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Abstract

According to regulations of the mining industry in China, it is necessary to carry out gas hazard prevention projects in advance when mining coal seams with gas hazard potential, and gas geological research should be taken as the basic work for optimal design and effective construction of gas hazard prevention projects. Research on coal seam with gas hazard potential have shown that anomalous geological area could be the gas hazard potential area as well, where superimposed tectonic and mining stress field usually results in tectonically disturbed coal and pressured gas. A 4D gas geological research method is used to find out the anomalous geological area and assess its gas hazard potential. The method covers two ranges of gas geological research: fine geological survey and 4D analysis. The former includes a comprehensive prospect of concealed small geological anomalies (such as small fault, small fold and coal thickness variation) by use of gas extraction projects; The latter includes a dynamic forecast of gas hazard potential from space-time perspective based on numerical simulation analysis on additional stress fields around small geological structures beyond coal mining face. Its research benefit the optimal design and effective implementation of gas hazard prevention measures in coal mining panel with high coal and gas outburst potential.

Keywords

gas geology, gas hazard prevention, small geological structure, fine geological survey, 4D analysis

RESEARCH ARTICLE

4D gas geological research on coal seam with gas hazard potential in mining panel

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Abstract

According to regulations of the mining industry in China, it is necessary to carry out gas hazard prevention projects in advance when mining coal seams with gas hazard potential, and gas geological research should be taken as the basic work for optimal design and effective construction of gas hazard prevention projects. Research on coal seam with gas hazard potential have shown that anomalous geological area could be the gas hazard potential area as well, where superimposed tectonic and mining stress field usually results in tectonically disturbed coal and pressured gas. A 4D gas geological research method is used to find out the anomalous geological area and assess its gas hazard potential. The method covers two ranges of gas geological research: fine geological survey and 4D analysis. The former includes a comprehensive prospect of concealed small geological anomalies (such as small fault, small fold and coal thickness variation) by use of gas extraction projects; The latter includes a dynamic forecast of gas hazard potential from space-time perspective based on numerical simulation analysis on additional stress fields around small geological structures beyond coal mining face. Its research benefit the optimal design and effective implementation of gas hazard prevention measures in coal mining panel with high coal and gas outburst potential.

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1. Introduction

In coal mining, there are many hazard potentials, especially gas disasters, such as coal and gas outburst. In China, after the implementation of the Rules for the Prevention and Control of Coal and Gas Outburst, remarkable effectiveness has been achieved in preventing and Controlling gas disasters. However, up to now, the predicting accuracy of coal and gas outburst potential zone is not high [1,2], and the gas disasters have not been completely avoided in China, which has posed a great threat to the safety of operating underground coal mines. The prime cause resulted in the problem is that the local anomalous geological areas, where usually are the gas hazard potential areas as well, could not be discovered before mining coal because they are too small to be found out by use of current exploration methods [3,4]. So, it is difficult to prevent and control gas disasters economically and efficiently based on existing exploring and predicting means.

As is known to all, the gas disasters, such as coal and gas outburst, mostly occur in anomalous geological areas caused by small faults and small folds [5–8]. Therefore, fine investigation of the small geological structures and accurate gas outburst potential zone prediction are the basis of gas disaster prevention and control.

Before the coal mining panel is formed in China, coal mining areas have gone through some geological exploring stages, such as the general exploration of the coalfield, supplementary exploration for well construction and regular exploration for production [9,10]. After all these exploring projects finished, large and medium-sized faults and folds were basically identified. Therefore, their influence can be eliminated by optimizing the coal mining design and

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preventive measures to avoid gas disasters. However, for small geological structures (faults with a drop less than 5 m or less than the thickness of coal seam and folds with a wavelength less than 100 m), it is difficult to identify by use of conventional geological surveys and investigations, even after roadways of coal mining panel have been finished. In addition, under mining influence, it may occur that geological structures react and change their mechanical properties [11,12]. Therefore, with the advance in coal mining face, the gas seepage field will also change dynamically in the coal mining panel, and the gas accumulation and migration in coal seam are restricted by geological factors as well as mining factors [13]. Which means that the gas geological conditions in coal mining panel have the characteristics of spatial–temporal four-dimensional variation. Therefore, a 4D analysis on gas geological conditions in coal mining panel should be carried out as well to improve predicting accuracy of gas hazard potential based on fine investigation of small geological structures.

