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A study of cut blasting for one-step raise excavation based on numerical simulation and field blast tests

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ABSTRACT

Over the past several decades, raise excavation has been widely employed in underground mining, civil engineering and military engineering. One-step raise excavation with burn cuts, where all the boreholes are pre-drilled and detonated at one time and no workers need to be underneath the freshly blasted and dangerous ground, is an important and promising method in raise excavation. Cut parameters, especially the parameters of prime cut which used empty hole as a free surface and swelling space, have significant influence on the effect of raise formed. In this study, two small-scale experimental methods, spiral hole spacing method and observation hole method, are designed to determine the prime cut parameters such as hole spacing (L), stemming length (L_{s1}, L_{s2}) and air deck length (L_a) which are normally determined by empirical formula. In order to study the feasibility of the two methods, numerical analysis and experimental tests are conducted in V zone of Sandaozhuang molybdenum mine (SMM), in which there are large numbers of underground goafs need to be controlled by filled raise. The Riedel–Hiermaier–Thoma (RHT) material model, which considers compression damage and tension damage effect under blasting loading, is employed in the LS-DYNA software to study the rock damage zone. Meanwhile, the field tests are carried out according to the two small-scale experimental methods. The comparison results show that the damage zone of numerical simulation has a good agreement with the experimental data. Further, the optimal prime cut parameters obtained from experimental tests are applied in one-step filled-raise excavation, and a 23 m raise that meets the design requirements is formed through the proposed technology. The results indicate that these cut parameters determined by the small-scale experiments are suited for one-step raise excavation. This study can provide two simple field experiments to determine the important prime cut parameters of one-step raise excavation.

1. Introduction

Over the past several decades, raise excavation has been widely employed in underground mining, civil engineering and military engineering.[1–3] The technology of raise excavation can be generally classified into mechanized methods and conventional methods.[4] The mechanized methods included Raise Boring Machine (RBM) and Shaft Boring Machine (SBM),[5] while drilling and blasting such as conventional ladder and Alimak belong to conventional methods. Compared with conventional methods, where miners should get access to the raise heading face and every excavating cycle is only 3–4 m, the mechanized methods have apparent advantages in high-speed excavation and safe operation environment as fewer people involved.[6] With the increasing of the mechanized methods application in raise excavation,[7] the conventional methods are gradually phased out due to its shortcomings such as low efficiency, unsafe operation environment and poor working conditions.[8] Nevertheless, the mechanized methods have limited application in the excavation of small raise such as slot raise and filled raise because the mechanized equipment is normally very large, and requires reasonably stable ground conditions in underground engineering. Moreover, the cost is usually more expensive than that of conventional methods. Therefore, an improved method or a new method is required for small raise excavation.

Recently, one-step raise excavation with burn cuts technology, where all the boreholes are pre-drilled and detonated at one time and no workers need to be underneath the freshly blasted and dangerous ground, is developed based on drilling and blasting.[9] It is an efficient, safe and low-cost technology in excavation of small raise.

The effect of one-step raise excavation with burn cuts is primarily determined by the size of cut cavity that is formed by a series of cut

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holes. In this process, a swelling space for each cut hole, especially the prime cut hole (first initiated), is required because rock fragmentation requires sufficient space to allow fragments swelling. Otherwise, even though the rock is fractured, the fragments may be jammed. Until now, existing research in raise excavation is relatively scarce except that in tunneling excavation.[10–14] Zare and Bruland[15] discussed the two cut models, i.e. NTNU (Norwegian University of Science and Technology) and Swedish, and their results indicated that the design of the cut mode should be based on the depth of the drilling hole and the diameter of the empty hole. Xie[16] numerically simulated the process of cut blasting under high in-situ stresses, and the RHT (Riedel–Hiermaier–Thoma) model in LS-DYNA yielded accurate rock behavior. Soroush and Mehdi[17] noted that the diameter of blast hole and the size of tunnel section were the most critical blasting parameters in tunnel excavation and explored the relationship of the two parameters under different cut modes. The above research results in tunnel cut blasting cannot be directly applied to raise excavation because raise cut is technically more complicated than tunneling cut. The depth of raise excavation is usually larger than that of tunnel and the drilling induced borehole deviation and confining effect in raise cut is more severe than that in tunneling. Generally speaking, the studies of cut blasting in tunnel excavation provide useful references for that in one-step raise excavation, however the experiences cannot be directly applied.

