Research on key technology of waterproof refuge chamber for non-coal mine disaster

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Abstract
Emergency refuge chambers have been mainly applied at coal mine against accidents such as fire, explosion, however, the research on refuge chamber for flood protection has turned out to be inadequate. Based on the practical situation at Guilaizhuang Gold Mine, the technical indexes in relation of flood protection refuge chamber have been concluded. The external protection structure of the chamber has been confirmed through theoretical calculation. The engineering calculation methods have been concluded for fundamental life sustaining technologies including air refreshing, temperature and humidity control, oxygen supplying system. The emergency ventilation and drainage system were studied, and the multi-driving air refreshing device and water - proof ventilation device were designed. With a on-site experiment and a 50-person/48hour manned test, the supporting structure and the internal system of the chamber were surveyed. The results show that the convergence rate values at between 0.022~0.035mm/d in average, the convergence of both sides and floor of the roadway was obvious; the running of multi driving air refreshing device, ventilation ducts and ice storage air conditioning systems was proved stable and reliable, providing a foundation for the designs and establishment of the criteria in relation of non-coal mine emergency chamber.
Key words: NON-COAL MINE, WATERPROOF REFUGE CHAMBER, EXTERNAL PROTECTION STRUCTURE, LIFE SUSTAINING SYSTEM, MANNED TEST

1. Introduction

China has an abundance of non-coal mine resources but lacks of relatively advanced mining technology. Underground non-coal mine accidents take place quite often due to the lack of necessary safety protections. Non-coal mine accidents saw a total death toll only second to the fatalities caused in traffic accidents and coal mine accidents, seriously jeopardizing the sustainable development of the mining industry of China[1~2]. Mine refuge chamber provides a safe and reliable protection for miners in emergency situations and promotes the rescue capacity and safety standards. At present, the research on refuge chamber technology in China mainly focus on coal mine accidents including coal & gas outburst, fire, explosion etc. [3~5], the study on non-coal mines has turned out to be inadequate. The existing coal mine emergency rescue technology was proved unable to meet the demands of rescue operations at non-coal mines. Compared with coal mine, the non-coal mines are much fragile in the face of disasters such as flood, fire and toxic smoke from explosion. With the deepening of mining excavation, risk for the occurrence of flood will become higher [6], therefore the research on emergency refuge chamber technology and its crucial equipment that special for dealing with accidents and environmental changes of the disasters at non-coal mine bears special significance.

With conducting an on-site survey at Guilaizhuang Gold Mine in Shandong Province, this paper analyzed the general conditions underground so as to decide the best location selection for an emergency refuge chamber, obtained the technical indexes of the refuge chamber with the reference of the characteristics of non-coal mine accidents and the safety technologies applied in subway and roadway construction, meanwhile studied the external protection structure and internal supply system of the refuge chamber. By using the methods of theoretical calculation and experiment, the structural layout of the flood protection refuge chamber at Guilaizhuang Gold Mine has been completed. Moreover, the refuge chamber passed a durability test, where all systems were tested running steady. The test offers a reference for the establishment of related criteria and paves way for the upgrading of the standards for non-coal mine emergency rescue.

1. Refuge chamber location and index analysis

1.1. General conditions of mine

Guilaizhuang gold mine is located in Pingyi County, Shandong province. The mine area is surrounded by hilly grounds with an elevation of 121.8~160.5 meters. Geological conditions and hydrogeological conditions for areas suitable for engineering purpose are at medium levels. Rock hardness coefficient is f=6~10. Karst development in the mining area is mainly concentrated in the shallow parts. Source of the water flowing into mine and roadway is mainly the karst water flowing through rock fractures. The main hazardous factors threatening the mine are risks of ceiling & roadway sides collapse, flooding, fire and toxic gas. At present, the exploitation of mine has been transited from open-pit mining to underground mining. Underground operational sections are mainly distributed at the middle geographical layer at - 130 - meter - 142 - meter, and - 150 - meter - 190 - meter. An expansion of the sections to - 230 meter is likely in the future. Deployment of the shifts underground as demonstrated in table 1.

Table1. Deployment of crew

Series no.	Job type	Shift		
		1	2	3
1	miner	27	35	27
2	excavator	8	11	8
3	executive & service supplier	0	12	0

1.2. Refuge Chamber location

An analysis over major hazardous factors underground has been conducted by the collecting of geographical data of the mining area. From comprehensively considering the basic conditions of the mining shaft including the roadway network layout, status-quo exploitation conditions, crew deployment, evacuation routes and ventilation system, etc., it was concluded that the flood protection refuge chamber should be set up in the rock layer north of the roadway between line 27 and 28 with a depth of 150 meters underground. The location is suitable for engineering construction for its proper geological conditions which are free of flooding, Karst caves, hazardous geological structure and stress area. The refuge chamber mainly serves the crew working at the middle section below at least 150 meters. Results of on-site tests show that the self-rescue process takes maximum 30 minutes, and the longest evacuation rates around the chamber are all within 1000 meters, which up to the safety requirements [7].

1.3. Technical indicators

According to the characteristics of the past mine accidents at Guilaizhuang gold mine, the chamber is mainly designed against flood, fire and toxic gas. It features functions such as flood protection, sealing properties, air refreshing, temperature and humidity control and oxygen supplying etc. with satisfaction of the demands necessary for the survival of the personnel sought asylum inside. According to the shifts deployment plan, miners deployed nearby the working section number 46 at maximum, consequently the refuge chamber has designed a maximum capacity of sheltering 50 people, with its backup coefficient up to 1.2. The maximum hydrostatic pressure which the chamber can sustain can be determined by the difference between the maximum height of the water level in the shaft submergence and the height at which the refuge chamber is located[8~9]. From the requirements of the underground flood protection designs applied to subway, roadway and underground civil air defense projects etc., the chamber should be added with waterproof feature at a certain degree and meet the security requirements as a safe and reliable living space.

