., Tangshan 063000, Hebei, China;

³Beijing Institute of Mining and Metallurgy, Beijing 100160, China

^a874595139@qq.com

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Abstract. The "golden section" is an ancient mathematical method, it is ubiquitous, and created all things beauty of harmony, over the years has frequently been applied to art, painting, design and other fields, and often play the beat all effect. According to many years of engineering practice, the "golden section" and blasting engineering examples, the application of golden section to open pit blasting, towering building (structure) building demolition blasting engineering, and have obtained very good blasting effect.

Introduction

In recent years, with the large-scale old city renovation, the reconstruction and expansion of mine factories, and the construction of infrastructure, blasting engineering has become more widely applied; the scale and difficulty of blasting projects have also increased; and the blasting technology and quality requirements have become higher and higher. Looking through the development of blasting technology in China, the predecessors have put forward some theoretical, empirical, semi-theoretical and semi-empirical equations based on the study of the blasting mechanism and engineering practices, providing theoretical guidance for technicians to carry out blasting design and construction. However, due to the large numbers of equations, some blasting technicians easily get confused at the design stage; moreover, the actual results differ from the ones calculated from some individual equations, which cannot guide the design process and construction appropriately, making it even harder to guarantee the safety of blasting projects [1-3].

"Optimization method" refers to a scientific method to study how to quickly find the optimal solution with fewer test times. The "0.618" in the optimization method is closely related to the golden section. It is Hua Luogeng who has discovered the profound scientific principle of the golden section. The "Optimization Law" promoted by him in previous years has made significant contributions to scientific experiments and solved many problems in real world [4]. In order to find a simple and practical theoretical method to guide engineering blasting, through many years of practice, the golden section method can also be applied in engineering blasting field, and guide the design and construction of blasting projects.

Application of Golden Section Method in Surface Blasting

Surface blasting is mainly deep hole blasting supplemented with shallow hole blasting. It is widely used in mine stripping, cutting excavation and hydropower engineering [5]. When decide the blasting techniques, theoretical analysis and empirical methods are usually used to obtain the values of blasting parameters. However, there are often certain errors occurring. By contrast, using golden section method in the design process, good results can be achieved.

Surface deep hole blasting

Explosives charge and the length of stemming of blast hole

For deep hole blasting (hole depth of 5 to 15 meters is preferred), the step parameters and blasting parameters determine the effect and quality of blasting, and the specific consumption of explosive is the key factor. When the step parameters, charging mass and density of explosive are fixed, the specific consumption of explosive will determine explosives loading and filling length of the blast hole. That is to say: Explosives charge and length of stemming of blast hole is actually the concrete expression and reflection of the specific consumption of explosive. Therefore, experienced and senior blasting technicians can predict the blasting effect by the explosives charge and the length of stemming of blast hole. A large number of blasting engineering experiences show that: if the length of stemming is too large, it will result in a large block rate at the top of the blast hole, a low loose coefficient, an increase in the cost of block holing, and safety hazard, meanwhile affecting the speed of excavation; if the length of charge is too long, it will not only increase the cost of blasting, but also causes fly rocks and accidents to happen.

A large number of engineering practices have proved that when the charge length is 0.618 times of the blast hole depth, good blasting effect can be seen. Over more than 20 years, via tens of thousands of deep hole blasting tests in more than thousands of different scaled explosion zones in various environment, the corresponding block rate and toe rate of blasting are obtained at different charging height, as shown in Table 1. The comparison and analysis can be seen in Figure 1. It can be seen that defining the length of charge by using the golden section ratio can greatly reduce the toe rate and block rate, and improve the blasting effect.

