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Theory and Construction of Emergency Refuge System in Underground Coal Mine

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Abstract

According to the improving construction requirements of emergency refuge system in underground coal mine, key issues to be solved in construction of emergency refuge system were listed as follows, safety investment deficiency, lack of legislative guarantee, imperfect evaluation system, unreasonable system structure design, education and training lag. Emergency refuge theory and practice of underground coal mine in mining developed countries were studied by comparison and Induction methods and the results show that good safety refuge system can effectively reduce casualty caused by mine disasters. Methods of building emergency refuge system in underground coal mine were proposed, that were, establish coal enterprises and government and banks trinity of financing model, improve and regulate the cost of accident, sound disaster evaluation index, build emergency rescue system based on refuge facilities, design on the whole system structure. Based on accident causal chain theory, emergency management theory and ideas of modern occupational safety and health management system, financing model of safety investment, emergency rescue model based on refuge facilities and structure of emergency refuge system in underground coal mine were designed, which would provide theoretical basis and mode guidance for improving construction of emergency refuge system in underground coal mine.

Keywords: Mining developed countries; emergency refuge; theory; system construction

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1. Introduction

Coal mine safety system in China are not perfect, and the fatal accidents in coal mine occur now and then. The fatal number of fire accidents, the roof accidents and gas accidents are the highest. Based on statistics of accidents and rescue experience, only less than 10% accounts die at once on the first field because of explosions and collapse, mostly are caused by exhausted oxygen surrounding and high concentrations of toxic and harmful gases and blocked escape routes due to fire and explosions, which form the direct cause of casualties. Mining-developed countries largely constructed emergency refuge system, safety refuge facilities, such as refuge chambers and rescue cabin, were found popular application, and large number case of successful rescue were reported (Zhao lian, Gao zhenyong and Li rifu 2009; Liu chengmi, 2009; Cheng jianwei, Yang shengqiang and Cheng tao ,2010). For the improvement of mine security system and reduction of fatalities in mining, China government enacted Document No. 23[2010] in 2010 requiring the construction of security refuge "six major system" in underground coal mines in 3 years, among these, emergency refuge system was the most difficult. This paper studies theory and construction of emergency refuge system in underground coal mine, analyses key problems existing in construction of emergency system, puts forward solutions for the problems related so as to support the construction of security refuge "six major system".

2. Theory research and development of emergency refuge system in underground coal mine

Research of underground emergency refuge system are more advanced in Canada, South Africa, the United States and other mining-developed countries, in Canada and South Africa, the use of refuge facilities has a long history. Studying theory and practice of emergency refuge in mining-developed countries have reference and practical performance on domestic construction of emergency refuge system in underground coal mine.

In Canada, research of underground emergency refuge system firstly began at Hollinger mine fire accident in 1928, the primary refuge chamber were built by the sealed roadway abandoned with the pressure air pipe providing breathable air through mask. When there had no air cleaning system, subsequently, gases handling system of CO and CO2 were put forward. Currently, in Canada, refuge chamber and rescue capsule are widely used in the way of combination by coal mine, related studies focus on the principle of refuge facility layout, position, the way of breathable air and others, emergency refuge system are required placement by legal means.

The first records were maintained in 1909, the United States Bureau of Mines has recorded that lives have been saved by barricading (Daniel Harrington, 1933). The initial refuge theory in U.S was that, a place of several hundred feet of entries or rooms away from the working face, barricades construction were either made of separation shelter wall built with cement block and timbres or isolated spaces built by hanging separation barrier in the roof and ribs, where should provide as much oxygen as possible and should be made air tight in an attempt to shutout toxic gases, thereby creating a gas-free atmosphere. Trapped miners within could depend upon the breathable air to maintain life while waiting for rescue. In 2006, several major incidents occurred at underground coal mines, resulting in 19 miners fatalities. These highly publicized mine disasters led to new approaches to mine safety and health, some federal legislation, such as the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), highlighted the role of refuge chamber /rescue capsule and emergency communications system in the action of refuge and rescue (United States Public Laws, 2006). Refuge chamber sometimes referred to as refuge alternatives. 2008, emergency refuge system were required into emergency response programmer (ERP) by the Final rule of Refuge Alternatives for Underground Coal Mines. Studies of emergency refuge system at this stage included: selection of refuge chamber /rescue capsule, layout position, escape routes, emergency
communications, training and drill, fresh air, track location, food and other life-sustaining system and the time of system providing independently, the Mine Safety and Health Administration (MSHA) also required that emergency refuge system should be included in the overall design of mining companies (Department of Labor, 2008; S.E. Jalali and M. Noroozi, 2009; Katherine A. Margolis et al., 2011).

