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Study on the long-hole raising technique using one blast based on vertical crater retreat multiple deck shots

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A B S T R A C T

Backfilling inaccessible cavity through raise can provide underground support for the active open-pit operations and the raise must be taken down in a single blast for safety reasons. Conventional raising techniques are not economically and technically feasible, and the maximum advance depth in one blast is limited. In this paper, small-scale crater tests were carried out in a site with cavities and field blasting test data were measured and evaluated to obtain the basic data for raise-scale blast designs. The raising design parameters with 250-mm hole diameter, including charge weight and height for each slice, slice height, hole spacing and delay interval, were derived. A scheme of multiple deck blasting based on vertical crater retreat (VCR) drop-raising method was designed for an abandoned cavity with 30-m cover. The lower 12-m cover was first blasted to investigate the practical blast performance. Charging and timing patterns were adjusted accordingly and the left 18-m cover was successfully opened up. Through raising tests, it is shown that the advantage of two available free surfaces up and down should be maximized, and smaller slice height and alternate initiation sequence are benefit for raising extension. A numerical model is then developed and it is calibrated against the 12-m raising test. By combining the calibrated numerical model with the raising test results, the effects of hole layout and in-slice delay are examined. It is shown that circular pattern and in-slice delay are positive for multiple-deck raising blast. Based on the foregoing analysis, the hole layout, charging and timing patterns are optimized. The optimized scheme was applied to field raising blast and a 32-m raise was successfully excavated in one blast.

1. Introduction

The existence of inaccessible abandoned cavities, which have been created by previous underground mining activities, imposes a potential hazard to current active aboveground mining operations. When the overlying strata becomes relatively thin during open-pit mining, the roof of cavity is highly susceptible to collapse due to bench blasting or repeated loading from the aboveground production vehicles, which endangers the safety of workers and heavy equipment and retards the open-pit mining progress.[1,2] It is therefore necessary to backfill the abandoned cavities, when their covers are thick enough, to provide underground support.

In practice, large-diameter borehole/pipeline and raise are commonly used to deliver the backfill materials into the underground mined-out area.[3,4] For the large-diameter borehole/pipeline, classified mill tailings and alluvial sands are suitable to allow trouble-free transport, but these backfill materials are needed to be prepared and characterized by low-strength and low-efficiency during backfilling. On the other hand when rock fill is used, the borehole/pipeline can be easily blocked. Moreover, for a large cavity, the backfill materials pumped into the cavity can only occupy a small room near the borehole/pipeline. Raises are essentially small upside down shafts and developed for a variety of purposes, such as ore and waste passes, ventilation passes, and slot raises in production stopes. Compared to the boreholes, backfill raise is compatible even with rock-fill materials due to its bigger cross section, which also contributes to higher efficiency of backfilling. In open-pit mines, rock fill generally refers to waste rock and its main attraction has always been the availability at mine sites. It is therefore a preferred option to backfill the underground cavities from ground surface through raises with rock fill. However, excavating raise is considered the most dangerous in all the development headings. Many serious accidents and fatalities caused by falls of ground have occurred in raise work over the years because access to raise face is often more difficult and unsafe. Fortunately, raising safety has been

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drastically improved by the development of new equipment and innovative blasting methods.

The significant developments of equipment that have improved raise access and working safety are the Alimak raise climber and raise-boring machine.[5,6] Alimak raise climber makes use of a rail mounted work platform to transport workers to the raise face with normal drill and blast methods, and its platform has a shield that protects miners from rock falls. However, this method is quite labour intensive and costly, and the only access for this equipment to develop raises is from the bottom. Abandoned cavities are usually unsafe to enter due to the extremely poor underground conditions, and therefore make such equipment not applicable. Although raise-boring is a safe and successful method, it is also very expensive.[7]

On the other hand, several blasting technique innovations have also improved the raising safety. In Canada in 1975, mining company INCO developed a mining method based on Livingston's cratering theory. This method is called vertical crater retreat (VCR) or vertical retreat mining (VRM) method. VCR method has been an established mining method being practiced in various mines all over the world.[8] An offshoot of this mining method is the VCR drop-raising technique that employs the same spherical crater charge technology as VCR method.[9,10] This technique has vastly improved raise blasting safety because top loading no longer requires workers to be underneath the freshly blasted and dangerous ground. VCR drop-raising method is also very cost effective because relatively less number of large holes is required, and this method is also very forgiving to moderate levels of hole-deviation. Miners have been refining this technique for almost 30 years and holes size for this application generally varies from 102 to 165 mm. It is widely used to develop backfill raises. However, VCR drop-raising is labour intensive. In this method, vertical large-diameter holes are drilled on a designed pattern from the ground surface or an overcut into the roof of the cavity, and spherical charges of explosives are placed in these holes at a calculated optimum distance from the bottom of the holes and detonated, a vertical thickness of rock mass will be blasted downwards into the cavity. After the first blast, the procedures of charging and blasting need to be repeated for the next same thickness of rock mass, and raising in the rock mass retreats in the form of horizontal slices in a vertical upward direction until the top slice is blasted and the raising is completed. VCR drop-raising essentially consists of a series of independent small shots. The existence of underground cavities makes it potentially dangerous to approach the ground after the first blast, which leads to that the raising must be taken down in a single blast, and therefore makes the conventional VCR drop-raising technique not applicable to excavate backfill raises over abandoned cavities.