Table1 The block rate and the toe rate of blasting in different charging height

The ratio of charging height to blast hole depth	Block rate/%	Toe rate/%
0.2		1.4
0.3	2.8	1.1
0.4	0.7	0.6
0.6	0.3	0.2
0.618	0.2	0.1
0.8	0.5	0.3
1	0.9	0.6

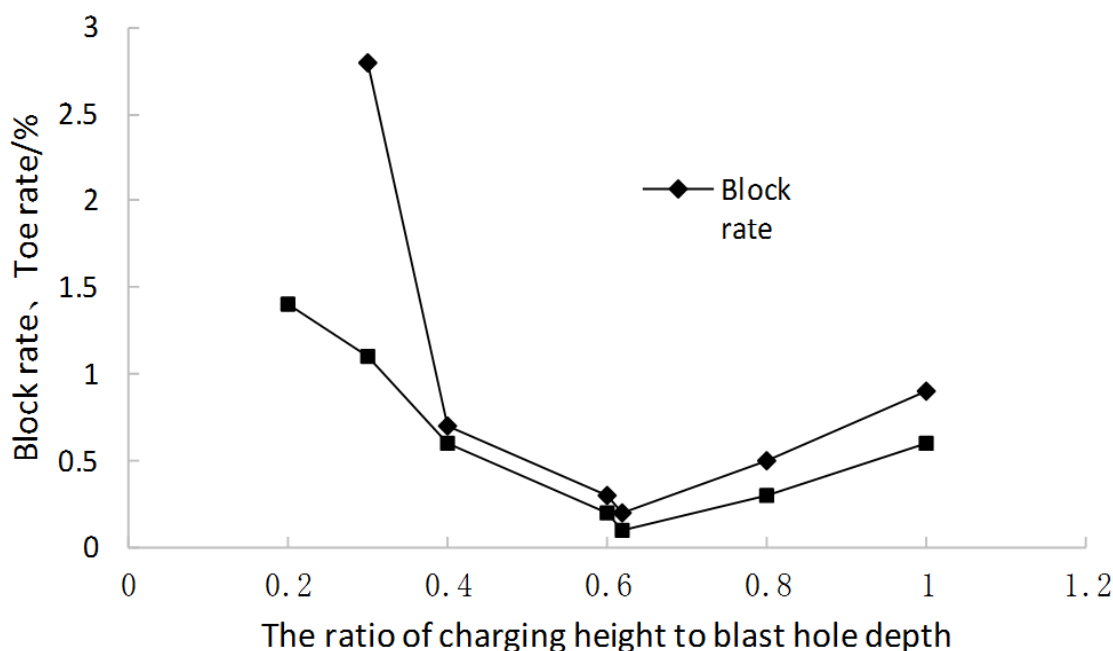


Fig.1 Blasting effects assay plan of determining the charge length by golden section method

Determination of the primer location

According to the requirement of the golden section method, followed the explosives charge and length of stemming of blast hole, the location of the primer should be determined. As it determines the direction of detonation, i.e., top initiation or bottom initiation, which directly related to the number and distance of the flying objects.

(1) a top initiation should be adopted in the case of fine surrounding environment in the blast zone, sufficient fragmentation and uniform block size needed, that is, the primer is placed under the explosive and at 0.618 times of the length of charge from top to bottom, as indicated in Figure 2(a).

(2) When the surrounding environment of the blasting area is relatively complex and the control of individual flying object is strictly required, the bottom initiation should be adopted, i.e., the primer is placed above the explosive and at 0.618 times the length of charge from bottom up, as indicated in Figure 2(b).

The use of "golden section method" to control the length of the charge of the blast hole and the position of the primer can effectively improve the blasting quality, reduce the blasting cost and avoid the occurrence of accidents.