2. External protection structures

2.1. Supporting method

In the vicinity of the refuge chamber, the surrounding rock mass is rated at Class III. The F value of the rock hardness is at 7. The rock mass is mainly consists of limestone. According to past engineering experience, the design section of the refuge chamber comprised of a three-center arch, with triple full-protection constructions. The initial protection uses wire mesh as a reinforce material to support the structure, the second protection uses waterproof concrete lining, and the third support uses concrete and reinforce bars to strengthen the support, as demonstrated in table 1.

With the engineering analogy method in the design of bolt support parameters, the phi 20mm x 2400mm sinistral no-longitudinal threaded anchorages. Bolt interval is 800 x 800 mm. Each bolt was fastened by resin adhesive “K2335” and” K2360d”. The bolt is initially shot with concrete with a strength grade of C25 and a thickness at 50mm. After the first spray, using a steel bar mesh with a diameter of Φ10mm and measured 150 x 150mm to strengthen the supporting, then coat again with concrete 95mm in thickness for the last reinforce.

C30 concrete is used for the secondary support and the coating layer is 100mm in thickness, and the 5mm thick polyurethane coating is arranged between the primary and secondary support. Learning from the related industrial standards applied to subway and roadway construction [10~12], the refuge chamber’s tertiary support uses C40 waterproof concrete 350 mm in thickness. The waterproof concrete’s impervious class is rated P8, built-in with double-layer reinforce bars. The main reinforcement mesh consists of Φ10*300*300mm steel bars, while the connection steel bars measure Φ10*600*600 mm.The protection layer measures 40 mm in thickness.

2.2. Study of waterproof gate and wall

2.2.1. Waterproof gate

The refuge chamber adopts a waterproof gate (MLY1.5/1.5/1.8) with pleural flat shell. The door plank is designed in dome structure, which is constructed by Q345R steel materials. The steel plate measures 12 ~ 14 mm in thicknesses. The door components are mounted on the shell plate concave with at least two transverse and longitudinal ribs. The door frame components consist of equicohesive door plate, which is on both sides of the narrow and wide in the middle, a doubling door frame, welded I-section steel beam frame and floor. Door hinge using rolling support bearings, square elastic rubber seal for sealing. The quick tightening mechanism adopts the wedge slide block tensioning device.

According to the standard of MT258-91, the pressure resistance of the waterproof gate was tested at the metal structure testing center of China State Shipbuilding Corporation. Door leaf key position is set up 20 measuring points (figure 2 (a).UCAM-70A digital strain meter is used to measure the points of measurement. Loading and unloading pressure program are from Starting from 0.0 MPa increased to 2.0 MPa by 0.5 MPa pressure gradients, constant pressure for 30 min. Then slow unloading pressure to zero by 0.5 MPa pressure drop gradient. Six points (Figure 2 (b) is obtained by the analysis. The strain value of the measured point is negative pressure, which is indicated by the tension and vice versa. The measuring point 3, 4, is located in the middle of the waterproof gate concave position strain value is positive, show the pull force. Point 6, 7, 12 and 20 strain values are negative performance for pressure. The experimental results show that, maximum strain measuring point 12 is under 2MPa -1013. According to Hooke’s law, it is found that the strain pressure is 211.7 MPa, far less than the yield strength of Q345R steel 340 MPa. There is no obvious deformation in the portal structure. The test results show that the waterproof gate can withstand the hydrostatic pressure of 2.0 MPa.

2.2.2. Wall structure design

1) Airtight wall length

Waterproof gate wall structure form can be chosen according to the size of the refuge chamber water pressure under cylindrical structure wedge structure