In order to achieve greater raising advance in one blast, some innovative blasting techniques have been tried but few reports can be tracked. Multiple deck shots in the VCR drop-raising was attempted by Sterk[11] at the Homestake mine but with poor performance. Using electronic detonators and creating stemming separation between decked charges, several Canadian mines have successfully carried out a series of up to three sequentially delay decked charges (normally 3 m per slice) to extend the length of advance.[10] Besides the VCR drop-raising-based techniques, long-hole drop-raising technique can also be used to blast raises. This technique uses smaller holes, ranging from 51 to 89 mm, and burn cut to provide relief. It can be charged from either the bottom up or the top down. Sterk[11] also practiced long-hole drop-raising at the Homestake mine, and single deck shot usually advanced the raise 3.048 m. Multiple deck shots were also tried but with low success rate. Fellows and Stolp[12] reported that using 76-mm diameter holes and a standard long-hole drop-raising pattern of 2.4-m spacing by 2.4-m burden, a raise with length up to 15.25 m was advanced in a single blast. In addition, it was reported that using an inverse drop-raising technique, a raise was blasted with a single blast up to 15 m from the bottom up at Elandsrand mine.[13] The greatest advance in one blast has been reported is the 29-m inverse drop-raising at Health Steele Mines,[14] which was designed and blasted by the blasting technology personnel from the Noranda Technology Centre in the fall of 1997. In this case, the raise and two blast rings were taken down by one blast with twenty-five long up-holes of 114 mm in diameter. Inverse drop-raising technique is essentially similar to the long-hole drop-raising technique, and the main difference is that it must be drilled and charged from the bottom up. Same as the burn cut of long-hole drop-raising method, it is also necessary to provide the initial relief volume, thus a 0.76-m-diameter raise bore in this case had to be drilled first. Therefore, the inverse drop-raising technique is not technically and economically feasible for abandoned cavities, and developing the long-hole raising technique using one blast for inaccessible abandoned cavities which have covers with large vertical thickness is still a big challenge.

This paper studies the effectiveness of long-hole raising technique using one blast to excavate backfill raises for inaccessible abandoned cavities in an open-pit mining site. A series of small-scale crater tests based on Livingston's cratering theory were carried out in the site and field blasting test data were measured. Data analysis and evaluation were performed to obtain the basic data for the raise-scale blast designs. With 250-mm hole diameter, the raising design parameters, including charge weight and height for each slice, slice height, hole spacing and delay interval, were derived. Aiming at an abandoned cavity with 30-m cover, a scheme of multiple deck blasting based on VCR drop-raising method was designed. To investigate the blast performance in practice, this raising blast was altered and divided into two single blasts. The first blast based upon VCR drop-raising method was to raise the lower 12 m of the cover, after that, the shape and dimensions of the freshly blasted raise was obtained by laser scans and the blasting result was analysed. Then the raising of upper 18 m was redesigned and blasted. Through these two single blasts, the 30-m cover was successfully opened up. According to the first raising blast, a detailed 3D finite element model is constructed in ANASYS, and LS-DYNA is employed to simulate the raising process. The numerical model is calibrated against the raising test data. By combining the calibrated numerical model with the raising test results, the effects of hole layout and in-slice delay are examined, and the hole layout, charging and timing patterns are optimized. The optimized scheme is applied to a 32-m raising blast and the cover is successfully broken through in one blast.

2. Site background

The Sandaozhuang molybdenum mine is located 3.6 km to the east of the town of Lengshui in Henan province of China. Industrial-scale extraction at this mine site began in the late 1960s and underground operations were the principal mining methods. Owing to the lack of planning and authorization, uncoordinated underground mining and spoliation of molybdenum-rich ores ever happened from the middle 1980s to early 1990s. In 2002, the underground production was totally converted to open-pit operations. After more than 30 years of underground mining, large amounts of underground cavities with a total volume of around 2×10^7 m^3, according to the latest statistics, were left. Currently, the left cavities are mainly located at elevations from 1160 to 1366 m.

In recent years, continuous open-pit stripping progresses toward the abandoned underground cavities. Some cavities collapsed due to adjacent bench blasting or repeated loading exerted by the aboveground production vehicles when the overlying strata became relatively thin. This situation constitutes a potential hazard to miners and heavy equipment. In order to avoid exposing aboveground mining operations to unsupported ground, the cavities under the benches are constantly surveyed using the Cavity-Autoscanning Laser System (C-ALS). The C-ALS consists of a laser unit in a motorised head that is capable of being inserted into the cavity via predrilled boreholes to locate and measure the cavity. However, this is obviously still not the final solution. Having considered several possible approaches, the most practical solution is to backfill the cavities with waste rock through raises, when the overlying strata are thick enough, to provide underground support.