Here, a 4D gas geological research method is put forward for finding out anomalous geological areas and assessing their gas hazard potential in advance before coal recovery in the mining panel. The method covers a fine survey of small geological structures and a 4D analysis of gas hazard potential around the small geological structures. The fine survey includes a comprehensive prospect of concealed small geological anomalies (such as small fault, small fold and coal thickness variation) by use of gas extraction engineering; The 4D analysis includes a dynamic forecast of gas hazard potential based on numerical simulation analysis of additional stress fields around small geological structures beyond coal mining face.

2. Technical line of 4D gas geological research

The 4D gas geological research follows the technical route listed below (Fig. 1). Firstly, regional gas geological research should be carried out. Through regional gas geological research, some background gas geological information, such as the relationship among geological structures of different sizes and the tectonic position of the targeted coal mining panel, should be known exactly to understand the characteristics of paleotectonic and current tectonic stress fields in the coal mining panel [14]; In addition, the general features of small geological structures in the coal mining panel should be found out based on existing seismic prospecting achievement and practical observation in mining roadways [15]; In particular, it is necessary to determine the general attitudes and mechanical properties of small faults and small folds developed in the coal mining panel [16,17], to provide the research basis for prediction of hidden small geological structures.

Based on the regional gas geological research, the fine gas geological investigation and current stress field observation should be carried out [18]. Through the failure observation of mining roadway and in-situ stress field measurement, the characteristics of current tectonic and mining stress fields should be revealed in the coal mining panel; Through the measurement of gas parameters and dynamic phenomena, the gas occurrence law could be analyzed in the coal mining panel [19,20]; The small gas geological structures concealed in coal mining panel could be exactly explored and forecasted by use of drilling holes for gas extraction, based on the small and medium-sized geological structures exposed by high-precision seismic exploration completed in advance [21,22], and with

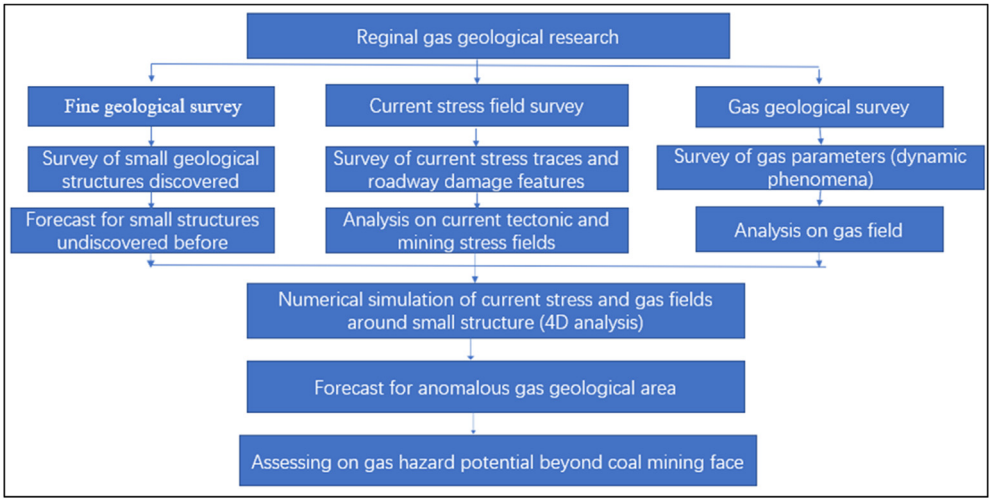

Fig. 1. Technical line of the 4D gas geological research.

the consideration of the general features of small geological structures revealed in the regional gas geological research.