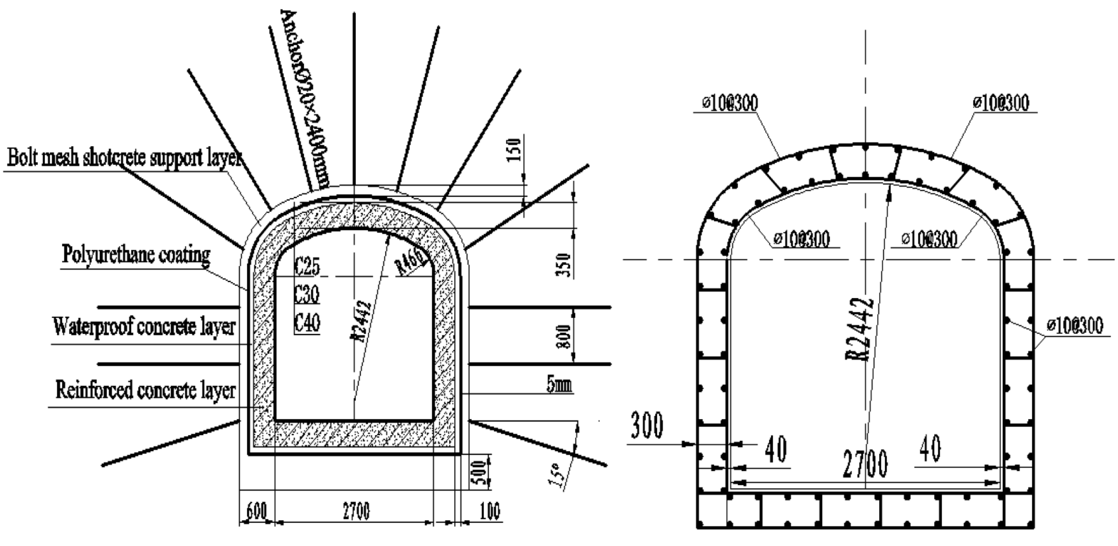


Figure 1. Supporting and reinforcement of roadway

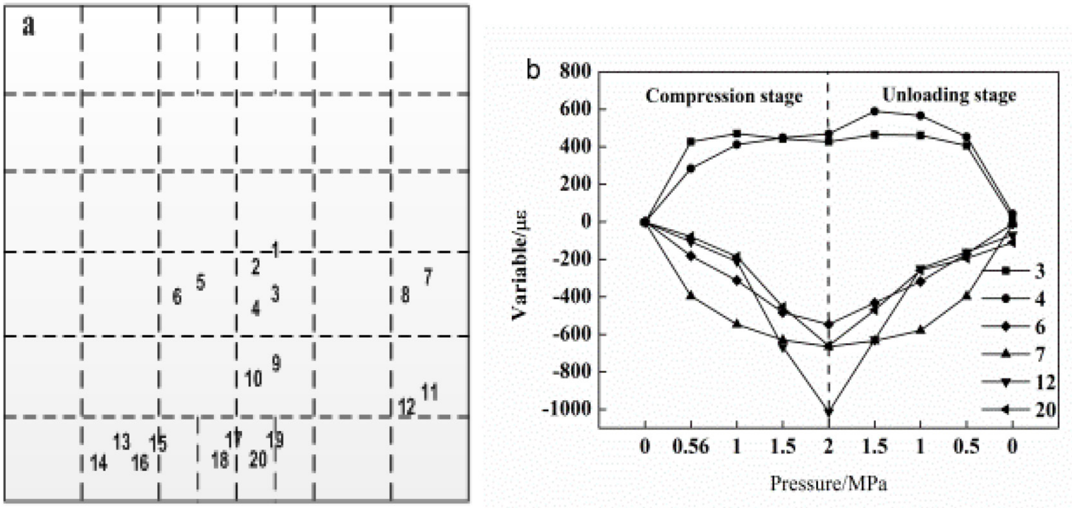


Figure 2. Measuring points distribution and testing result of waterproof sluicegate

and the tapered structures. Guilaizhuang waterproof gate refuge chamber is designed for 1.5 MPa. The maximum hydrostatic pressure in the refuge chamber is less than 1.6 MPa. So the design of wedge structure is adopted. The width and height of the roadways in front and rear wall are 2.7 m. Waterproof gate around the use of C40 concrete support. The wall length L (type 1) was calculated according to the wedge compression strength. According to the shear strength of concrete (type 2) and the anti-seepage condition (type 3), the thickness of the closed wall of the waterproof gate is checked.

$$L = \frac{H+B}{4\tan\alpha}\left(\sqrt{1+\frac{4\gamma_0\gamma_f\gamma_d HBP}{(B+H)^2 f_{cc}}}-1\right) \quad (1)$$

$$L = \frac{3.3PS}{2(B+H)\times 0.75\sqrt{f_c f_t}} \quad (2)$$

$$B_B = 4800KPS \quad (3)$$

In the formula, L – the gate wall length, unit: m; H – height of the roadway in the front and rear wall, unit: m; B – width of the roadway in the front and rear wall, unit: m; S – net area of roadway, unit: m^2; α – the angle between the supporting surface of the chamber and the center line of the roadway, because the rock hardness f>6, so α = 30°; γ_0 – structural importance coefficient, take 1.1; γ_f – partial coefficient of effect, take 1.3; γ_d – structure coefficient, take 1.75; Water pressure in the design of the waterproof gate chamber, N/mm^2; f_{cc} – design value of axial compressive strength of plain concrete, take 0.95 f_c, N/mm^2; f_c – design value of axial compressive strength of concrete, take 19.1 f_c, N/mm^2; f_t – design value of axial tensile strength of concrete, take1.71 N/mm^2; BB – calculation of the thickness of the closed wall of the waterproof gate by the concrete anti permeability condition, unit: m; K – concrete permeability coefficient, take 0.25×10-4.

The length of sluice wall is calculated by the compressive strength L = 0.23 m. According to the shear strength of concrete and the anti-seepage condition, the length of sluice wall is 0.78 m and 1.25 m. From the safety point of view, select the larger value, considering the additional safety factor of 2 times [13], the waterproof gate chamber wall length is 2.50 m.

2) Embedded depth of surrounding rock

$$E = k\frac{pf}{Ral} \quad (4)$$

In the formula, E – groove depth of sluice wall; k – sluice wall design safety system to take 2.5; P – maximum net water pressure; f – net area of sluice wall facing water; l – net circumference of water gate wall by the water; R_a – the design of the concrete compressive strength.

Embedded depth of surrounding rock E = 135 mm, the design is rounded up to 150 mm. The waterproof wall structure of the refuge chamber is shown in Figure 3.

2.2.3. Other requirements

From photo elastic test, the stress concentration phenomenon of the waterproof gate of the refuge chamber is known. To strengthen the compressive and shear strength at the end of the refuge chamber and improve the stress distribution, outside to meet the water lateral of the refuge chamber door frame is made of horn shape (at 45 degrees and the midline). The length of the wall is 5 m. The floor is higher than roadway 500mm. All the pipelines are connected by the pre embedding method inside the refuge chamber. The distance between through-wall pipe, inner tube wall and the convex positions is greater than 250 mm.

