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Study on Safety Hazard Investigation and Treatment Scheme in a Marble Mine Goaf

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Abstract: *In this paper, Pengxi mine and its surrounding area are taken as the research object to carry out the investigation of potential safety hazards. The three-dimensional laser scanning technology is used to detect the goaf, and the pillar method is used to evaluate the safety. Through the investigation of domestic and foreign cases, combined with the urban development planning and land use planning of Shenzhen, the comprehensive utilization scheme of underground goaf is put forward on the basis of comprehensive consideration of technical feasibility, economy and treatment effect, so as to eliminate the potential safety hazards.*

Keywords: *underground goaf; safety hazard investigation; treatment scheme*

1. Introduction

Mineral resources have made significant contributions to the rapid development of the national economy, and a large number of mined-out areas have been left while underground mining is carried out. Mined-out areas, as known as goaf, refers to the cavity area formed by artificial excavation or natural geological movement under the surface. Its spatial structure is complex and difficult to control, which has become the main hidden danger that threatens the mine production and surface safety[1] .Over the years, domestic and foreign scholars have made a lot of achievements in goaf governance [2-12], but there are few studies on the redevelopment and utilization of goaf as underground space resources. With the development of society and economy, surface land resources are becoming increasingly tense. As an important underground space resource, goaf should be prioritized for urban infrastructure and public service facilities to achieve intensive and economical use of urban space resources. Therefore, on the basis of scientific investigation and evaluation of goaf stability, the comprehensive, systematic development and reuse of the goaf has become an inevitable trend of urban modernization and sustainable development.

2. Engineering background

2.1 Overview of mining area

Pengxi Mine is an underground mining marble mine, located in Pingshan District, Shenzhen City. Its traffic location is shown in Figure 1. The room and pillar mining method was used and the parameters are as follows, the dimensions of room and pillar are 12 m×12 m and 15 m×15 m, semi-circular arch with the mining height is 15 m. The schematic diagram of the stope structure is shown in Fig. 2. The mine was officially put into operation in 1996, and fully stopped mining in 2006. After more than 10 years of production, a large number of unfilled goafs have been left. In addition, the lack of planning and private mining made the shape and spatial distribution of underground goaf more complicated.

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Figure 1: Traffic location of mining area

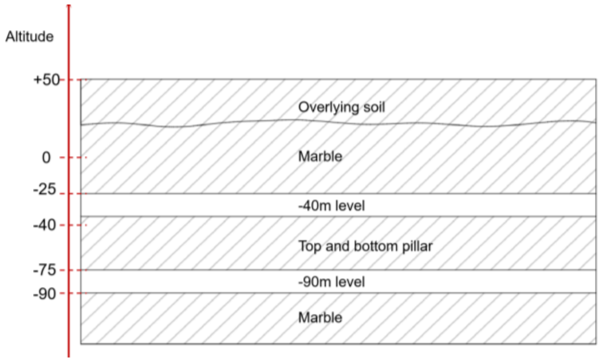

Figure 2: Schematic diagram of stope structure

2.2 Engineering geology

The geology of the mining area is shown in Fig. 3. The area is divided into four engineering geological rock groups according to geotechnical engineering geological conditions, namely hard rock group, semi-hard rock group, weak rock group and loose soil group.

(1) The hard rock group is distributed in the valley and its periphery, consisting of Yanshanian granite and marble of the Lower Carboniferous Shidengzi Formation. Among them, the granite distribution elevation is 100 ~ 527.8m. Due to long-term regional tectonics, joint fissures are more developed. The rock in this group is hard and strong, and the UCS is 60 – 134 MPa.

(2) The semi-hard rock group is distributed between the bottom of the strong wind zone and the middle weathering zone of the Devonian Chunwan Formation, the Carboniferous Shishui Formation sandstone, shale and granite in the periphery of the valley. The fractures are developed, and the rocks are relatively broken. The uniaxial compressive strength is 30 – 60 MPa.

(3)The weak rock group is mainly composed of granite, marble and shale in strong weathering zone, fault zone and joint fissure dense zone. The rocks in the valley edge of the region are subjected to long-term weathering erosion, and the thickness of the weathering layer is generally 20 – 30 m. In the local fracture and joint dense parts, the rock is broken, the strength is significantly reduced, and the uniaxial compressive strength is less than 30 MPa.