Underground coal mining in South Africa accounts for 51%, long wall mining and room-and-pillar mining are main methods. Shelter as blind lane with compressed air emerged in 1970s, while, study for refuge shelter focused on fire and explosion and other disaster. South Africa Standards Authority (SAQA) are responsible for the setting of refuge standards, classify refuge shelter as refuge chamber and rescue capsule, and require that mine operators should include refuge shelter in emergency rescue plan. In refuge chamber, ventilation and drinking water are provided mostly by drilling through the ground, refuge should layout within 750m of the working face in the long wall mining and within 1000m of the working face in room-and-pillar mining. Refuge shelter should be clearly identified, and should have ventilation, telephone, and drinking water and other alternative self-rescuer, etc. Refuge systems of "self-rescuer + relay station" were adopted also by Australia.

Up to 95% of underground mining in China coal, complex storage conditions, intensive employees, and backward emergency refuge system building. On the emergency system construction, more attention was paid to self-contained self-rescuer (SCCSR), while, the refuge chamber and refuge cabin were put little importance. In some coal mines, simple chamber were layout in mining/excavating work face and other areas prone to outburst, where accommodated smaller, with pressurized air, not airtight and could not provide food, water, communications and other life-sustaining things. These primary refuge chambers played limited role and could not meet the life-sustaining needs during an underground mine emergency. The important role foreign emergency refuge system played in mine rescue, promoted the domestic coal mine development of emergency refuge system. Some useful suggestions and methods, such as facilities selection, deployment principles, system structure, product standards and system implementation, were put forward, but could not satisfy the real needs in theory, technical specifications and system construction, etc (Yang daming, 2010; Wang guanchang, 2010; Sun jiping, 2011). Due to most overall designs in coal mine did not include the emergency system, construction of emergency refuge system in underground coal mine has become a difficulty of national "six major system".

Mining-developed countries have built a more perfect emergency refuge system in underground mine, through legislation, technology, training and drill, safety culture and other channels, have completed the transformation of coal mine accident rate from high to low and into the stage of "high-yield and low-casualty", emergency refuge system play an important role in the protection of miner’s life and improvement of emergency rescue capabilities (Wang xianzheng, 2001). According to the data from China State Administration of Work Safety and the Mine Safety and Health Administration (U.S), as table 1 shown, a comparison table of coal mine accidents from 2000 to 2009 in the United States, South Africa and China was created (National Center for International Cooperation in Work Safety, 2010; MASH, 2009).

As table 1 shows, the number of fatality and Million tons mortality was decreased significantly in recent decade, but still much higher than the United States, South Africa. The number of million tons mortality of china coal mine was dropped 84.8 percent from 2000 to 2009, and in 2008, the number of million tons mortality in china was 1.182, however, 42.2 times of the United States while 14.8 times of South Africa. The number of fatality in U.S. coal mine was dropped 42.2 percent, from 38 fatalities in 2000 to 18 in 2009, in the meantime, 35.5 percent decline in South Africa between 2000 and 2008. The number of fatality in china coal mine fell 54.6 percent from 2000 to 2009, but the number of death was still bigger due to large death base, 3215 miners died in 2008, in contrast, 107 times of the United States while 160 times of South Africa. To some extent, these figures indicates that construction of emergency
refuge system in underground in mining developed countries play an important role in reducing fatality of coal mine accidents.

<table>
<thead>
<tr>
<th>year</th>
<th>USA Fatality</th>
<th>Million tons mortality</th>
<th>SOUTH AFRICA Fatality</th>
<th>Million tons mortality</th>
<th>CHINA Fatality</th>
<th>Million tons mortality</th>
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<tr>
<td>2000</td>
<td>38</td>
<td>0.039</td>
<td>31</td>
<td>0.14</td>
<td>5798</td>
<td>5.86</td>
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<td>2001</td>
<td>42</td>
<td>0.04</td>
<td>19</td>
<td>0.08</td>
<td>5670</td>
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<tr>
<td>2002</td>
<td>27</td>
<td>0.027</td>
<td>20</td>
<td>0.09</td>
<td>6995</td>
<td>5.02</td>
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<tr>
<td>2003</td>
<td>30</td>
<td>0.03</td>
<td>22</td>
<td>0.09</td>
<td>6434</td>
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<tr>
<td>2004</td>
<td>28</td>
<td>0.028</td>
<td>20</td>
<td>0.08</td>
<td>6027</td>
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<tr>
<td>2005</td>
<td>23</td>
<td>0.02</td>
<td>16</td>
<td>0.07</td>
<td>5938</td>
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<td>47</td>
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<td>19</td>
<td>0.07</td>
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<tr>
<td>2007</td>
<td>34</td>
<td>0.033</td>
<td>13</td>
<td>0.05</td>
<td>3786</td>
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<tr>
<td>2008</td>
<td>30</td>
<td>0.028</td>
<td>20</td>
<td>0.08</td>
<td>3215</td>
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<td>18</td>
<td>0.018</td>
<td>-</td>
<td>-</td>
<td>2631</td>
<td>0.892</td>
</tr>
</tbody>
</table>