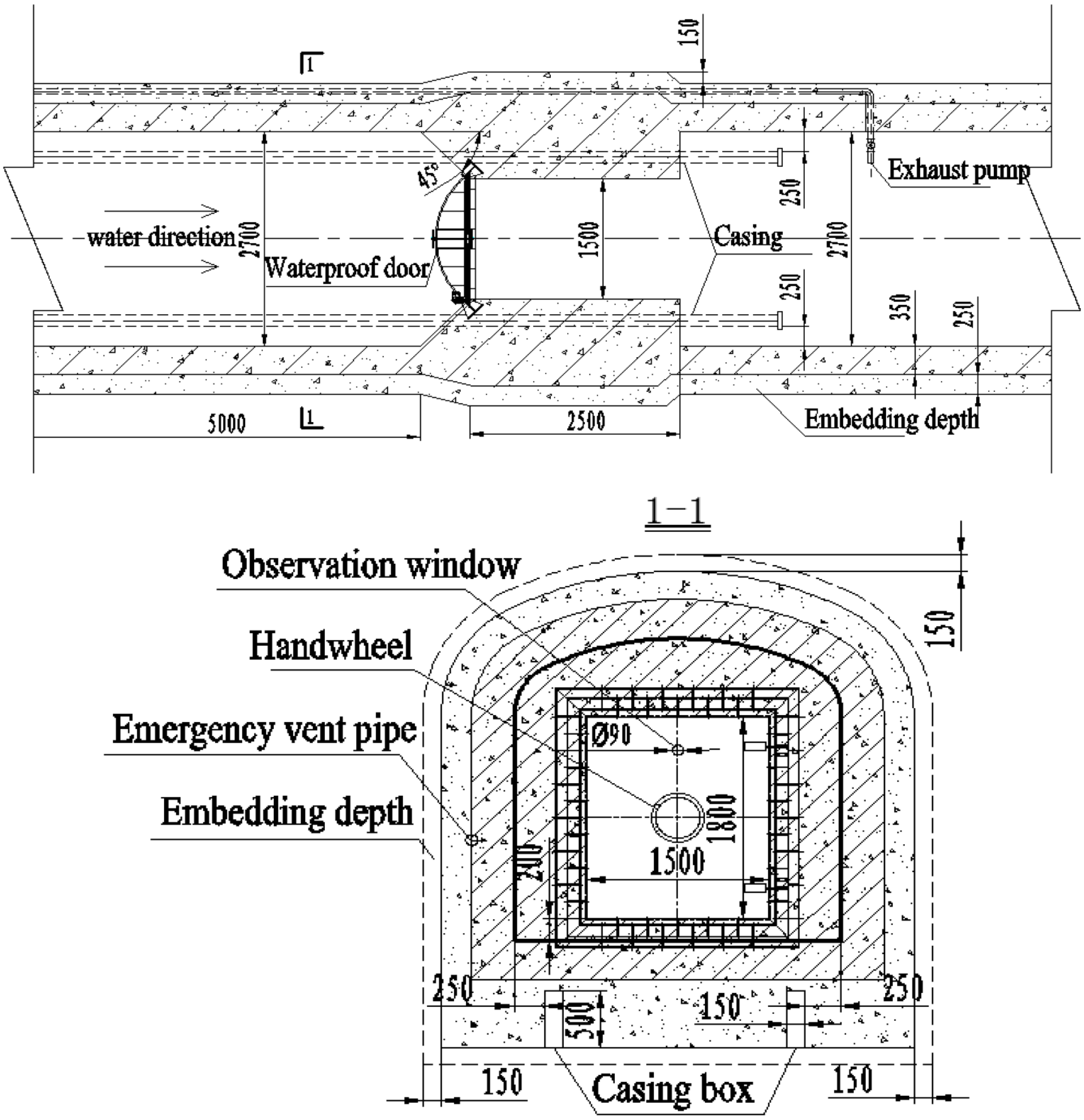


Figure 3. Structure diagram of waterproof airtight wall

The distance between the adjacent through-wall pipes is greater than 300 mm. The static pressure water pipe, air duct, reserved pipe, pressure pipe, drainage pipe and emergency exhaust pipes are directly buried in concrete with stationary and waterproof method. When the diameter is larger than 50mm, welded the sealing ring on the main pipe, and reserved grooves with sealing material filling density on the upstream face of the main pipe. When the diameter is less than 50mm, used water swelling rubber ring. Power cable and communication cable use rigid water string. The through-wall part welded with wing ring. Block the space between the cable and rigid water string with cement and oil flax. All the ends of the embedded concrete thickness are not less than 250 mm, otherwise take local thickening processing. In order to ensure the integrity of the waterproof wall, door frame and embedded pipe need to be pouring as a whole.

3. Internal life support system of refuge chamber

3.1. Air purification system

Currently, most of the safety air refreshing devices are electricity powered single drive mode, a small number of them using pneumatic double drive and manpower. When an accident occurs, the power or the air pressure system in the chamber may be damaged, resulting in a single operation mode of the purification device cannot be used. The refuge chamber is designed by means of an air refreshing device with multiple drivers. Its operating modes include: 1. Electric mode, 24 V power supply by mine power grid or battery; 2. Pneumatic mode, compressed air or high pressure gas supply from the underground pressure air supply pipeline, external compression gas pressure 0.4~0.8 MPa; Manual mode, the normal operation of the emergency personnel to maintain device by hand device, manual wheel speed > 60 /min. Device structure as shown in figure 4. The device can be used in different conditions of coal mine, which is adaptable. The device can reduce the impact of disaster environment on it, and effectively improve the independence and reliability [14].

The multi - driving air purification device is composed of an electric and pneumatic air blower through a one-way clutch. Each fan air volume is calculated by the following formula:

$$Q = \frac{60nM_{co_2}}{1000\eta C_{co_2}} \quad (5)$$

In the formula, Q – supply air rate, m^3/h; M_{co2} – per capita CO_2 production quantity, L/min; n – the number of refugees, NUM. η – removalrate; concentration of CO_2.

The air flow of the fan was calculated to be not less than 420 m^3/h, the system resistance is 254 Pa, 1%.

3.2. Temperature and humidity control system

The ice storage refrigeration system is used in the chamber. In the normal condition of the mine electric power supply, the cooling air conditioning system of the chamber is used for cooling, and the cooling capacity is stored in the form of ice. When the accident happens, the ice melting process of the heat effect to release of the cooling load in order to adjust the temperature and humidity. The storage capacity and the circulating wind speed as the main working parameters of the storage refrigerator can be calculated by the following formula [15].

3.2.1. Ice storage capacity

$$m_{ice} = \frac{W}{C_{p1}T_1 + r + C_{p2}T_2} \quad (6)$$

m_{ice}– ice storage capacity, kg; W – The thermal load of the refuge chamber, mainly from personnel and equipment, W; C_{p1}–specific heat capacity of water, 4.165 kJ/(kg·℃); C_{p2}–specific heat capacity of ice,2.1kJ/(kg·℃); T_1–Temperature change of water, ℃; T_2–Temperature change of ice, ℃; r–dissolution heat, 335 kJ/(kg·℃).

Through calculation, the ice volume is 8.15 m^3. There are two sets of system in the chamber. The air duct and the coil of each ice storage is about 23%. Therefore, the storage is designed for the upper and lower split type. The net size is 2.4m*1.3m*0.9m, the total volume is 5.6 m^3 to meet the requirements.

3.2.2. Outlet air velocity

The high speed jet which is produced by the air flow in the ice storage can achieve the low temperature air supply, so as to achieve the purpose of regulating the air in the refuge chamber. According to the air supply air jet axis orbit, the equation can be obtained.

