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SAFETY PROBLEM OF CAVITY UNDER OPEN PIT BENCH

ZAGADNIENIE BEZPIECZEŃSTWA ZAPADLISK POD WARSTWĄ WYBIERANIA W KOPALNI ODKRYWKOWEJ

Some open pits in China are severely threatened by hidden cavities under benches which are always inaccessible and unmapped. The first thing to be well considered is safe and precise cavity detection, as the conventional detection methods cannot output a clear cavity vision, a three-dimensional laser measurement system is employed to perform detection, which is deployed from the surface through boreholes. The results from the scanner demonstrated very well the detailed level of information that can be collected in a cavity using this method, with the cavities' layout under various benches being fully mapped. As detected cavities are always in horizontal and vaulted roof shape, two different theoretical calculation methods are proposed to analyze the cap rock stability for different roof shape. And also, the three-dimensional solid model generated through scanned laser data is used for stability numerical simulation by converting the data format into the one that recognized in corresponding software. Furthermore, acoustic emission technique is adopted to carry out long term real time rupture monitoring in cap rock, and four kinds of typical monitoring results are discussed which represent the rupture behavior in cap rock of unstable cavity, stable cavity, cavity with large working drill above and cavity beside explosion site. Thus, a complete safety evaluation system for such cavity will be established to ensure safe operation above.

Keywords: Cavity, Open pit, Laser scanning, Stability analysis, Acoustic emission monitoring

W wielu kopalniach odkrywkowych na terenie Chin powstało zagrożenie wskutek istnienia ukrytych pustek pod warstwami wybierania (ławami), część z nich jest trudno dostępna, a niektóre nie są nawet naniesione na mapach. Najważniejszą kwestią jest więc bezpieczna i dokładna lokalizacja pustek. Ponieważ konwencjonalne metody wykrywania nie są w stanie ujawnić dokładnego obrazu pustek, zastosowano trójwymiarowy laserowy system detekcji pustek, zakładany z powierzchni poprzez wywiercone otwory. Odczyty ze skanera ujawniły dokładne zarysy pustek. Z pomocą tej metody można dokładnie obrazować układy pustek pod warstwami wybierania (ławami). Ponieważ stropy w wykrywanych pustkach są zawsze poziome lub sklepione, zaproponowano dwie teoretyczne metody obliczania stabilność stropu dla różnych

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jego kształtów. Ponadto, na podstawie danych ze skanera wygenerowano model bryły trójwymiarowej, który wykorzystany został do numerycznych badań stabilności stropu poprzez przekształcenie formatu danych na format rozpoznawalny w zastosowanym oprogramowaniu. Zastosowano także techniki pomiary emisji akustycznej w długofalowym monitorowaniu spękań stropu w czasie rzeczywistym, przeanalizowano cztery rodzaje uzyskanych wyników opisujących zachowanie stropu w przypadku pustek niestabilnych, stabilnych, pustek ponad którymi wykonano otwory znacznych rozmiarów oraz pustek w pobliżu miejsc prowadzenia prac strzałowych. Opracowano w ten sposób pełny system oceny stabilności pustek zapewniający bezpieczne prowadzenie prac ponad nimi.

Słowa kluczowe: pustki, kopalnie odkrywkowe, skanowanie laserowe, analiza stabilności, monitorowanie emisji akustycznej

1. Introduction

Cavity is always one of the big problems in mines which result in mining damages that are always in the form of roof collapse of operating area and surface subsidence, especially those indisposed cavities can seriously restrict the further exploitation and threaten the safety of personnel and equipments. There have many accidents every year in mines of China due to the presence of various abandoned & unmapped underground cavities left over from previous mining operations, and the disasters caused by cavities have been numerous & disastrous (Li et al., 2006). We know that cavities are those mined-out areas left by underground mining operations. However, some of the open pits in China also suffered terrible tragedies resulting from underground inaccessible cavities. These cavities are unfilled ones handed down by previously underground mining, and are always unmapped, hidden under working pit which make the condition even more complicated, the occurrence of this situation is mainly caused by unreasonable mining planning and disordered exploitation during the past several decades. Workers and equipments are severely threatened by those hidden danger. It is clear that accurate cavity detection & mapping is vital firstly, then the stability of cap rock over cavities should be well appraised, and the real time stability monitoring of cap rock is also necessary. This is what we concerned in this paper the safety problems of cavity under open pit benches.

As we said, mapping out the hidden cavity is vital, regarding conventional detection methods of cavity detection, these have required an understanding of the high precision equipment. It has also required deep analysis of the acquired data and details of the geology in the vicinity of the cavity. Currently, cavities are always detected by the way of engineering drilling, geophysical exploration, hydrological experiment, gravity and magnetic observation. The main cavity detection methods are: micro-gravity method, Direct Current (DC) electrical method, transient electromagnetic method (TEM), high-density resistivity method, ground penetrating radar technique, transient Rayleigh wave method, seismic tomography method (CT), shallow seismic exploration and radioactive gas measurement technique etc. (Tong, 2004; Grandjean & Leparoux, 2004). However, these various conventional methods do not easily produce accurate 3D models of the cavity under investigation. Further, since the detection of abnormalities by these methods is dependent on the rock mass and geological conditions around the cavity, different methods must be used according to the local geological condition. Given the complexity of geological conditions commonly found around cavities, the accurate interpretation of the results is very difficult. For this reason, various methods are combined to overcome the limitation of a single detection method, causing the operation to become more complex & costly. 3D laser scanning however does provide a means of highly accurate modelling of cavities. This method uses a pulsed, infra-red laser, measuring the ‘time-of-flight’ of the laser pulse to calculate distance measurements which will not be affected by the geology around the cavity and obtain a very clear visual 3D model of the cavity in a very short time. It is the most accurate way to perform cavity detection now. It is also the method we employed to perform detection of cavity under open pit benches in this paper.