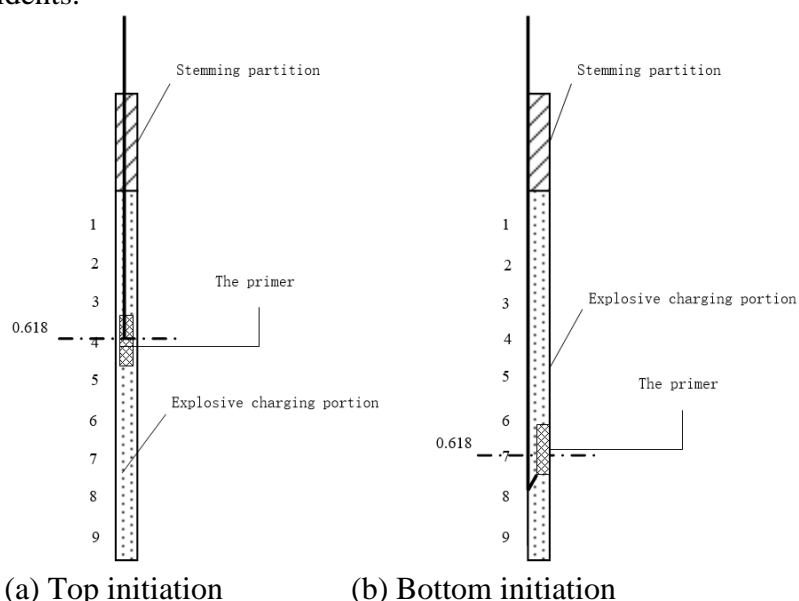


Fig.2 Diagram of primer location in top and bottom initiations

Surface shallow hole blasting

Shallow hole blasting is a widely used traditional blasting method, characterized by simple construction equipment, convenient operation and flexibility. However, due to the relatively large specific consumption of explosive, line of resistance or the length of stemming is generally small, it is easy to cause flying rocks and then explosion accidents. Therefore, the reasonable length of charges and stemming are the key to reducing accidents and ensure blasting safety.

Over years of practice, the principle for determining the length of charge and stemming for shallow hole blasting is the opposite to that in deep hole blasting, i.e., the length of stemming is 0.618 times the length of the blast hole, and the length of the stemming and the length of charge are expressed as follows respectively:

$$\begin{aligned} L_t &= 0.618H \\ L_y &= H - L_t \end{aligned} \quad (1)$$

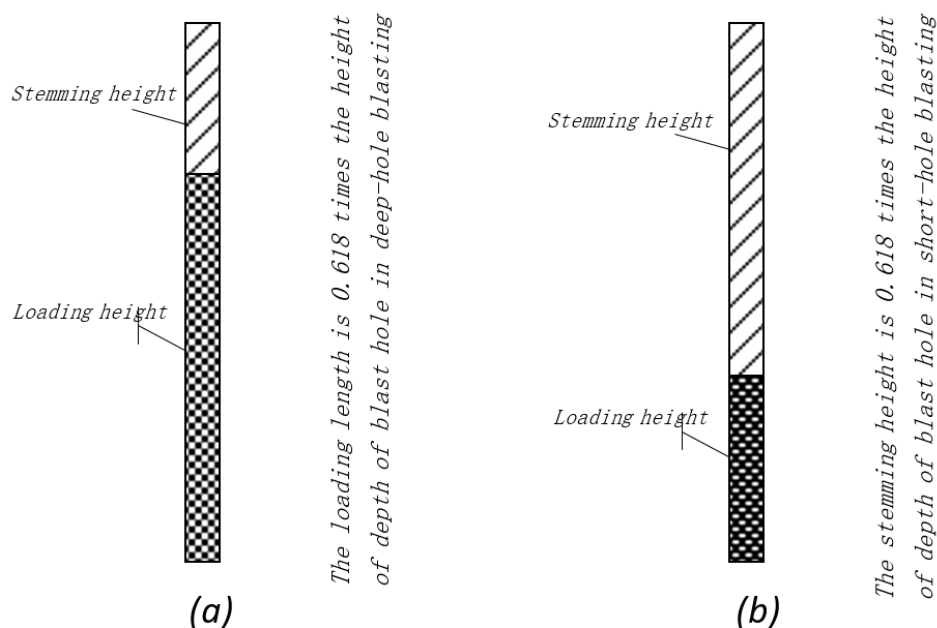
In the equation

H – the depth of the blast hole, m;

L_y — the length of the charge, m;

L_t — the length of the tamping, m.

The stemming height and loading height in golden section are demonstrated in Figure 3.