As the gas geological conditions, such as the small structures distribution, gas occurrence characteristics and the current stress fields features in the coal mining panel, have been understood, a 4D analysis could be carried out by use of numerical simulation technology to reveal the additional stress field features and gas abnormalities around small gas geological structures, and then their gas hazard potential could be evaluated [23]. Furthermore, the dangerous area in front of the mining face and the dangerous position at the mining face could be predicted in time.

The two most critical steps in 4D gas geological research are exploring and forecasting small gas geological structures concealed in coal mining panel, and carrying out 4D analysis on their gas hazard potential. The two steps will be explained below in detail with some practical examples.

3. Fine exploration and forecast of small geological structures

In fact, the large and medium-sized geological structures have been found in the coal mining area after some projects, such as regional geological exploration, high-precision seismic exploration, etc. Even the general characteristics of possible small structures, including axial direction of small folds, attitudes and mechanical properties of small faults, have been accurately predicted as well according to the characteristics of tectonic and mining stress fields discovered [24]. The key problem is how to economically and effectively explore and predict the exact location of concealed small geological structures in coal mining panel.

In China, to eliminate coal and gas outburst, extensive gas drainage holes have to be drilled before mining coal to abide by the industry regulations. The drilling hole spacing can be reached within 5 m (Fig. 2). These gas extraction boreholes provide unprecedented engineering conditions for fine exploration and forecast of small geological structure. Therefore, based on these gas extraction holes, this paper puts forward the technical route of exploration and prediction of a concealed small structure in coal mining panel (Fig. 3).

Firstly, the relative coordinate system is established to observe and record parameters of the gas drainage drilling holes; Next, the coordinates of some points, such as the origin point of drilling site, entering and leaving coal seam points of drilling holes, are calculated through mathematical models and error correction (Fig. 4); And then, some maps for predicting small geological structures are made [25,26], including contour map (3D map) of coal seam floor (or roof), isopach map of coal seam, trend and residual error map of coal seam attitude [27]; Furthermore, the anomalous areas (zones) of coal seam could be found out based on these predicting maps; Finally, the type, location and attitude of concealed small geological structures could be forecasted in coal mining panel with the reference of some information [28–30], such as the dynamic phenomena observed during drilling operation, the distribution and general features of small geological structures discovered in the coal mining area.

The following is an example of predicting small concealed faults in coal mining panel based on gas extraction boreholes (Figs. 5–9). The predicting project was carried out at Mining Panel 14171 in a coal mine in Henan, China, where the average thickness of the coal seam is 4.8 m. A concealed fault with an attitude 45°∠39° and a drop of 1.5 m was successfully predicted at 50 m in front of the coal mining face in the project.

4. 4D analysis

Because there is a common phenomenon that there is gas accumulation, concentrated stress and tectonically deformed coal around small geological

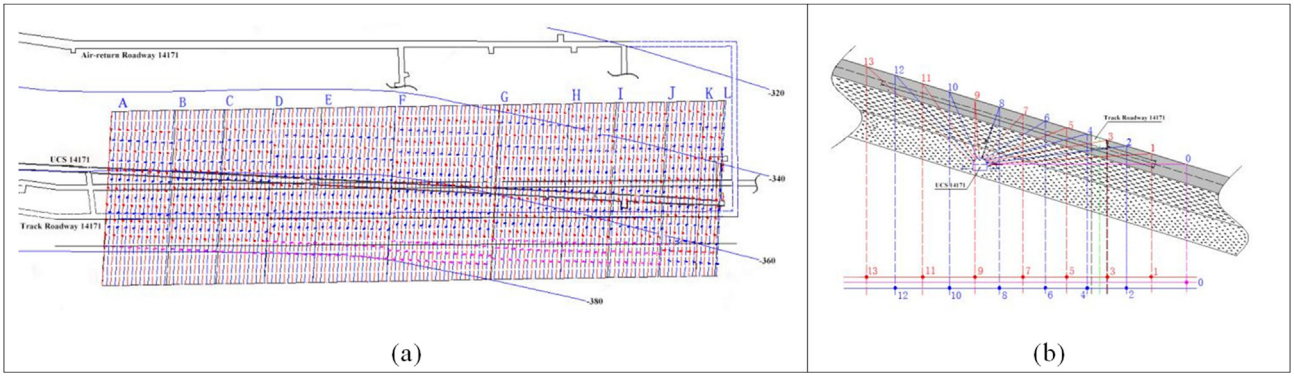

Fig. 2. Conventional arrangement of gas drainage holes in coal mining panel. (a) Plan map (b) Section map A.