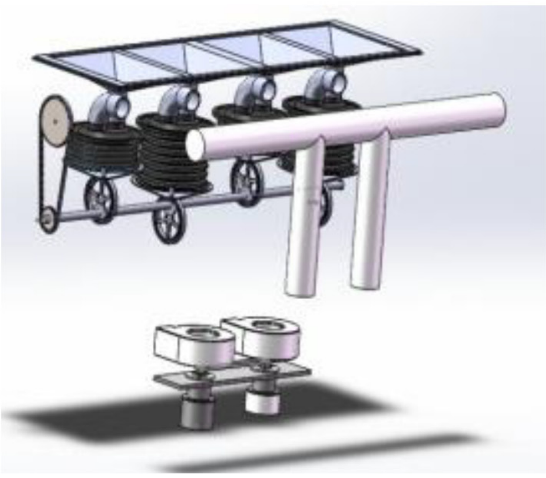
$$\frac{y}{d_e} = \frac{x}{d_e}\tan\beta + Ar\left(\frac{x}{d_e\cos\beta}\right)^2\left(0.51\frac{ax}{d_e\cos\beta} + 0.35\right) \quad (7)$$

$$Ar = \frac{gd_e(T_{in} - T_{out})}{v_s{}^2(273 + T_{in})} \quad (8)$$

Simultaneous formula 7~8, inferred that the wind speed of the storage refrigerator should be calculated by the following formula:

$$v_s = x\sqrt{\frac{gd_e(T_{in} - T_{out})}{(273 + T_{in})(0.51axy + 0.35yd_e)}} \quad (9)$$

y–The vertical drop of the distance between the center of the jet trajectory and the outlet center, m; x–Jet range, m; d_e–Nozzle equivalent diameter, take 0.27; β–Nozzle inclination angle, take 0°; α–Nozzle turbulence coefficient, α=0.08; g–Gravity acceleration, take 9.81 m/s^2; tin–intake airtemperature, ℃, tout–outlet temperature, ℃; vs–Outlet wind speed,



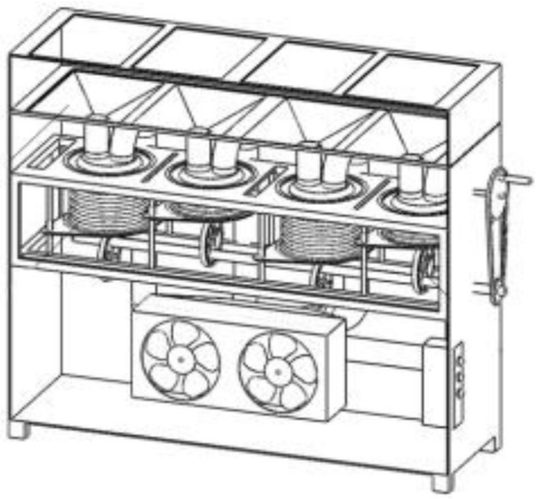


Figure 4. Structure diagram of multiple driving air purifier

m/s. The wind speed of ice storage is calculated of 7.35m/s vs.

3.3. Oxygen supply system

3.3.1. Oxygen bottle support

According to the relevant standards, the oxygen supply is not less than 0.5L/ (min). The mine refuge chamber is designed for 50 people, with a reserve factor of 1.2. To achieve the protection time of 96h, the total oxygen demand Q is 172800L. The selection of standard is 40L and 15 MPa oxygen bottles. O_2 volume can be stored for 5800L (STP). Therefore, the refuge chamber is equipped with a total of 30 oxygen bottles.

3.3.2. Mine pressure air supply

The system uses the underground pressure pipe to provide air for asylum seekers. In order to meet the mine pressure air to the room, to achieve the uniform air distribution, the air ducts are connected to the refuge chamber to meet the conditions of uniform air supply. According to the requirements of the relevant standards, when chamber air supply per person not less than 0.3m3/min, the noise is not higher than 70 dB, space height of 3.5 m, scattered flow is neck maximum blower speed should be less than 6.5 m/s. Therefore, the refuge chamber living area is designed for the 6 diffuser, which is arranged along the central line. To calculate parameters of supply air duct by Static Regain Method, uniform air supply piping design as shown in figure 5 and iteration results are shown in table 2.

By calculating the overall system resistance is 55.37 Pa, System of a–1–2 pipeline is the most unfavorable loop. Unbalance rate of resistance of node a, c are 3.8% and 2.6%, to meet no more than 15% design specifications. To test the performance of the designed pressure air pipe line, when the wind speed is 1080m3/h, the results of wind speed and noise in

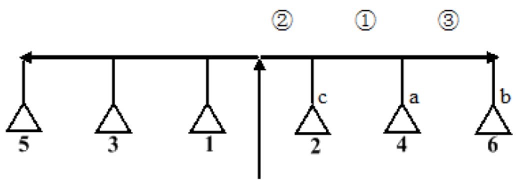


Figure 5. Schematic diagram of proportioned air ducts

the test flow of 1 m below are shown in Figure 6. By the graph, the internal noise intensity in the chamber is satisfied with the requirement, and the distribution of the flow is uniform.

According to the scheme, the air flow organization is calculated and the average wind speed in the refuge chamber is satisfied with:

$$v_{pj} = 1.2 \times \frac{0.381nA}{[A^2/4 + H^2]^{0.5}} \quad (10)$$

In the formula, A–partition length of diffuser, m; H–partition length height of diffuser, m; n–range and the partition length ratio of the diffuser, 0.375.

By calculation, v_{pj}=0.14m/s <0.3 m/s is to meet the requirements of the air conditioning area of human comfort air flow.

3.4. Assistant system

3.4.1. Emergency exhaust system

The air return pipe is arranged in the waterproof wall to ensure the internal pressure in the normal range. However, the external water gets into the refuge chamber through the air return pipe in the flood. A new type of waterproof exhaust valve (Figure 7) [17] is used in the design of the refuge chamber of Guilaizhuang gold mine. The device is connected with return air inlet of the refuge chamber by the combination of hydrostatic release unit and the exhaust valve. When the chamber water depth is reached 1m in flood, hydrostatic release unit will release hook ring under hydrostatic pressure by deformation. Piston will push the gate to close the exhaust valve under the action of compression spring in order to insulate the refuge chamber and the outside world.