(a) deep-hole blasting $L \geq 5\text{m}$ (b) short-hole blasting $L' \leq 5\text{m}$

Fig.3 Golden section of stemming height and loading height

In accordance with the "golden section method" to determine the length of charge and length of stemming, one can improve the blasting effect meanwhile control the radius and span of flying rocks.

Deep open pit excavation blasting

Analysis of deep open pit excavation blasting

During open-pit mining process, after the pit entered the closed loop, especially when it extended to the deep pit mining stage, the amount of ground water increased, the rate of hole forming of the drilling rig reduced dramatically, thus it becomes increasingly difficult to open up new-level excavation of inclined trench. For many years, the inclined trench excavation has been restricted by traditional one-way excavation and is in a passive state of production organization. By means of the research and analysis on different influence factors of the excavation projects in each mining area of Shougang iron mine over years, the author found that the main reasons affecting the excavation speed are: first, the time to form the first blasting zone of trenching blasting is too long, and the scale is small. Second, due to the limitation of drainage, the electric shovel advances slowly. The traditional method drains the water backwards, the water level drops slowly, however the shovel is digging forward and downward with a certain slope, which causes the drainage facilities to move frequently, and the shovel dipper frequently relocated downwards, which greatly reduces the working efficiency of the main equipment. Third, the effect of blasting is poor, and block rate and toe rate are far higher than the regular production blasting zone.

In order to overcome these unfavorable factors, the "Golden Section Method" was applied to trenching blasting and received significant results. It is mainly used for the selection of the first blasting position, determining the explosives charging construction, and the optimal position of the drainage facility.

Excavation project (ditching) position of the first blasting zone and drainage facility

(1) Method for determining the center of the first blasting zone

$$L_d = 0.618L_1 \quad (2)$$

In the equation,

L_d : the distance from the center of the first blasting zone to the bottom of the trench, m;

L_1 : the total length of the ditch, m.

If the design horizon interval is 12 m, the climbing ability of the mining vehicle is 8%, and the total length of the ditch is about 150 m. According to equation (2), the distance from the center of the first blasting to the bottom of the inclined trench can be found to be 92.7 m.

(2) Reasonable location of temporary drainage facilities

According to the same principle, as per the result from equation (2), 92.7m away from the bottom of the ditch is the best location for temporary drainage facilities.

This setting can reduce the relative water level of the temporary blast holes, increase the efficiency of drilling rigs, and decrease the rate of spent holes. At the same time, drainage in front of the electric shovel can form the first half of the ditches in accordance with the design slope, greatly improving the operating efficiency of the electric shovel. Since this drainage method changed the traditional one-way excavation, the drainage facility was set in front of electric shovel instead of in the rear, so it was called the "forward drainage" method.

determine a reasonable charging construction

(1) Match between the length of the explosive column and the depth of the blast hole.

During the trenching blasting, the spacing pattern parameters are generally reduced and the specific consumption of explosives is increased to overcome the clamping force of the surrounding medium. Sometimes, the traditional method of increasing the depth of the blast hole and full explosive charging is also used so that the stemming material of blast hole is less than 3 meters. It has been proved that when the specific consumption of explosive is too small, the loosening coefficient of the explosive zone is lower than a regular value. However, when the explosive consumption is too big, a large quantity of explosive gas with high-temperature and high-pressure will spill over, resulting in "popping explosive" and great energy efficiency decreases (the efficiency is normally less than 15%). Through the experiments on more than 4,000 blast holes in over 100 explosion zones, it was found that when the charge length is close to 0.618 times depth of the blast hole, the block rate is about 0.1%. There is basically no toe rock, and the blasting effect is at its optimal condition.

The charge length of trenching blasting can be calculated as follows.

$$h_y = 0.618h_k \quad (3)$$

In the equation,

hk: the depth of charge of the blast hole, m;

Hv: the depth of the blast hole, m.

