Analysis and Practice of Detection Methods for Goafs in Complex Coal Mines

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Abstract: The structure of the coal mine goaf is complex and its stability is easily affected by many factors. The use of reasonable detection methods to obtain basic data on the development characteristics of the overburden cavities, cracks and separations in the goaf is very important for the development and construction of the goaf. Meaning. The article summarizes and analyzes the currently commonly used goaf detection methods, and compares their applicability and advantages and disadvantages. Finally, the combination of engineering examples verifies the use of drilling core, drilling TV camera technology, and geophysical logging. The method provides a certain reference for the design and construction of the goaf detection project for the reliability of the goaf detection.

1. Introduction
In recent years, the continuous improvement of the level of urbanization has greatly promoted the development of infrastructure. However, in some resource-based cities, due to the shortage of land resources, the land above the old goaf has to be considered. The mining of underground coal resources has caused great damage to the structure of the mined-out area and its overlying rock. Although it can reach a relatively stable state in the long-term physical and mechanical balance process, it is subject to spontaneous combustion, weathering, load, and earthquake under the influence of internal and external factors, there is still the possibility of secondary "activation". Therefore, when engineering construction is carried out above the mined-out area, in order to ensure safety, it is necessary to detect and analyze the mined-out area and its overlying rock structure, and accurately grasp the distribution of its cavities and the development characteristics of cracks. At present, there are many methods of goaf detection technology [1-4], but there is no unified standard and lack of systematic research. Therefore, further research on goaf detection technology has important theoretical and practical significance.

2. The type of goaf
The coal mining methods used in coal mines in my country can be divided into dry mining and water mining. The water mining is based on the whole layer mining of the pillar system. The dry mining can be divided into the wall system and the pillar system. The wall system is also It can be divided into whole layer mining and layered mining, and the pillar system is whole layer mining. According to the statistics of key state-owned coal mines in 1997, dry mining accounted for 98.47%, water mining accounted for 98.47%, water mining only
accounted for 1.53%, dry mining in wall mining accounted for 98.14%, and pillar mining accounted for 1.86%.

2.1. Goaf formed by longwall mining
Longwall mining is a mining method that has been gradually developed and widely used after the founding of New China. According to incomplete statistics, the current wall system mining method has accounted for more than 98% of the total coal mining. The mined-out areas formed by wall mining are widespread in various mining bases across the country, such as Shanxi, Neimeng, Liaoning, Shandong, Hebei, etc. Domestic scholars have done a lot of research on the types of mined-out areas and overlying rock damage caused by longwall mining, and they are relatively comprehensive. In the case of full mining, the overburden damage caused by the longwall caving method is the most serious. When the caving method is used to manage the roof for longwall face mining, the roof rock generally suffers from caving and cracking damage. "Three belts" are formed within the rock formations [5-7] (Figure 1).

Figure 1 The failure structure model of the overlying rock in the old goaf of the long wall

2.2. Mined-out areas formed by short-wall mining
Short-wall mining is mainly divided into hydraulic mining, strip mining and room and pillar mining [8-10].

At present, short-wall unsupported hydraulic coal mining methods are commonly used in water mining wells in my country. The development principles of water mining wells and dry mining wells are basically the same. The goaf formed by water mining is similar to traditional pillar mining. Strip mining is based on calculations in the mining process to mine one and leave one, so that the remaining coal pillars are sufficient to support the weight of the overlying rock, so as to achieve the purpose of reducing the damage of the overlying rock and protecting the surface buildings. Pillar system mining can be divided into room and pillar mining. The difference between room mining and room and pillar mining is that the pillars of the room mining method are left unmined, and the room and pillar mining In the coal method, the coal pillars must be recovered as much as possible after the coal house is mined. Pillar mining was mainly used before the 1970s, especially before the founding of the People’s Republic of China. It is suitable for township coal mines with a low level of mechanization and areas with more complex geological structures. At present, some small coal mines with abundant coal, such as Neimeng, Xinjiang and other pillar-type coal mining methods are also common. The mined-out areas formed by the pillar mining method are sporadically distributed in terms of scope, and exist in Hunan, Guizhou, Neimeng, Xinjiang and other places. The characteristic of the goaf formed by the columnar semi-caving strip mining is that the roof does not collapse during the mining, and after a period of time, the roof does not fully collapse. The characteristics of the goaf formed by the short-wall non-caving strip mining face are that the roof is quite complete, the coal seam is hard, the mining width is small, the mining-retention ratio is small, and the coal pillar can form long-term support.
3. Analysis of goaf detection technology

3.1. Detected objects and key points in the goaf

The structure of the goaf is different from other engineering geological structures. When the mining activity is over, after a long period of further compaction, it can be roughly considered that the goaf has reached a stable state, but after a large amount of field data proves that the goaf although it has been compacted for a long time, there are still a certain number of separated layers, cavities and poorly stable masonry beam structures, different mining methods, roof management methods, goaf sizes, overlying rock properties, etc. This results in a big difference in the structure of the mined-out area and its overlying rock\textsuperscript{[11-12]}.