In order to verify the function of a new type of water-proof exhaust valve, test the sensitivity of hydrostatic pressure release, box, and a certain gas is filled in the self - made sealed box. The pressure of the hydrostatic pressure is detected by the pressure of the pressure test. The hydraulic pressure is simulated by using air pressure to detect the release of the hydrostatic pressure. Experimental results are shown in figure 7, hydrostatic release unit releasing pressure maintained in the 9.5~10 KPa. In depth of 0.97~1.01 m, hook will be released, meet the design requirements.

Table 2. Iterative results of proportioned air ducts based on static regain method

Main pipe						Branch pipe				
section code	ventilation volume / m^3/s	diameter / mm	flow rate inside pipe /m/s	pipe length/m	total resistance	Section code	diameter / mm	neck flow rate/m/s	total resistance	Imbalance rate/%
2	0.15	150	8.4	1.5	9.39	c	100	6.37	47.23	2.6
1	0.10	140	6.5	3.0	16.76	a	100	6.37	29.22	3.8
3	0.05	100	6.37	3.0	23	b	100	6.37	5.11	-

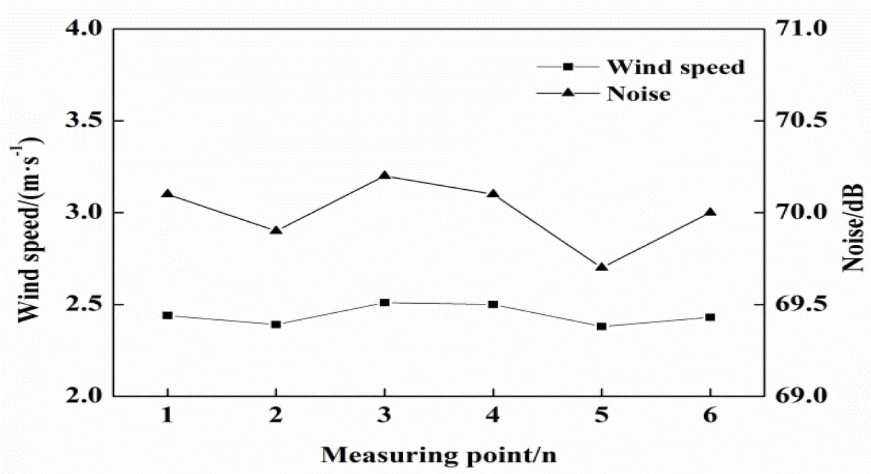


Figure 6. Result of wind speed and noise in air ducts

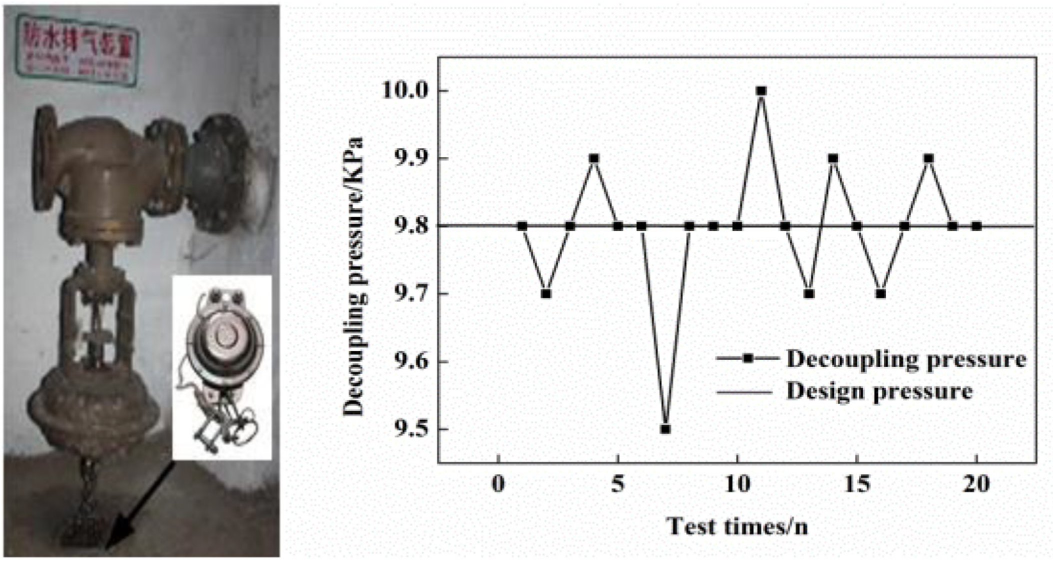


Figure 7. Result of waterproof exhaust valve performance

In addition, when mine flood and return air pipes are closed, if the use of oxygen supply is special pipes, chamber pressure will rise rapidly. It is harmful to the health and safety of refugees. In order to maintain the pressure difference inside and outside the refuge chamber, the refuge chamber is provided with an emergency exhaust device. The device is composed of an exhaust pump, a sealing valve and exhaust pipes. The exhaust pipes are extended to the middle part of the -110 m by a pre buried. According to the field manned test, the per capita minimum air pressure of the chamber is 0.05 m^3/min, which can meet the needs of the human body. Therefore, the flow of the exhaust pump is selected by 150m^3/h, and the intermittent working condition is adopted.

3.4.2. Emergency drainage system

The water drain pipe is discharged into the large roadway through the pre buried drain pipe. When the flood accident occurs, the water level of the large roadway is raised so high that Drainage can't work. The emergency drainage system was set up on the two sides of the refuge chamber transition section of Guilaizhuang gold mine.

The system is connected with the conventional drain pipe and the drain pump. The connection is provided with a valve well. The detail structure of the valve well is enhanced with the waterproof design (Figure 8).

The loss of lift of emergency drainage system is calculated by the following formula:

$$\Delta H_z = \frac{\lambda L v^2}{2gD} + \xi \frac{v^2}{2g} \qquad (11)$$

In the formula, λ – Friction loss factors, ζ – coefficient of local resistance; L – length of straight pipe, m; D – inside diameter of pipeline, m; v – mean flow rate , m/s; g – gravitational acceleration, 9.81m/s^2.