(2) The relationship between the length of explosive column and the depth of the blast hole in fixed tunnels

In fixed tunnel excavation, the depth of the blast hole in the trench blasting varies with the gradient. When it is greater than 10m, the charge length is still calculated using equation (3); when the blast hole depth is less than 10m, the equation should be calculated as follows.

$$h_y' = (1 - 0.618)h_k' \quad (4)$$

hy': the depth of the charge (hole depth is less than 10m), m;

hk': the depth of hole, m, which is less than 10m.

(3) Reasonable position of the primer in the explosive column

The different locations of the primer will also have a certain impact on the blasting effect. With a lot of production practice, people are accustomed to placing the primer at a distance of 2/3 times the length of the explosive column from the bottom of the blast hole. This proportion is also very close to the golden section. It has been proved that this method can generate a good blasting effect. According to the "golden section" method:

$$L_q = 0.618h_y \quad (5)$$

Lq: the distance between the primer to the bottom of the bole, m;

hy: the length of the charge, m.

Using the "golden section" method to determine the rational charge construction of the trenching zone and the best location of the first blasting zone and drainage facilities is economical and efficient, and can greatly improve the operating efficiency of the main mining equipment. At the same time, it also improved the blasting effect of the trenching blasting zone and cut down time for the excavation project.

Application of Golden Section Method in Demolition Blasting of High-rise Buildings

High-rise Buildings such as chimneys and water towers are mostly tubular or square structures. In demolition blasting construction, to determine the reasonable length of the blasting incision (including the length of the lower edge of the guide window) is the key to the success of the blasting. If the length of the blasting incision is insufficient, it will cause explosion without falling. If the length of the blasting incision is too long, recoil or inclination will occur, resulting in blasting accidents [6-7].

After dozens of projects of high-rise tubular buildings blasting, applying the “golden section method” to determine the reasonable length and reserved length of blasting notch is a simple and rational. The equation is expressed below.

$$L_q = 0.618C \quad (6)$$

In the equation,

L_a : the length of the blasting incision, m;

C : the perimeter of the blasting site, m.

Traditional blasting incision ranges from 210° to 230° . The supporting area is between 130° and 150° . The ration of blasting incision to supporting incision falls under the range of 0.588 and 0.683, 0.613 in average. According to the golden section method, when the incision is 222.5° , the ration is 0.618, which agrees with results of the equation using perimeters of the blasting site.

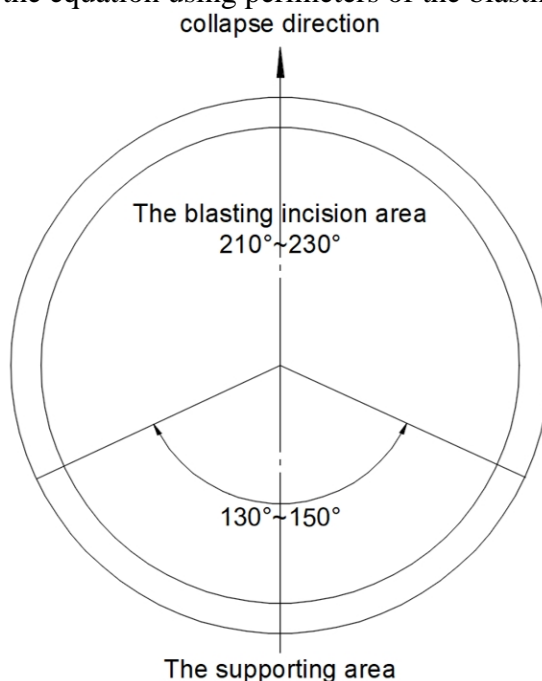


Fig.4 Diagram of blasting incision area and supporting area

Engineering projects have verified that when demolishing tubular structured high-rise buildings, appropriate pre-treatment was made on the inner lining and the partition wall, and the blasting height is reasonable, using the golden section method to calculate the blasting incision length (angle) and reserved length (angle) can achieve good blasting effects.

Conclusions

In recent years, the golden section method has been increasingly applied to various fields. The author applied the golden section method to the field of blasting engineering, simplified the calculation method, which is easier to learn, and has received unexpected results. However, the reasons for this are still up to be analyzed and studied.

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