Source: National Center for International Cooperation in Work Safety, Coal Mine Safety State and Accident Cases in the world’s major Coal-producing Countries2010; 2009 Fatalgrams and Fatal Investigation ReportsCoal Mines; 2010 china national safety production situation

3. Key issues to be solved in construction of underground mine emergency refuge system

3.1 safety investment deficiency

Safety investment is the foundation for building security capacity, meanwhile, the material basis of construction of underground mine emergency system. Safety inputs in China coal mine were in a state of long-term debts, only the debts of state-owned coal mine on safety facilities and safety engineering was about 50 billion Yuan (Liu tiemin and Qin huali, 2006). For the benefits generated by safety inputs with a lag and indirect, the enthusiasms of initiative investment on safety of coal mining companies is not high. The lack of investment in the mine safety has seriously slowed the development of underground mine emergency refuge system.

3.2 Lack of legislative guarantee

Constructions of emergency refuge system are enforced by legislation in mining-developed countries, and legislation has a powerful operability. construction of emergency refuge system in domestic is in the initial stage ,there are something ,such as the concept of the national level, system function, the lack of uniform standards on product and maintain, that urgently need to be guaranteed by national legislation. Although there is deadline for "six major system", but slow implementation all over, construction of emergency refuge system needs to enforce through legislation

3.3 Imperfect evaluation system
Emergency refuge system is the physical basis of enhancing capability of coal mine safety. A professional disaster assessment system has been built in mining developed countries and could support the emergency system building. Immature evaluation standards and evaluation methods and imperfect evaluation index of domestic emergency system construction, and the assessment of mine disasters based on experience, are the state of current emergency evaluation system. Deployment of refuge chamber/rescue capsule and design of escape routes usually lack effective data support, affecting the function of emergency system.

3.4 Unreasonable system structure design

The Selection and layout of refuge facilities are the key and difficult of construction of emergency refuge system. Refuge chamber and rescue capsule are only the part of the architecture, need to be compatible with mine-related safety systems, only in this way, can the functions of refuge facilities and refuge resources be fully played. The structure of the emergency system, mission, targets capacity and the standards of refuge facilities are defined in detail abroad. Research and development of domestic mine rescue cabin and refuge chamber and supporting facilities are still at the initial stage, testing of product safety and laboratorial standards aren’t unite, so it is necessary that study of emergency refuge structure should aim at special types of coal mine disasters.

3.5 Education and training lag

Emergency system is not actually omnipotent, life-sustaining functions provided by the system concern with whether the persons trapped can use or not in case of accident self-rescuer, rescue capsule and other refuge facilities, involving the miner’s concept of the emergency system, psychology regulation during emergencies, drill and training proficiency of operating refuge facilities. At present, understanding few of coal emergency refuge system, lack of training and drills for refuge facilities, even not knowing what are the refuge chamber and rescue capsule, thus ,comparing with mining developed countries, there is huge disparity in institutional drill and training for emergency refuge, which will seriously restrict domestic construction of emergency system in underground coal mine.

4. Construction of emergency refuge system in underground coal mine

4.1 Establish coal enterprises, government and banks trinity of financing model

The trinity of financing model can effectively solve the problem of safety investment deficiency on construction of emergency refuge system. that is, as shown in figure 1, the main body of coal mine enterprises, governments and banks all pull together and mutual benefit. Governments support mine enterprises to develop and research through fiscal transfers and research funding and other forms, mine enterprises employ the local persons and offer tax for the local government, which can promote the local social stability. Banks provide loans for coal enterprises, in turn, get interest and operating funds. Coal enterprises may implement special funds of system construction by improving tons of coal / per capita ratio of safety investment, and enterprises own can get profits and production safety. In U.S, cost of emergency refuge system construction of coal mine operators account for 0.4% of annual revenue, this practice can be referenced by China (Department of labor, 2008, P80692).
4.2 Improve and regulate the cost of accident

Through the economic leverage, China government may improve and regulate the compensation standards of coal mine accident casualties and implement strict accountability system so that the coal mine operators can not afford to pay or compensation in excess of safety investment, which will enforce enterprises actively improve the construction of emergency refuge system in underground coal mine. Through reference to practices of mining developed countries such as South Africa, according to annual per capital disposable income, china government can dynamically regulate the minimum standards of mine disaster compensation.