After the cavity was accurately mapped, the crucial problem is to ensure the cap rock over cavity is strong enough to bear its own weight. Many scholars employed various theoretical and numerical simulation methods for underground cavity stability analysis, however, cavities are always simplified to be in relatively regular shape in these methods, seldom has them based on the measured 3D model. As we understand that the best way for such stability analyzing is to choose proper method for specific cavity based on the detailed cavity information. So, if we accurately mapped the cavity through 3D laser scanning technique, the appropriate theoretical methods can be selected for stability analysis considering the different cavity shape, and also the cavity 3D data can be processed to be a calculation model for numerical simulation, which we believe that such analyzing would be closer to the on-site situation.

Accurate cavity detection and cap rock stability analysis can only provide a general understanding of such cavity, some real time monitoring measures should be adopted to evaluate the stability status of cap rock during its existing period. For cap rock monitoring of such cavity, the most direct way is to monitor the rupturing process in cap rock, and the acoustic emission technique is undoubtedly an ideal means. Since its application in rock engineering, acoustic emission technique has been proved to be an effective way for rock structure stability monitoring, and it is also employed in our research.

Accurate detection, stability analysis, rupture monitoring are the necessary steps to evaluate the safety of cavity under open pit bench, the ultimate goal of the outlines above is to establish a complete safety evaluation system for safety guarantee of operation personnel and equipment on the surface, and these are the main contents discussed here.

2. General Situations of Engineering

An open pit named Sandaozhuang mine run by Luoyang Luanchuan Molybdenum CO., Ltd. is the one that is severely threatened by cavities under working pit. Sandaozhuang mine is one of the largest molybdenum mines in China, with 529 million tons molybdenum and tungsten geological reserves, the verified molybdenum reserves is 2.52% of the world’s total, and the daily production reaches 40000t at present. Sandaozhuang mine experienced 20 more years of unreasonable underground mining since 1980s, and was totally transformed into open pit in 2003, there have massive cavities left by sublevel open stope mining and large amount of unclear cavities left by private mining. Statistically, there have more than 100 hidden cavities of various shape and size under the open pit. As bench blasting proceeds, the cap rock becomes thinner, workers and equipments on benches are directly threatened by underground cavities, and the cap rock collapse would be fatal as shown in Fig.1. These cavities greatly embarrassed mine safe production, safety problems of cavity are the mostly concerned task in the whole process of open pit mining.

Fig. 1. A collapsed cavity after bench blasting

3. Cavity Laser 3D Detection

In recent years, 3D cavity detection methods based on laser range finding techniques have been widely used in mines around the world. Results have proved it to be a very successful method of 3D cavity detection. The lasers used in 3D cavity measurements are generally based on a laser measuring technique called 'time-of-flight'. The basic principle is to measure the time taken for a laser pulse to travel from the receiving optic to the target and back to the receiving optic. This time is then used to calculate the distance travelled by the laser pulse.

As early as 1989, a laser system was tested by the Gaspé mining company, its detection range was limited in 60 meters, and the system was not automated in any way. Since then, many companies tested various laser range-finding systems for underground cavity detection (Miller et al., 1992; Shaffer & Stentz, 1993). These laser rangefinders and scanners have been used in mines for a wide variety of applications: performing the detection of cavities and excavation spaces; 3D modelling of underground spaces by mounting the laser on a moving vehicle (Huber & Vandapel, 2006); scanning of rock mass joint surfaces (Fardin et al., 2003), and monitoring vehicles in underground mines and open pits etc. (Syddell, 2005). Some of the main manufacturers of laser surveying systems used in these applications are I-Site in Australia, Measurement Devices Ltd (MDL) in United Kingdom, Optech in Canada, Cypa in Unite states, Riegl in Austria and Callidus in Germany. However, for particular, inaccessible cavities such as those under open pits, cavities under highways or buildings etc, the laser scanner needs to be deployed through a borehole if we want to carry out laser 3D detection as there is no other way of entering the void with laser equipment. This laser system therefore needs to have an extremely small cross-section to fit through the drilled hole. It also needs to be flexible, rugged, easy to deploy & recover, and to incorporate an orientation system to automatically correct the resulting data according to the angle of the instrument during the survey. At present, there are two kinds of laser detection system in the world which are designed to be suitable for surveys of inaccessible cavities: Optech's CMS (Cavity Monitoring System) and MDL's C-ALS (Cavity Auto-scanning Laser System). The CMS and C-ALS have been widely used in mines around the world since the 1990s (Stuttle, 1999; Jarosz & Shepherd, 2000; Guo et al., 2005; Liu et al., 2008a).