The main detection contents involved in the goaf detection include the distribution of the goaf and the old kiln, the water filling situation, the distribution of the two zones, the existence and distribution of the separation layer, the development of cracks, the distribution of voids, the distribution of residual roadways, The upper part and surrounding geological structure, the treatment effect of the goaf, etc.

3.2. Several commonly used detection methods

Drilling and geophysical technology are important methods in the goaf detection engineering. At present, the commonly used drilling and geophysical methods in the detection of old goafs are also diverse\textsuperscript{[13-15]}. The following is a brief analysis of several more commonly used methods.

1) Comprehensive logging. Comprehensive logging can form accurate borehole histograms, and accurately obtain the following parameters: 1) Determine the depth, thickness, structure and layer position of the coal (mine) layer and goaf. 2) Divide the borehole lithology section to determine the lithology, depth, thickness and geological age of each rock layer. 3) Determine the lithology, depth, and thickness of the water-bearing layer. 4) Explain the depth and thickness of the broken zone. 5) Provide data on borehole diameter, well inclination and part of the borehole strata occurrence. 6) Study the changing laws of rocks, ore layers, goafs, and geological structures, etc. It is extremely important to supplement and perfect the phenomenon of insufficient core adoption rate caused by factors such as rock collapse and fracture development.

2) Observation of the leakage of drilling fluid. The main advantages of this method are simple, easy to operate, reliable, and practical, and the observation data can better reflect the actual water conduction situation. At present, it is still the main method to obtain the height and characteristics of the collapse zone and the water conduction fracture zone. The main disadvantage of the borehole flushing fluid method is that reliable data cannot be obtained in some areas where the original rock fissures are developed, and the requirements for grasping the timing of observation are relatively high. In addition, this method is slow and expensive, and it is difficult to determine the boundary of the goaf. This method is obviously powerless for large-scale goafs and groups of goafs formed by indiscriminate mining.

3) Color drilling TV system. The biggest advantage of this method is that the integrity of the rock in the hole, the degree of crack development, and the collapse of the goaf can be directly observed through the image, and the core adoption rate caused by factors such as rock collapse and crack development is insufficient. It is extremely important to complement and improve. The system is highly intelligent. During the test, the probe can be raised and lowered automatically, and the full-hole video image can be expanded and spliced in real time. In addition, the real-time moving video of the probe in the hole can be seen in the acquisition state. The operation of the instrument is convenient and stable.

4) CT detection with resistivity method between holes. Inter-hole resistivity CT detection technology is a geophysical prospecting method that uses boreholes in the detection area as a point source emission area or measurement area to obtain the distribution characteristics of the electric field in space. Because the resistivity is directly related to the lithology of the formation, the rock pores and the fluid properties in the pores, the inter-hole electrical imaging is very useful for identifying fractured zones, faults, oil and gas layers, water sources and pollution, etc. The inter-hole electrical imaging It has higher resolution than conventional resistivity exploration methods.
(5) EH-4 conductivity imaging system. The EH-4 conductivity imaging system not only has the stability of active electric detection method, but also has the energy saving and lightness of passive electromagnetic method. It can realize continuous measurement of dense points (connected end to end), continuous observation of EMAP, and minimize static effect. In addition, real-time data processing and display can be realized, and the image is intuitive. It has a wide range of applications, and it can be better used in many aspects such as the distribution of cavities in the goaf, the development of cracks, and the detection of grouting effects.

(6) Nuclear exploration. Nuclear exploration is the use of nuclear physics techniques and methods to measure the changes in the energy and activity of natural or artificial radioactive rays in the earth’s medium to reveal the law of changes in the content or concentration of elements in the earth’s crust, and to explore mineral resources and solutions. Some geophysical exploration methods for geological problems can be used as an important basis for identifying structural fracture zones, mined-out areas, collapsed columns and groundwater resources in terms of mined-out areas.