The calculation of the head loss is about 6m, and the design of the emergency drainage system is 40m (a middle section of the roadway. Therefore, selec-

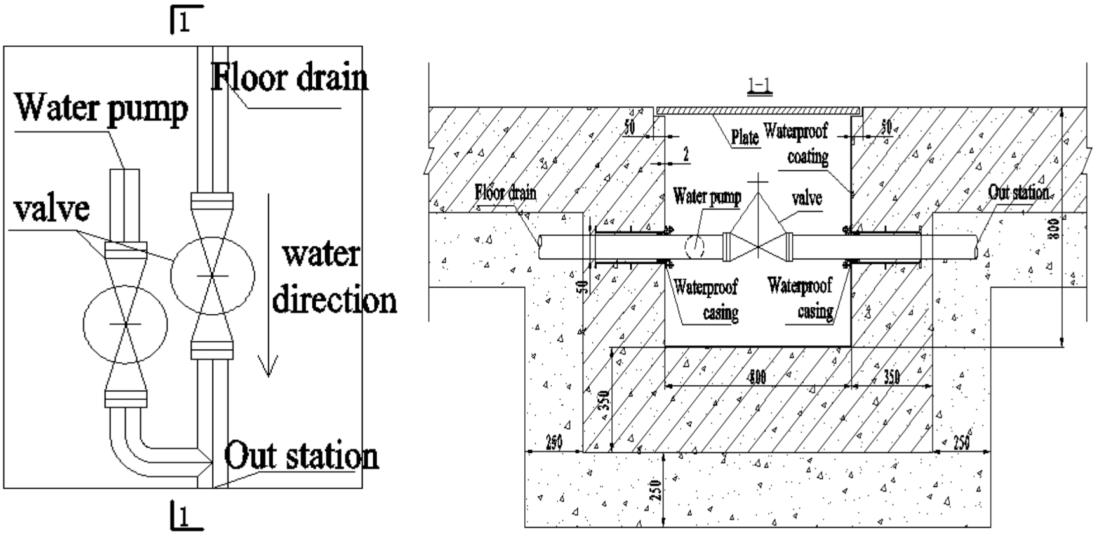


Figure 8. Structure diagram of emergencydrainagesystem

tion of the unilateral pump is 50QW20-50-7.5KW-2P, the diameter of drainage is 50 mm, and the flow is 20 m^3/h, the head is 50 m.

4. Field applications

4.1. Roadway stability test

By monitoring the deformation of the roadway surrounding rock and analyzing the convergence value, we can study the deformation development law of engineering support, the effect of the support and the evaluation of the engineering stability [18-19]. In order to detect the effect of the support in the roadway, the convergence of the whole supporting system was tested.

Finishing the construction, the roadway is required to pass a test in support effectiveness with the use of a convergence tester. During the test, two sections from the chamber's surviving area and transition area will be selected and four testing spots will be selected on the ceiling, side walls and floor of each section. The distribution of testing lines as demonstrated in graph 9(a). Each line represents the convergence rate between the two testing points. Routine monitor will be carried out once in every 2 or 3 days since the setup of the spots. The interval between routine monitors will be prolonged to once a week or a month in a gradual fashion if data collected show improving in stability. Monitoring frequency should be intensified if abnormality is shown by collected data.

Testing results as demonstrated in graph 9(b), available convergence status as demonstrated in Table 3.

Analysis shows that the roadway was gradually converging but with a decelerating convergence rate after the construction of the roadway support. The roadway went through a full-section convergence which was most obviously on the sides and floor. The roadway deformation valued between 3.69-5.66 mm

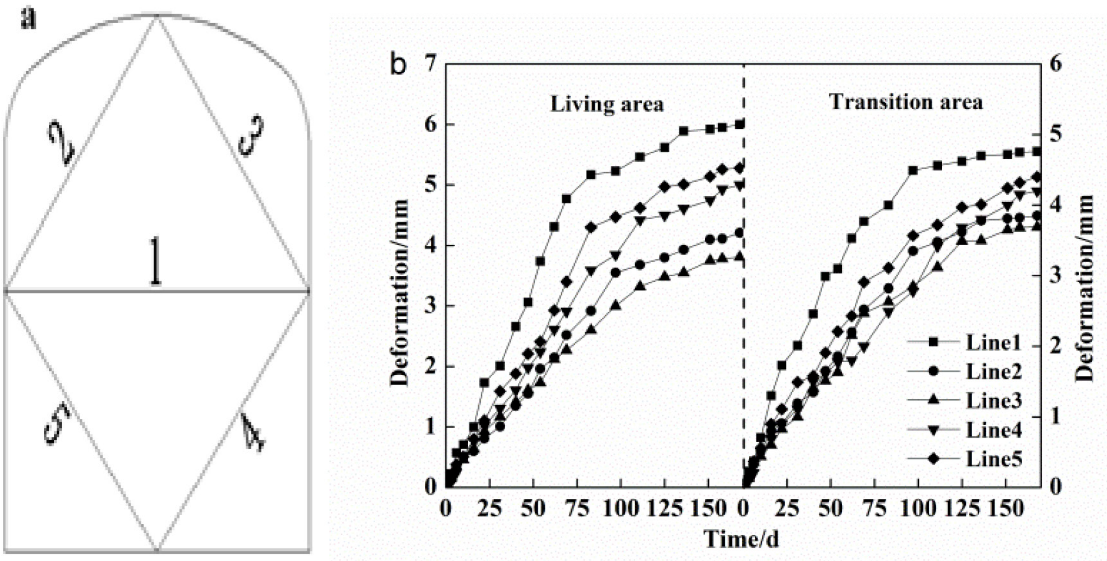


Figure 9. Testing results and line layout of convergence indicator

Table 3. Convergence of refuge station roadway

Testing line	Surviving area		Transition area	
	Convergence volume in total /mm	Convergence rate/ $mm \cdot d^{-1}$	Convergence volume in total/mm	Convergence rate/ $mm \cdot d^{-1}$
1	5.99	0.035	4.76	0.028
2	4.21	0.025	3.85	0.023
3	3.81	0.022	3.69	0.022
4	5.1	0.030	4.2	0.025
5	5.28	0.031	4.41	0.026

in total, with a convergence rate between 0.022-0.035 mm/d in average. The convergence rate and time curve explain that the refuge chamber's roadway remained stability with the convergence rate dropping from less than 0.1 mm/d to below 0.02 mm/d. As a result, the roadway support has been tested effective and stable.