Detection of cavities under open pit benches needs to be carried out on the surface, rather than from underground, and in this case, the laser instrument needs to be deployed through a borehole. Having a small cross-sectional profile and accurate, integrated orientation system, MDL's C-ALS laser scanner was selected to carry out cavity detection in Luanchuan open pit. C-ALS has a flexible ruggedized laser scanner which can be deployed through a borehole with diameter minimum to 70mm. It will measure the deviation of the borehole while deploying the scanner into the cavity, and the scanning will be carried out through remote control software module (Fig. 2). The raw data observed by the scanner will be as follows (Liu et al., 2008a):

1) The horizontal and vertical direction of the laser beam based either on the angle of a continuously rotating mirror, used to reflect the laser, or on the angle of the laser head, moved mechanically by motors in the instrument;
2) The distance between the instrument and the measured point, calculated from the laser pulse's 'time-of flight';
3) The intensity of the reflection of the scanned point. The data from 1) and 2) are used to calculate the three dimensional coordinate values, and the reflection intensity is used to color the measured points according to their signal strength.

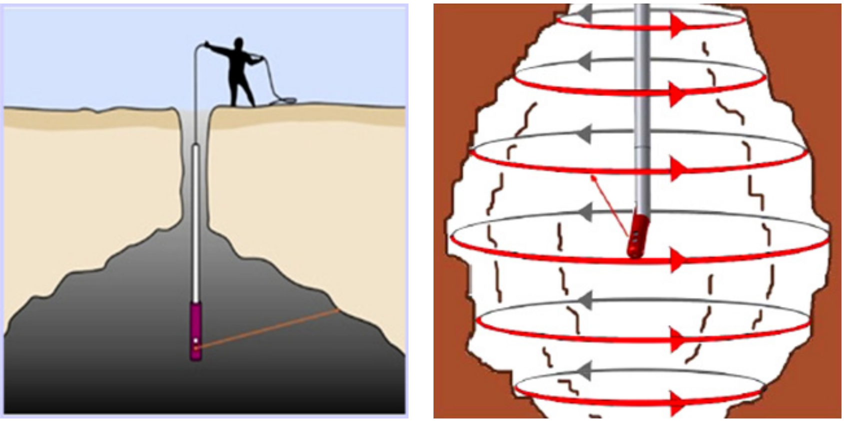
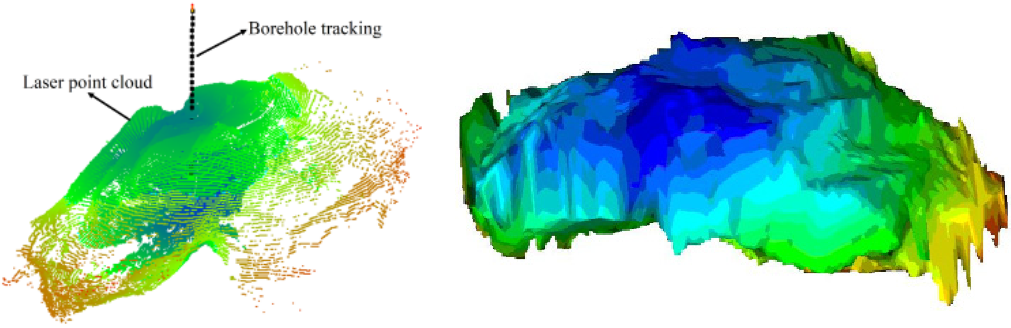


Fig. 2. Deploy C-ALS through borehole to perform detection

C-ALS was frequently used in Luanchuan open pit. Some drilling machines for geological exploitation and bench blasting are assigned for finding out the existence of underground cavities as well. After these drilling machines drilled down to a cavity, C-ALS was used to detect through borehole. The scanned data was edited in Cavity-Scan processing software and a 3D modelling package to form an oriented, geo-referenced 'point cloud' (Fig. 3(a)) and 3D solid model (Fig. 3(b)), either of which can be exported into Surpac and CAD (Computer Aided Design). The projective ichnography of the cavity is of most use on-site. This data can be transformed into exploitation ichnography in CAD to outline the cavity boundary as shown in Fig. 4. We can also calculate the roof and floor elevation of any point in the projective ichnography to output sections by processing the scanned data, in Fig. 4, the roof and floor elevation of grid intersection points were marked, and these data are required at a later design stage.