In order to ensure the success of the cut blasting, the optimization study of cut parameters such as empty hole diameter, hole spacing, stemming length and air deck length of prime cut hole is carried out in the present study. There are three types of method used to determine the cut parameters, including empirical analysis method, numerical analysis method and experimental analysis method in rock blasting. Numerical method is an efficient technique to enhance the understanding of the rock failure process of cut blasting and experimental analysis method has some advantages in measurement of parameters such as cut cavity shape and muck distribution for a specific project. Therefore, the methods, i.e. numerical simulation and field experiment, are used to determine the cut parameters that combine the advantages of them in this study.

2. Engineering background

Sandaozhuang molybdenum mine (SMM) was established in 1960s. Due to long-term mining activities, there are large numbers of underground goafs in the mine area. Since none of the goafs was filled, the 2×10^7 m^3 goafs bring high safety issue to mining production and residents around that district.

The goafs are divided into I, II, III, IV, V, VI six zones according to their distribution and shape. Taking zone V of SMM as an example, the goafs geological distribution profile is shown in Fig. 1. It can be seen that the goafs are distributed from 1330 levels to 1234 levels. The thickness of rock between upper level goaf and lower goaf is small, and the minimum thickness is only 3 m. Furthermore, there are four faults through the V zone and piles of rubble on the ground. More seriously, personnel and equipment cannot access to the goafs through drifts which are completely destroyed. Therefore, it is difficult to control the goafs with conventional methods such as closing goaf and filling with tailings.

These untreated goafs in SMM have become serious safety issues, from1994 to 1998 the surface subsidence accidents happened 3 times in this area. Due to all the drifts destroyed, one-step raise excavation technology becomes an appropriate method to excavate a filled raise connecting goaf and ground surface. This technology does not need miner and equipment into the goafs because it uses the waste rock on the surface to fill goafs. To ensure success of the one-step raise excavation, the cut parameters optimization should be investigated. In this paper, two small-scale experimental methods, spiral spacing hole method and observation hole method, are designed to determine the cut parameters including hole spacing, stemming length and air deck length. The RHT model for rock material, which takes both the compression failure and tensile failure into consideration, is used in the numerical model to preliminarily simulate the effects of the two methods. Then the experimental tests are carried out in SMM to verify the two methods. Further, the optimal parameters obtained from the validation tests are applied in the one-step raise excavation.

3. Small-scale experimental methods

3.1. The process of prime cut hole blasting in one-step raise excavation with burn cuts

The simplified process of prime cut hole blasting is shown in Fig. 2. It can be seen that the axial de-coupling charge structure, in which the explosive cartridges are detonated at the same time by detonating cord, is used in the prime cut hole to reduce the borehole wall pressure induced by blast loading in Fig. 2(a). Compared to a smaller borehole with continuous charge, such de-coupling charge arrangement can increase the total length of the stress wave at roughly the same construction cost. The larger empty hole is used as a free surface and swelling space for the prime cut hole, and the burden rock is broken and filled the swelling space after the prime cut hole is detonated, as shown in Fig. 2(b). Finally, the rock fragments fell and the cavity that is used as the swelling spacing for the subsequent initiation cut hole is formed, as shown in Fig. 2(c). The effect of prime cut hole blasting is the most crucial and the most difficult part of one-step raise excavation with

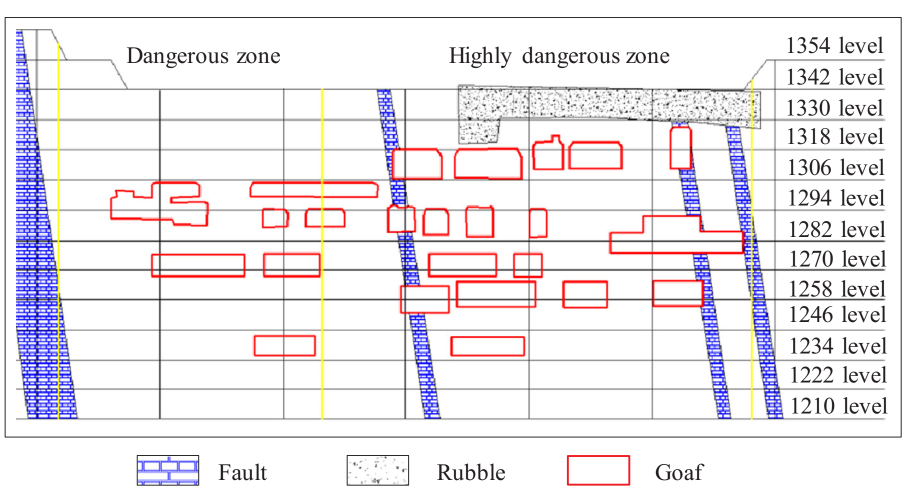

Fig. 1. Profile of goafs distribution in V zone.