(4) The loose soil types are mainly Quaternary residual layer, residual-slope layer, alluvial-diluvial layer and alluvial layer. Among them, the residual layer is mainly composed of sandy and gravelly cohesive soil, and the residual-slope layer is mainly composed of sandy and silty clay. The alluvial layer is mainly composed of gravelly sand, gravelly cohesive soil and a small amount of silty soil. The loose soil has a relatively good engineering geological conditions with the standard value of bearing capacity of 120 ~ 250 kPa.

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3. Investigation and Evaluation of Goaf

3.1 Survey of mined-out areas

Limited by underground space, the mined-out areas are dark and difficult to observe, and their shape is irregular. Among them, the mined-out areas with a large exposed surface have a certain risk of collapse, which brings certain difficulty to the investigation of mined-out area. In this paper, the t3D laser scanning technology is used to detect the goaf, which has the advantages of strong real-time performance, high efficiency and non-contact. The 3D laser scanner obtains the 3D surface data of the target object, and processes, calculates and analyzes the obtained point cloud data. The composition of 3D laser scanning system and point cloud renderings are shown in Figure 4 and Figure 5.

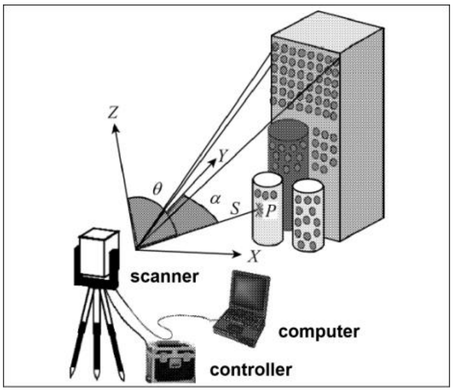

Figure 3: Composition and coordinate

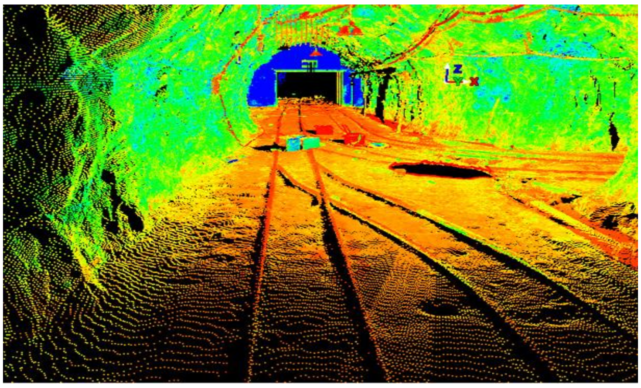

Figure 4: Single site cloud data effect diagram system of laser scanner

Through the three-dimensional laser scanning of underground roadway and goaf , 949046280 point cloud data were formed,. It was clear that the goaf of Pengxi Coal Mine was composed of two parts of underground − 40 m level and − 90 m level. Among them, the length of various mining roadways was about 10 km, the area of goaf was 100,000 m2, and the spatial volume was 1 million m3. The distribution map of goaf boundary and spatial position is shown in Fig.5. In addition, the underground mined-out area is projected on the surface, which is f north to Jinbi Road, from south to Pingshan Avenue, from east to Huayi Brothers Cultural City, and west to southwest corner of Pingshan Xinghua Primary School.

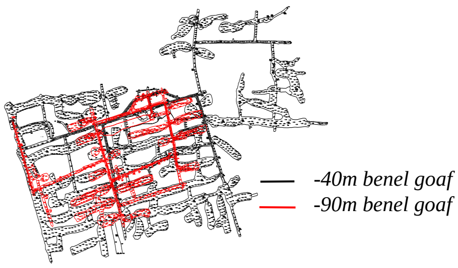

Figure 5: Spatial distribution of goaf

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3.2 Evaluation of mined-out areas

3.2.1 Calculation of pillar safety factor

The pillar stability calculation is actually the pillar strength calculation. Taking into account the change of rock dip angle in Pengxi Mine, the calculation is carried out according to the two conditions of gentle and steep incline respectively. The size of the room pillar and the physical and mechanical parameters of the rock body are shown in table 1.