(a) point cloud (b) cavity 3D model

Fig. 3. Point cloud and 3D model in processing software

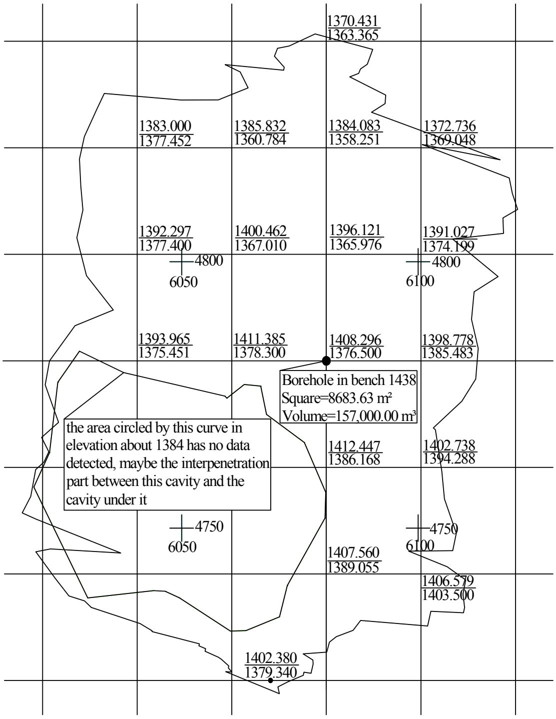


Fig. 4. Cavity ichnography with roof and floor elevation of grid intersection point

The cavities underneath Sandaozhuang open pit will be a source of risk throughout the exploitation of the mine. To illustrate the problem, in Table 1 below are listed the details of some of the detected cavities under working bench. We know from various surveys that safe mine production is increasingly threatened by those cavities under the open pit boundaries as the bench blasting continues to progress. The potential danger from these cavities, situated at various depths and with various shapes and volumes, is extremely severe. This is especially true of the largest cavities with complex shapes and which are often interconnected with other adjacent voids.

TABLE 1

Some detected cavities under different benches

Cavity position	Borehole depth, (m)	Cavity height under borehole, (m)	Cavity volume, (m^3)
Bench 1330	15.2	4.2	647
Bench 1414	14	2.4	174
Bench 1438-1	29.4	31.8	157078
Bench 1438-2	17.8	8.1	2722
Bench 1450	21	7.8	3198
Bench 1462-1	16	5.9	2177
Bench 1462-2	16	5.4	2087

4. Cap rock stability analysis of detected cavity based on 3D scanning data

4.1. Theoretical stability analysis of cavity with horizontal and vaulted roof shape

Laser 3D detecting results shown that roof of the detected cavities are always in horizontal and vaulted shape, so we should choose proper method for different shape to calculate the stability of cap rock over cavity.

As for cavity with horizontal roof, the cap rock can be assumed as a beam with both its ends clamped and loaded under its own weight (Fig. 5). In this way the outer fiber bending stress is compared with the tensile strength of the rock. The following relationship has therefore been used to determine the maximum stress (σ_m) (Swift & Reddish, 2002):

$$\sigma_m = \frac{\gamma L^2}{2d} \tag{1}$$

where γ is rock density (MN/m^3); L is cap rock span (m); and d is cap rock thickness (m).

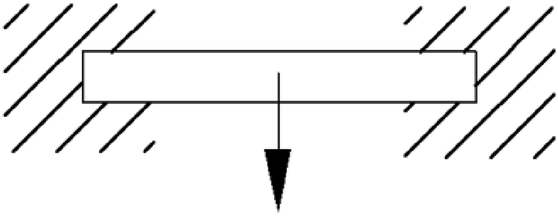


Fig. 5. Mechanical model of cavity with horizontal roof

For those cavities with vaulted roof shape, there should have a particular method to calculate their stability. Vaziri et al. (2001) discussed an analytical model for stability analysis of rock layer over circular opening. It is assumed that the roof is axisymmetric and parabolic in shape in the vertical plane passing through the axis of symmetry, and we modified the model and equations to be adaptive for our case (Liu, 2008b). Fig. 6 illustrates the configuration of the compression arch in cap rock.

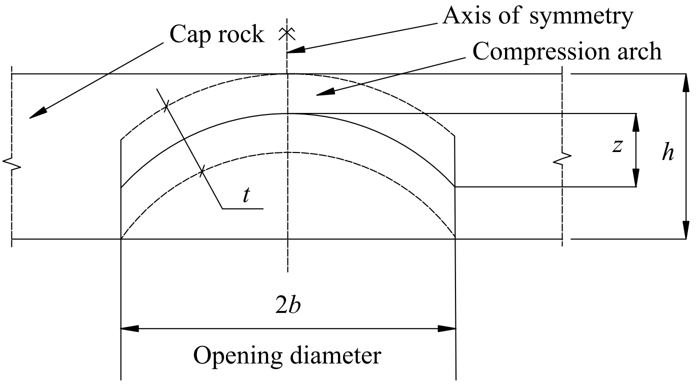


Fig. 6. The schematic of the compression arch within cap rock

The maximum tangential stress $(\sigma_\theta)_{\max}$ and radial stress $(\sigma_\varphi)_{\max}$ can be calculated through Eq. (2) and Eq. (3):

$$(\sigma_\theta)_{\max} = \lim_{x\to 0} \frac{qx\cos^2\left(\operatorname{atan}\left(\frac{2z}{b^2}x\right)\right)}{t\sin\left(\operatorname{atan}\left(\frac{2z}{b^2}x\right)\right)} \tag{2}$$

$$(\sigma_\varphi)_{\max} = \frac{qb}{2t\sin\left(\operatorname{atan}\left(\frac{2z}{b}\right)\right)} \tag{3}$$

where q is stress loaded upon the compression arch; b is the half span of the arch; t is the thickness of rupture arch; z is the height of rupture arch.