4.3 Sound disaster evaluation index

Ignorance of hazards is the premise of the accident, evaluation of hazards is the basic of deployment and function of emergency refuge system. Some hazard assessment indicators which closely related to emergency refuge system and the functioning, such as coal mine disaster-prone type, coal-rock geological conditions, location and extent of outburst district, roof supporting conditions, roadway engineering factors and gas monitoring data, etc should be included in evaluation index system of construction of emergency refuge system in underground coal mine.

4.4 Build emergency rescue system based on refuge facilities

Construction of emergency refuge system in underground coal mine is only part of perfecting safety refuge system of coal mine, and should be include in the mine emergency rescue plan and integrate with the existing security system. At the same time, mine operators should build new emergency rescue system based on emergency refuge facilities. Based on the ideas of emergency management theory, as figure 2 shown, a new model of emergency rescue system was built. Emergencies, people trapped should quickly be back to the surface along the escape routes in the first, when initial escape impossible, enter the refuge chamber/rescue capsule and wait rescue. Emergency rescue center assess the incident
according to the monitoring information on accidents, start the emergency response plan, mobilize rescue teams and relief goods to implement rescue.

![Emergency rescue model based on refuge facilities](image)

**Fig. 2 Emergency rescue model based on refuge facilities**

4.5 **Design on the whole system structure**

4.5.1 **Basic theory of emergency refuge system design**

Accident causal chain theory suggests that the occurrence of injury is not an isolated event, injury may occur in a moment, but it is results of a series of reciprocal causation events occurred continuously. Disaster accidents are usually caused by ignorance of hazards, invalid or missing refuge system and improper rescue. Life cycle of emergency management is a dynamic behavior, including "prevention, preparedness, response, recovery" stages. Modern occupational safety and health management systems regard that corporate leadership attention, hazard control, people-oriented and document management are the main features of the modern security management, reflecting the thinking of system security. Based on the theory and ideas above, emergency refuge system of underground coal mine was designed.

4.5.2 **Structure of underground mine emergency refuge system**

The structure of underground mine emergency refuge system is divided into four levels. As shown in Figure 3, the bottom layer is guarantee for capital and technology investment, the sign of the emergency system level, the purpose of the layer is to solve the basic issues of historical debts on mine safety input; The third level for the training of miners in their ability on act of rescue, this level can solve the problem of hazard identification and increasing refuge skills, including the use of self-contained self -rescuers, location sensor, gas detector, co detector, communications and other personal protective equipments, and hazard perception based on accident analysis and act of rescue training; Second layer for refuge facilities,
the core and difficult point of the emergency architecture. Second layer include selection of refuge facility type, deployment principles and number, supporting ventilation and communications and other life-supporting systems; Top layer for the operation and maintenance, including interfaces integrated with other security refuge system. Top layer can play a key role on the functioning of emergency refuge system, in the meantime, also is an important stage for the emergency management response and recovery. Connected with emergency management system of government, business and social, the 4-levels structure can mobilize the whole community resources to carry out emergency rescue and refuge system construction.

5. Conclusions

(1) Good emergency refuge system in underground coal mine can increase security capabilities and effectively reduce mortality rate in mine accidents.

(2) Safety investment deficiency, lack of legislative guarantee, imperfect evaluation system, unreasonable system structure design, education and training lag, were the key issues and difficulties of restricting construction of emergency refuge system in underground coal mine.

(3) Emergency refuge system in underground coal mine can be effectively built by the following way: establish coal enterprises and government and banks trinity of financing model, improve and regulate the cost of accident, sound disaster evaluation index, build emergency rescue system based on refuge facilities, design on the whole system structure.

(4) Accident causal chain theory, emergency management theory and ideas of modern occupational safety and health management system could provide theoretical and methodological support for the building underground coal mine emergency refuge system. Financing model of safety investment, emergency rescue model based on refuge facilities and structure of emergency refuge system in underground coal mine, provide a way and mode for building emergency refuge system, which can provide theoretical basis and mode guidance for improving "six major system" construction of emergency
refuge system in underground coal mine. While, emergency system models and building methods have yet to be perfected and revised in practice.

References