Table 1: Size of Pillar and Physical and Mechanical Parameters of Rock in Pengxi Mine

parameter	Density γ (kg/m^3)	The mining depth upper level H (m)	Mining depth at lower level H (m)	Pillar support area S_k (m^2)	Cross-sectional area of pillar S_z (m^2)	correction coefficient R	correction factor K	mean molar quantity obliquity	Coefficient K'
numerical value	2.8×10^3	90	140	30	15	1	1	55°	1.4

(1) Slowly inclined strata

This method assumes that the rock stratum is elastic and isotropic, and the failure of the pillar is mainly caused by the vertical stress. The calculation formula of pillar safety factor is as follows :

$$n = \frac{S_z\left[\sigma_c\right]K}{9.8\gamma \cdot HS_k R} \tag{1}$$

Where, γ is the average density of overlying strata, kg / m3. H is the mining depth, m. Sk is pillar support area, m2. Sz is the pillar cross-sectional area, m2. R is the correction coefficient of mining depth, mining height and mining range. σc is compressive strength of rock mass, Pa.K is the correction coefficient of pillar shape. n is the safety factor.

When the compressive strength of rock mass (minimum) [σc]＝18×106 Pa：

Safety factor of upper level pillar n = 3.64. Lower horizontal pillar safety factor n = 2.26.

When the compressive strength of rock mass (average) [σc]＝49.3×106 Pa :

Safety factor of upper level pillar n = 9.98. The lower horizontal pillar safety factor n = 6.19.

(2) Steeply inclined strata

The calculation method is the same as the calculation formula of pillar strength in gently inclined strata, except that the influence coefficient of dip angle is added. The correction coefficient of known mining depth, mining height and mining range is R = 1, and the correction coefficient of pillar shape is K = 1. The calculation formula of pillar safety factor in steeply inclined strata is as follows:

$$n = \frac{\left[\sigma_c\right]}{9.8\gamma \cdot H} \cdot \frac{wb}{K'\left(w+b\right)+Kwb} \tag{2}$$

where w is the span of the mine room before modification, m. b For pillar width before correction, m. K ′ is the stress influence coefficient.

When the compressive strength of rock mass (minimum)[σc]＝18×106 Pa：Safety factor of upper level pillar n = 2.6. Lower horizontal pillar safety factor n = 1.62.

When the compressive strength of rock mass (average)[σc]＝49.3×106 Pa:

Safety factor of upper level pillar n = 7.12. Lower horizontal pillar safety factor n = 4.42.

The calculation shows that under the conditions of gently inclined rock and steeply inclined rock, the safety factor of pillar meets the requirements and the pillar is stable.

3.2.2 Limit span of goaf roof

For the room-column method, the maximum span when the goaf can maintain its self-stability is called the limit span,. It is generally calculated by engineering analogy method. The limit span is estimated according to Q-L diagram. The rock quality index Q can be calculated by formula 3 :

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$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF} \tag{3}$$

Where, RQD is the rock quality index. Jn is the joint group. Jr is the joint roughness coefficient. Ja is the reduction coefficient of joint strength. Jw is the reduction coefficient of joint water content. SRF is the stress reduction coefficient.

Based on the joint fracture investigation and indoor rock mechanics test of Pengxi Mine, the RQD of rock mass in Pengxi Mine is determined to be 90. Jn is 0.75. The joint roughness coefficient Jr is 2.5. The strength reduction factor Ja is 0.75. The water cut reduction factor Jw is 1.0. The stress reduction coefficient SRF is 1.0. The rock mass quality index Q - unsupported span L curve is shown in Figure 5.

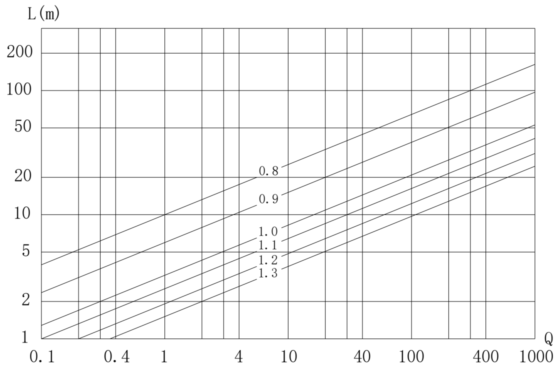

Figure 6: Q-L curve of rock mass quality index without support span

After calculation, the rock quality index Q of Pengxi Mine is 400. According to figure 6, the limit span of goaf is 18-40 m, which is larger than the actual mining span of 12-15 m. Therefore, Pengxi mine goaf span is less than the limit span, indicating that the mining room is stable.