The cavity under bench 1438 and bench 1414 in Fig. 7 and Fig. 8 is the typical one with horizontal and vaulted roof shape respectively. The maximum stress in cap rock of cavity in Fig. 7 can be calculated through Eq. (1), the maximum tangential stress and radial stress in cap rock of cavity in Fig. 8 can be calculated through Eq. (2), (3), and the parameters used in these equations can be easily obtained in mine geological data and laser scanned 3D data.

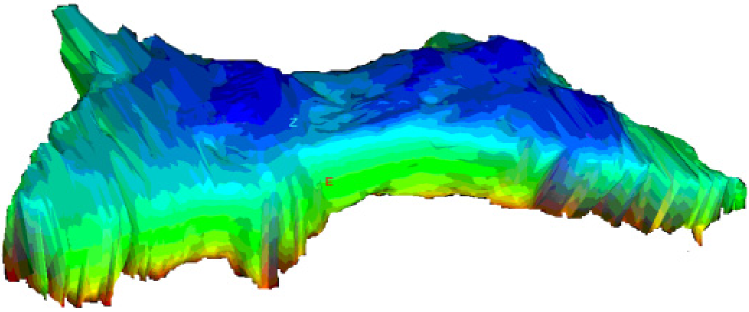


Fig. 7. 3D model of cavity under bench 1438

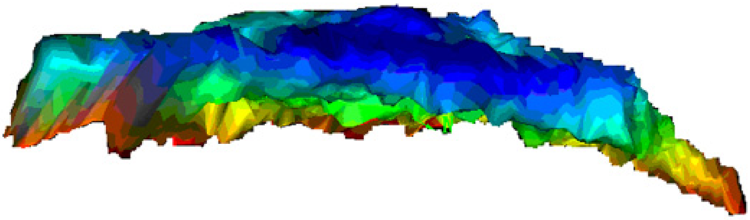


Fig. 8. 3D model of cavity under bench 1414

4.2. Numerical simulation based on 3D scanning data

The data scanned by laser system can be edited to form oriented, geo-referenced ‘point cloud’ and 3D solid model in processing software which will provide detailed information of cavity. What we concern now is whether the 3D data of cavity can be adopted to perform numeric simulation. Generally, models were built for numeric simulation are the ideal ones founded on basic information of the structures, these models are always in regular shape such as tunnels, underground storage room etc., and some complicated structures are also simplified to be in relatively regular shape. As we known that the underground excavation space are always in irregular shape, especially those inaccessible cavities under open pit benches, experienced long-term impact of ground pressure and blasting vibration making them in mess, and a simplified model cannot illustrate what they really looks like. So, if the cavities were fully scanned by laser system, the data can be exported into Surpac to form 3D solid model, then we can transfer this 3D solid model into FLAC3D through proper way to implement numeric simulation.

The 3D solid model in Surpac can be processed to form a block model which constituted by small hexahedral elements, these elements carry the information of their location, rock mass characteristics etc. The memorized hexahedral element’s location information is the coordinate of center point $p(x,y,z)$ and the length of each edge- dx, dy, dz. Correspondingly, there also have a hexahedral element in FLAC3D, however, the memorized information of this element in FLAC3D is the coordinate of each node $p_i(x_i,y_i,z_i)\,(i = 0,1,...,7)$. As shown in Fig. 9, the coordinates of nodes can be easily calculated through coordinate of center point and edge length:

$$p_0(x_0 = x - dx/2, y_0 = y - dy/2, z_0 = z - dz/2) \tag{4}$$

$$p_1(x_1 = x + dx/2, y_1 = y - dy/2, z_1 = z - dz/2) \tag{5}$$

$$p_2(x_2 = x - dx/2, y_2 = y + dy/2, z_2 = z - dz/2) \tag{6}$$

$$p_3(x_3 = x - dx/2, y_3 = y - dy/2, z_3 = z + dz/2) \tag{7}$$

$$p_4(x_4 = x + dx/2, y_4 = y + dy/2, z_4 = z - dz/2) \tag{8}$$

$$p_5(x_5 = x - dx/2, y_5 = y + dy/2, z_5 = z + dz/2) \tag{9}$$

$$p_6(x_6 = x + dx/2, y_6 = y - dy/2, z_6 = z + dz/2) \tag{10}$$

$$p_7(x_7 = x + dx/2, y_7 = y + dy/2, z_7 = z + dz/2) \tag{11}$$

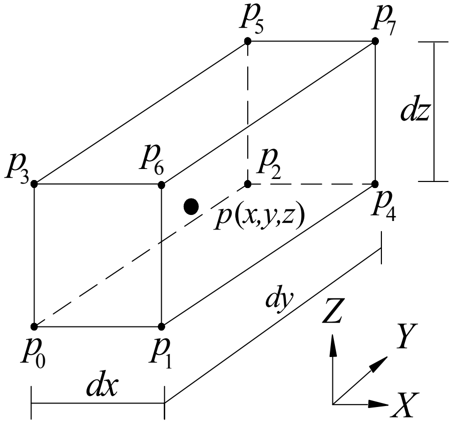


Fig. 9. Hexahedral element in Surpac and FLAC3D

After the oriented, geo-referenced ‘point cloud’ of cavity was collected by laser scanner, we can process the ‘point cloud’ to build a solid model, and export this solid model into Surpac to form a block model, then the data of block model can be converted into the format that recognized in FLAC3D through Eq. (4)-(11) above. By such steps, cap rock stability numeric simulation can be performed in FLAC3D based on laser 3D scanning data. Fig. 10 is the generated block model in Surpac of cavity in Fig. 3(b), and Fig. 11 is its calculation model in FLAC3D. Then, some results will be obtained by numerical simulation, such as the displacement and stress distribution shown in Fig. 12 and Fig. 13.