4.2. Manned test of the refuge chamber

In order to verify the reliability of the overall design of the chamber, the 48 h manned test was carried out in the field. The test is divided into three stages: cold test, pressure air supply and compressed oxygen supply. The stability and equipment running status of the various systems of the refuge chamber are tested by simulating different environment. The test procedure and contents are shown in table 4.

The internal environment parameters of the chamber through the test are shown in Figure 10. 1,2, 3 in figure, representing the 3 stages of testing respectively. as we can seen, In the initial passive stage of the test, indoor CO^2, the temperature and humidity increase sharply, while the O^2 is decreased. After opening compressed air of the refuge chamber, the internal environment changes rapidly. And the internal environment parameters of the refuge chamber under different pressure air volume (150~900m^3/h) meet the relevant standards. The noise of the chamber is less than 70 dB and the pressure difference is maintained at 150~450 Pa. In stage of the oxygen by, oxygen bottle, the ice storage air conditioning and the multi - drive air purification device is in a state of intermittent operation. When the CO^2 concentration

Table 4. Experiment process

Stage	Time	Processes	Objectives
1-passive test	8 h	close air compressing, refreshing, temperature & humidity control systems	Test & compare environmental indexes under passive conditions
2-compressed air supply	19 h	Close temperature & humidity control, air refreshing systems Open air compressor, adjust ventilation strength	Test internal environmental indexes at different ventilation levels
3- compressed oxygen supply	21 h	Close air compressor, open oxygen cylinder, air refreshing, temperature & humidity control systems	Test independent operation of chamber equipment

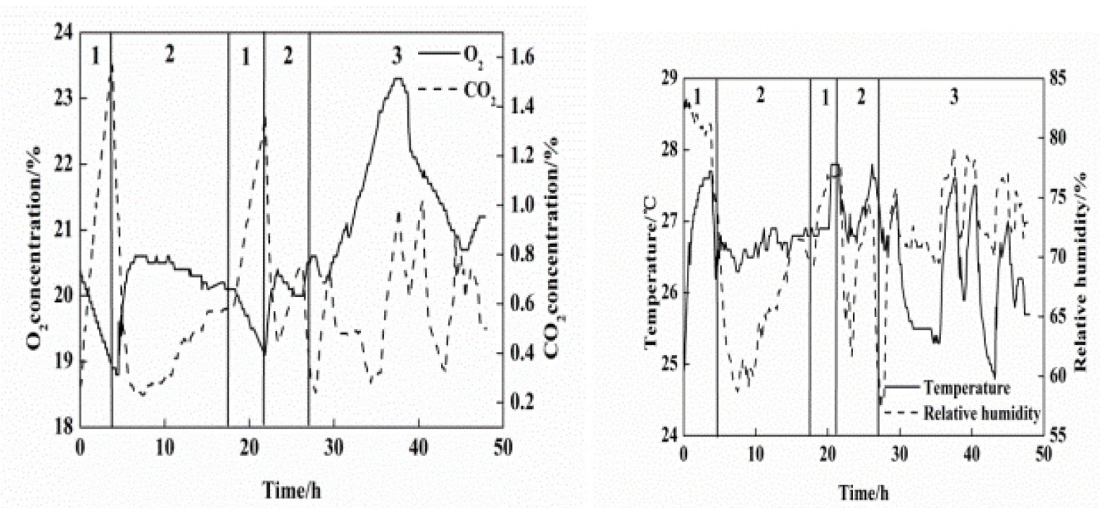


Figure 10. Environmental parameters of refuge station inner

rose to 1%, it was turned on, and turned off at 0.3%. During the test, the ambient temperature is between 24.8~27.6, and the relative humidity is between 69.5~79.1%. The air cleaner is stable, and the CO^2 of different volume fraction has been removed efficient.

5. Conclusions

1) Based on the analysis of the hydrogeological conditions of the return of the Zhuang Gold Mine, the flood protection refuge chamber is located in the middle of -150 m, Between 27 lines and 28 lines. The waterproof pressure of chamber is 1.5 MPa, the waterproof grade is 2, the anti-permeability rating is P8, the rated number is 50, the service life is 5.

2) By using the method of engineering analogy and theoretical calculation, the external protection structure of refuge chamber is studied. The chamber roadway uses three full supports, the total thickness of support for 600 mm; Choose add pleural flat shell waterproof gate, the test can withstand the pressure of 2.0 MPa. The wall length is 2.5 m, and the embedded depth is 150 mm.

3) Design and propose a multi - driven air purification device, and the key parameters were calculated. The formula for calculating the wind speed of ice storage air conditioning is put forward; Based on the static regain method to design the proportioned air ducts, and of space airflow distribution were calculated. The field test designed to meet the requirements.

4) In view of the characteristics of the non-coal mine flooding accidents, the emergency exhaust system and the emergency drainage system are proposed, and the waterproof and exhaust device is designed based on the hydrostatic pressure release device. After the test that the valve is decoupled from the pressure at 9.5~10 KPa; the waterproof internal structure of emergency drainage system is presented, and the drainage pump head is 50 m.

5) By the field test, the chamber roadway shows a full face convergence, and both sides and bottom arch are relatively convergent. The average convergence rate is 0.022~0.035 mm/d. The convergence rate is less than 0.1 mm/d and tends to be 0.02mm/d. The stability of the roadway is good, and the support effect is significantly. The reliability of each system of the chamber was proved by the manned test.The internal key equipment are running stalely, meet the requirements of emergency hedge.

Conflict of interest

The author confirms that this article content has no conflict of interest.

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The economic efficiency of ore fields development technology combination

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