In summary, the stability of pillar and room in Pengxi Mine is good, indicating that there will be no large-scale instability goaf, and the overall stability is good.

4. Gob governance scheme

The treatment plan of Pengxi Mine goaf should be combined with urban development planning, land use planning and other types of planning, but also to meet the requirements of eliminating safety hazards. In this paper, according to the control effect of goaf t, the degree of development and utilization of the mined-out area and the above-ground space, also combined with its own advantages of Pengxi mine, the scheme of mine park development for safety hazard management is put forward. .

4.1 Advantages of mines

(a) Underground roadway *(b) Underground stalactite landscape*

Figure 7: Photos under Pengxi Mine

Pengxi mine is a marble mine, and its typical karst landform is particularly unique. The stalactites, which are only 1 cm long in 100 years in other places, can be 2 to 3 cm long each year, and the

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underground space is huge and, and its scale is extremely rare in the country and even the world, as shown in Fig. 7. Therefore, Pengxi Mine is of great development value as a valuable mining geological and production relic.

In addition, as early as August 2005, Pengxi Mine was listed in the first batch of national mine parks with the highest score in comprehensive index evaluation. Therefore, it has the basic conditions for the construction of mine parks. At the same time, the management of potential safety hazard combined with the development of mine parks is in response to the national call of "Notice on Strengthening the Construction of National Mine Park", which meet the need to carry out the ecological restoration of the geological environment of abandoned mines, and the need to build Shenzhen business card and show the characteristics of Shenzhen Special Zone.

4.2 Planning and location advantages

The surface of the mining area is planned as green space and square land, and the surrounding areas are planned as schools, kindergartens, residential land, etc., with complete matching. There are also Biling Wetland Park and Huayi Brothers Cultural City, among which the development and construction of Huayi Brothers Cultural City has begun to take shape. Pengxi mine national mine park combined with the surrounding resources is easily to form a functional industrial chain integrating tourism, entertainment and leisure.

4.3 Reference of successful cases

With the joint efforts of the government and entrepreneurs, there are many abandoned mines revitalize the mine again. Among them, Mines and Meadowsin in Pennsylvania, United States and Kailuan Coal Mine in Tangshan, Hebei, build a mine park or recreational place based on the remains of the mine which have become the classics of mine utilization, as shown in Fig8.

Figure 8: Mines and Meadows

In these classic cases of waste mine reuse, some of the mine congenital conditions do not have more development advantages than Pengxi mine. With its typical karst landform, large-scale underground mined-out roadway and unique metallogenic mechanism of deposits, Pengxi Mine, as a valuable mining relic, has high geological significance and scientific research value. These have long been recognized by the state Combined with the unique mine park planning, it is bound to have high development value and development prospect.

In summary, combined with the development of mine parks, the goaf treatment is technically feasible and economically reasonable, which not only meets the requirements of eliminating potential safety hazards, but also realizes the reuse of underground space resources, which meets the requirements of urban modernization and sustainable development.

5. Conclusion

(1) Through to the investigation, the goaf of Pengxi Coal Mine is composed of two parts of − 40 m underground level and − 90 m underground level. With the help of 3D laser scanning technology, the basic information of the three-dimensional shape, spatial position and actual boundary of the goaf of Pengxi Coal Mine are mastered. Among them, the length of various mining roadways is about 10 km, the area of goaf is 100,000 m2, and the spatial volume is 1 million m3.

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(2) Based on the empirical method and theoretical research method, the safety factors of pillars under gently inclined and steep inclined strata are calculated to be 2.26 - 9.98 and 1.62 - 7.12, respectively. The roof span meets the requirements of 18-40 m, indicating that the stability of pillars and rooms is good, indicating that there will be no large-scale instability in goaf and the overall stability is good.

(3) Combined with Pengxi Mine 's own situation, the scheme of goaf treatment combined with mine park development is proposed. The scheme is feasible in technology and reasonable in economy, and realizes the reuse of underground space resources while eliminating safety hazards.

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