Up to now, theoretical and numeric methods which based on laser 3D scanning data are proposed to analyze cavity stability. The numeric simulation method can be used for every detected cavity, however, regarding the complicated rock mass structure and on-site situation, any of the method at present is not enough for such analysis, and various ones can make things more reliable. As a matter of fact, calculation results of the methods proposed above can only make us have a rough evaluation of whether the cap rock can bear its own weight or not, the real-time monitoring is much more useful and essential, this is what we will discuss next.

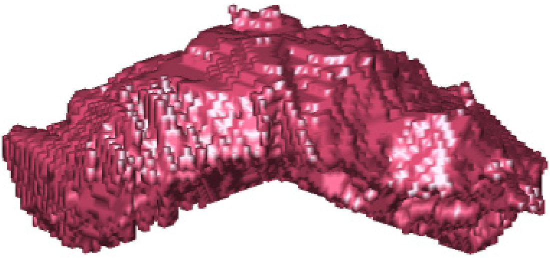


Fig. 10. Block model in Surpac of cavity in Fig. 3(b)

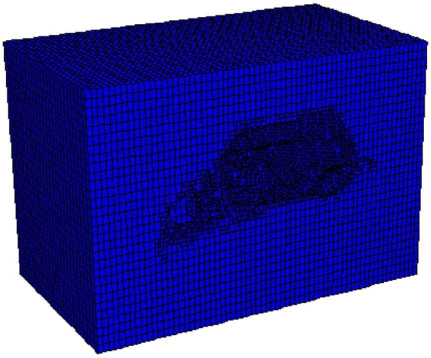


Fig. 11. Calculation model of Fig. 10 in FLAC3D

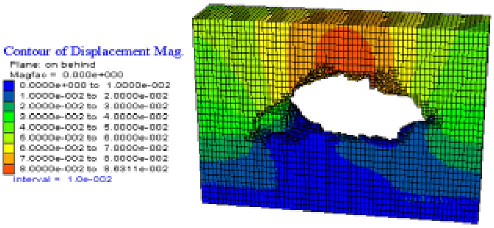


Fig. 12. Displacement distribution of one slice

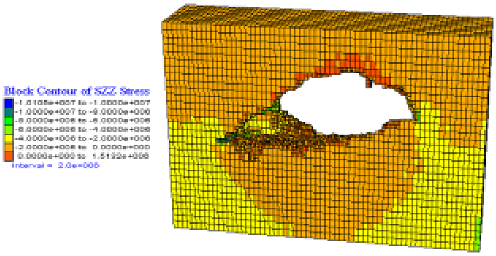


Fig. 13. Stress distribution of one slice

5. Acoustic emission monitoring of cap rock

For monitoring of such inaccessible cavities under open pit benches, works should be performed on the surface. As blasting advances and large equipments operating on the benches, the selected monitoring technique must be either effective or applicable to the on-site situation, thus, the progress of cracking in cap rock is the only one can be monitored. As a nondestructive testing technique, acoustic emission (AE) has been widely used in geotechnical engineering for rock crack monitoring, and is an ideal means in our case.

Three AE parameters will be considered-Total Events Number, Large Events Number and Energy Rate. Total Events Number is the cumulative events number in unit time, this parameter responds to AE frequency, it is the important indication of damage initiation in rock mass. Large Events Number is the number of events with amplitude larger than the set value, this parameter responds to AE extent, the proportion of large events in total events will indicate the trend of rock mass damage. Energy Rate is the cumulative value of AE energy in unit time which indicates the variation of damaging speed and magnitude in rock mass.

Acoustic emission monitoring tasks in Sandaozhuang open pit are numerous for the large amount of underground cavities. Four kinds of typical monitoring results were selected to discuss here, which represent the rupture behavior in cap rock of unstable cavity (C1414), stable cavity (C1450), cavity with large working drill above (C1438-2) and cavity beside explosion site

(C1438-1). The cumulative curve of large events number, total events number and energy rate of C1414, C1450 and C1438-2 are displayed in Figs. 14-16. Monitoring of C1414 and C1450 were carried out in different times of each day, and lasted 21 days. Monitoring of C1438-2 is synchronized with the working drill above, which intended to provide some real time monitoring for drilling safety, and also to find out what the acoustic emission monitoring parameters will present while having large drilling machine working above. With about 43 meters thickness in average of cap rock and 157,078m^3 in volume, C1438-1 is a typical large cavity and is the one of focus during mining operation. Monitoring of C1438-1 lasted 20 days which was carried out for the purpose of investigating the effect of bench blasting to cap rock, the results are listed in Table 2.