(7) Seismic exploration. Seismic exploration refers to a geophysical exploration method that uses the difference in elasticity and density of underground media for elastic waves caused by artificial excitation, and infers the nature and shape of underground rock formations by observing and analyzing the propagation law of seismic waves generated by artificial earthquakes in the ground. It can be used for roof damage, spatial distribution, and fracture development in the goaf.

4. Engineering examples
The project area is located above a multi-layer goaf in Jiaozuo City, Shanxi Province. It mainly involves two coal mines. The longwall coal mining method is adopted. The working face is generally 600 m long and 100~200 m wide with temporary hydraulic support. Protection system, the roof collapses naturally, and the recovery rate of the mining area reaches 80~90%. Through the use of drilling core, drilling TV camera technology, and geophysical logging methods, the detection technology of the old goaf was studied.

The principle of dividing the bending zone is to first transform the Quaternary strata into bending zones, and secondly, the bedrock cracks are not developed, and there is no epigenetic longitudinal cracks caused by the influence of mining. The performance has not been damaged, and the development of cracks is rarely seen. When there are cracks, they are limited to local intervals. Combined with mud consumption, logging curves, and downhole TV images, they can be distinguished from fractures in the fracture zone. The fissure zone is mainly divided according to the development degree of the epigenetic longitudinal fissure caused by the influence of the mining, the artificial gamma curve of the comprehensive logging data and the television logging image. The water-conducting fissure zone is mainly divided according to the consumption of drilling mud and the degree of connectivity with the lower caving zone; the caving zone is mainly determined according to the degree of drilling core fragmentation and the position of the drill drop, as well as comprehensive logging data and television logging data.

Table 1 shows the high statistics of the "three zones" of some boreholes.

Figure 2 Core of caving zone
This survey comprehensively analyzes TV borehole wall images, geophysical well data, excavation engineering plan and drilling core and mud consumption data, block dropping, drill dropping, and stuck position data, and it is divided into three zones. Comparing various methods, the results of the main detection results are basically the same, and they have played a role of mutual verification and complementation, and inferred that if a building is built above the project area, the goaf must be reinforced.

| Hole number | depth/m | Bend band/m | Fracture zone/m | Collapse zone/m | Water-conducting fracture zone/m |
|-------------|---------|-------------|-----------------|-----------------|----------------------------------|
| GY-2        | 127.64  | 29.71       | 29.97           | 5.53            | 35.5                             |
| GY-3        | 176.05  | 70.5        | 40.0            | 5.7             | 45.7                             |
| GY-4        | 123.15  | 20.0        | 41.0            | 19.5            | 60.5                             |
| GY-5        | 119.51  | 20.0        | 44.0            | 8.1             | 52.1                             |
| GY-6        | 175.04  | 65.3        | 42.7            | 6.0             | 48.7                             |
| GY-8        | 155.91  | 58.0        | 35.5            | 8.7             | 44.2                             |
| GY-11       | 77.84   | 32.5        | 23.9            | 5.4             | 29.3                             |
| GY-12       | 114.34  | 35.0        | 23.4            | 2.3             | 25.7                             |
5. Conclusion

(1) The structure of the mined-out area is complex, and its stability is greatly affected by internal and external factors. Under normal circumstances, it is difficult to accurately judge its stability. It must be explored and mastered during engineering construction above it. Its internal structure. Summarized the current drilling and geophysical technologies that are widely used in the mined-out area, and briefly analyzed their respective scope of application.

(2) The drilling technology is relatively mature and reliable, but the engineering volume is generally large and it takes a long time. Although geophysical detection technology has the advantages of low cost, fast speed, and high efficiency, it also has certain limitations. Generally, only qualitative evaluation of engineering quality can be carried out. The comprehensive geophysical method is combined with a small amount of drilling detection to detect the same project. Various methods cooperate with each other to give full play to the advantages of various detection methods and obtain the best detection effect and detection accuracy.

(3) Drilling technology and geophysical technology can be better applied in the field of goaf detection, but with the continuous deepening of exploration work, people's requirements for exploration accuracy continue to increase, and the complexity and difficulty of the problems to be solved have increased. A single detection method can no longer meet the requirements of the new situation. Although some methods have obvious advantages, a single method is often difficult to characterize geological anomalies. Therefore, different detection methods should be selected according to the characteristics of different projects to optimize and verify each other.

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