The cumulative curves in Fig. 14 and Fig. 15 show the typical acoustic emission behavior of unstable and stable cap rock. There have obvious difference between Fig. 14 and Fig. 15, the curves in Fig. 14 grow steadily, and approximately are straight lines with large cumulative value of Total Events Number, Large Events Number and Energy Rate, which signify that the sustained rupture with large magnitude occurs in cap rock, that is to say the cap rock of C1414 is unstable, and measures should be adopted as soon as possible to avoid unexpected collapse. However, the curves in Fig.15 are in leap-growth mode with small cumulative value of Total Events Number, Large Events Number and Energy Rate, corresponding to mostly the zero figures and small magnitude in recording table, which signify that the cap rock of C1450 is stable, and seldom has the rupture occur. The same situation presented in Fig. 16, with small cumulative value, total and large events occur intermittently, and mostly in drill working time, this indicates that the monitored data are mainly generated by drilling impact, and this cannot result in large-scale destruction in cap rock.

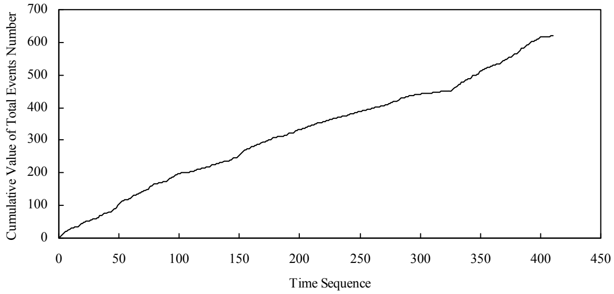
Bench blasting is the major task in open pit operation, usually, hundreds of tons of explosives are used, and the consequential vibration has a great influence on cap rock stability. Monitoring of C1438-1 commenced since it was detected, as well as the monitoring before and after the nearby bench blasting. As shown in Table 2, no data was recorded before bench blasting, which means that the cap rock is stable; there have data recorded on the day bench blasting just finished and the day after, and then nothing recorded any more. This indicates that the rupturing process in cap rock may last for a couple of days after the end of bench blasting, and neighboring cavities should be cordoned till the cap rock turns to stable, but it is also possible that the blast induced rupturing continue and accordingly result in cap rock collapse.

TABLE 2

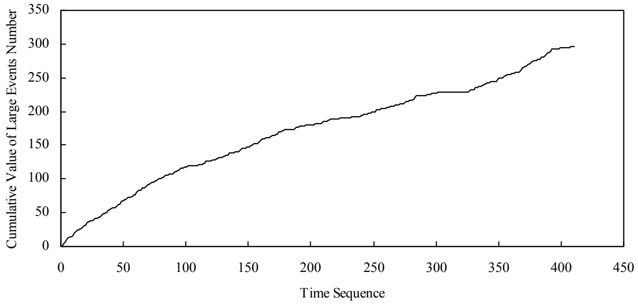
Acoustic emission monitoring results of C1438-1

Time /Month-Day	Large Events Number	Total Events Number	Energy Rate	Remarks
08-06～08-15	0	0	0	
08-16	7	14	710	The day bench blasting just finished
08-17	0	7	258	The day after bench blasting
08-18～08-26	0	0	0	

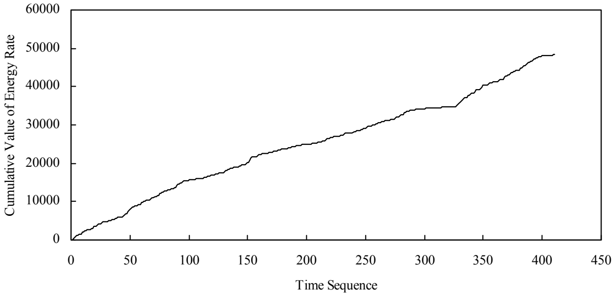
The descriptions above can be a reference to other on-site monitoring results, and we can also have a general understanding of rupturing trend in cap rock by analyzing the monitored data, then to evaluate whether the cap rock is stable or not. Although, we cannot give the exact acoustic emission values of at what extent the cap rock would collapse and the cavity should be



(a) Cumulative Curve of Total Events Number



(b) Cumulative Curve of Large Events Number



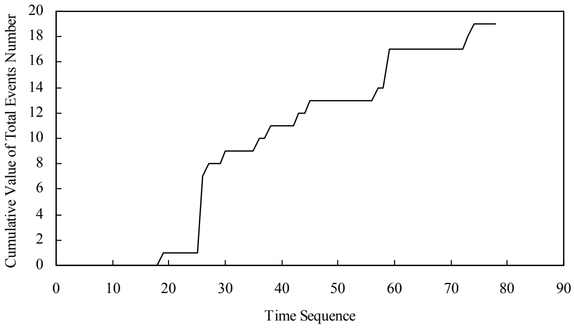
(c) Cumulative Curve of Energy Rate

Fig. 14. Monitoring results of C1414

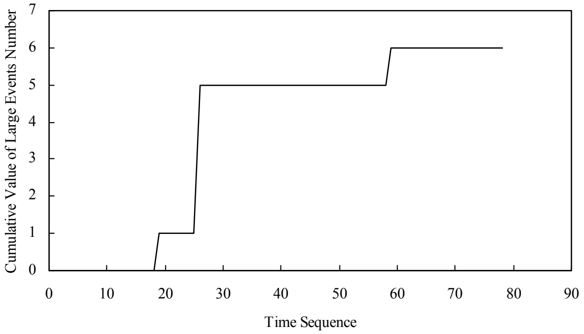
cordoned for safety, however, sufficient attention should be paid if there have continuous events monitored, this is also the ideal result of what we expected by acoustic emission monitoring under such circumstance.

6. Conclusions

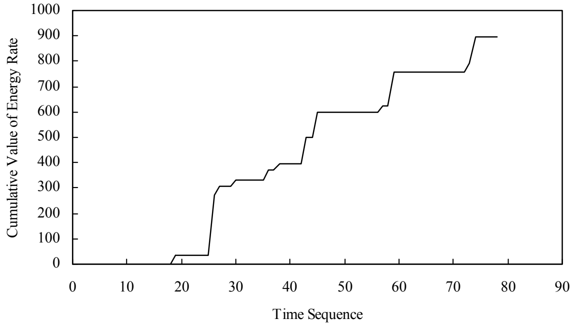
For the inaccessible cavities under open pit benches, a clear description is critical, with a small diameter, high accuracy and unique deployment method, C-ALS can not only provide the detailed



(a) Cumulative Curve of Total Events Number



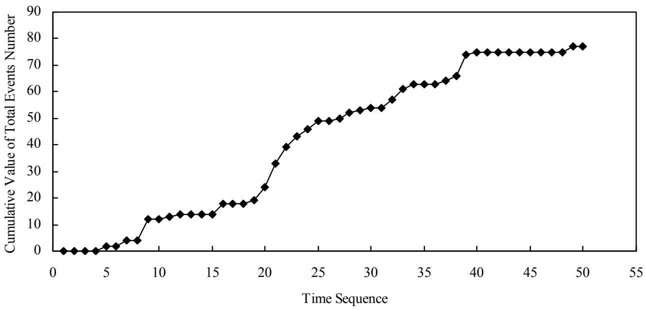
(b) Cumulative Curve of Large Events Number



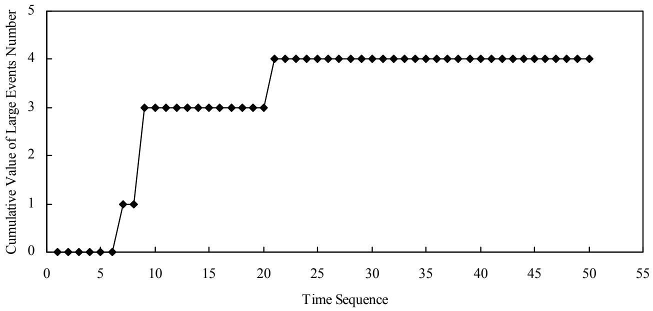
(c) Cumulative Curve of Energy Rate

Fig. 15. Monitoring results of C1450

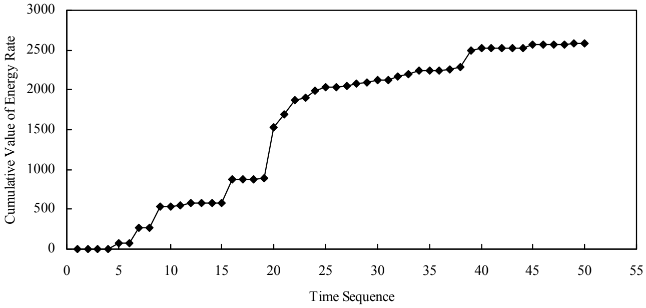
information of cavity, but also ensure the safety of the personnel deploying the equipment who are able to remain removed from the dangerous areas being investigated. This unit has proved to be very suitable for such detection by the long-term on site application. As laser reflections from water and glass back to the receiving optics is almost zero, and the ability of the laser to measure ranges is limited by the 'line-of-sight' within the underground cavity, the influence of water, fog (such as blasting fumes) and humidity in the cavity can have a detrimental affect on laser scanning results. Thus, extra boreholes are also necessary in some case to verify the laser detecting results.



(a) Cumulative Curve of Total Events Number



(b) Cumulative Curve of Large Events Number



(c) Cumulative Curve of Energy Rate

Fig. 16. Monitoring results of C1438-2

Different theoretical calculation methods corresponding to different cavity roof shape as well as the numerical simulation one are proposed to carry out stability analysis of cap rock, which all based on the laser detected 3D data. The results can be used to provide a general understanding of stable condition in cap rock. However, such analysis can not feedback the real time stable information of cap rock during its existence, thus, the acoustic emission technique is adopted to monitor the rock mass rupturing process for real time safety forewarning, and four kinds of typical on site monitoring results are displayed.

So, the detailed data detected by laser scanning device can be used to determine the risk level, and to delineate the hazardous area of cavity. Then, the stability calculation methods proposed in this paper based on laser 3D data can be employed to estimate whether the cap rock could bear its own weight. Finally, acoustic emission technique was used for real time rupturing monitoring in cap rock. By these steps, a complete safety evaluation system of cavity under open pit bench will be established to ensure safe operation above, and this would be a good reference for other mines with such problems.

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