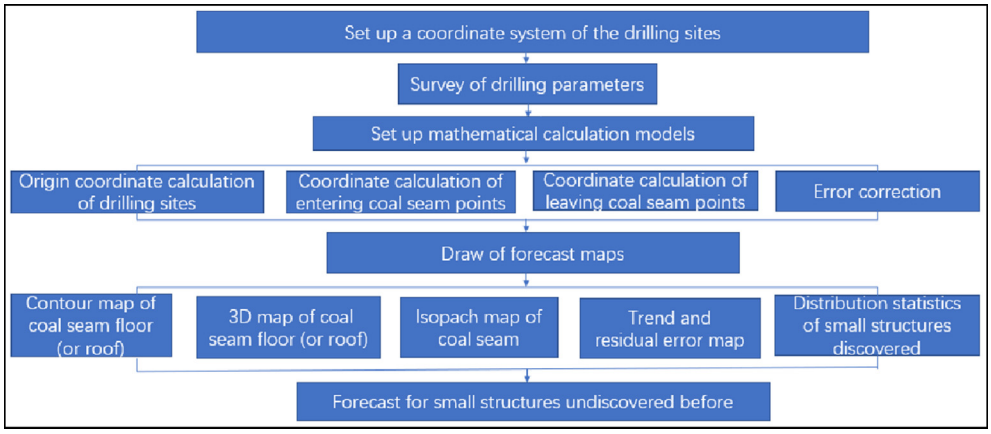

Fig. 3. Technical route of small fault forecast based on gas drainage holes.

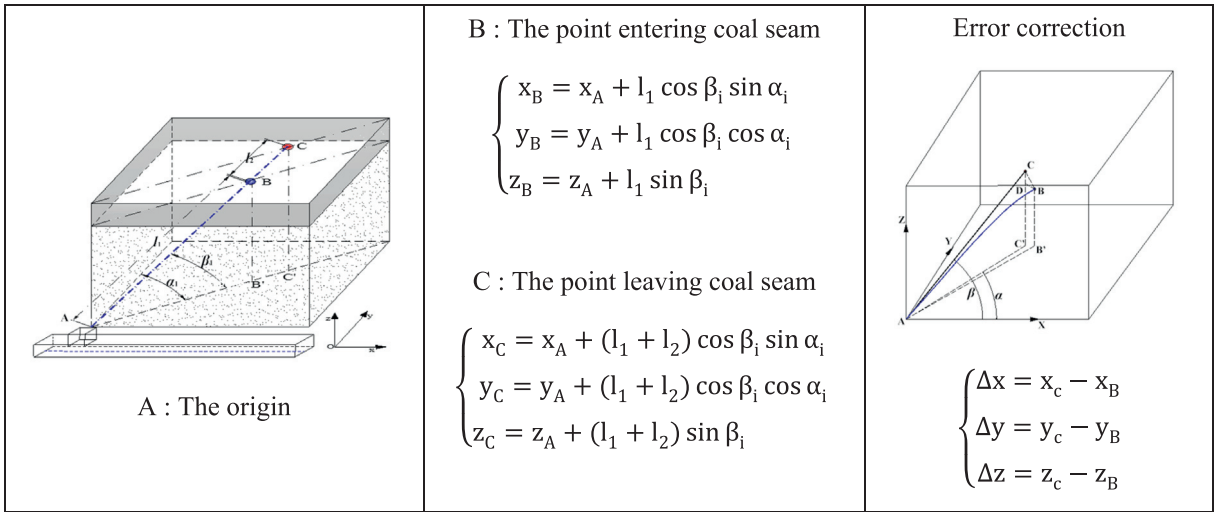

Fig. 4. Calculation of key points for a drainage hole.

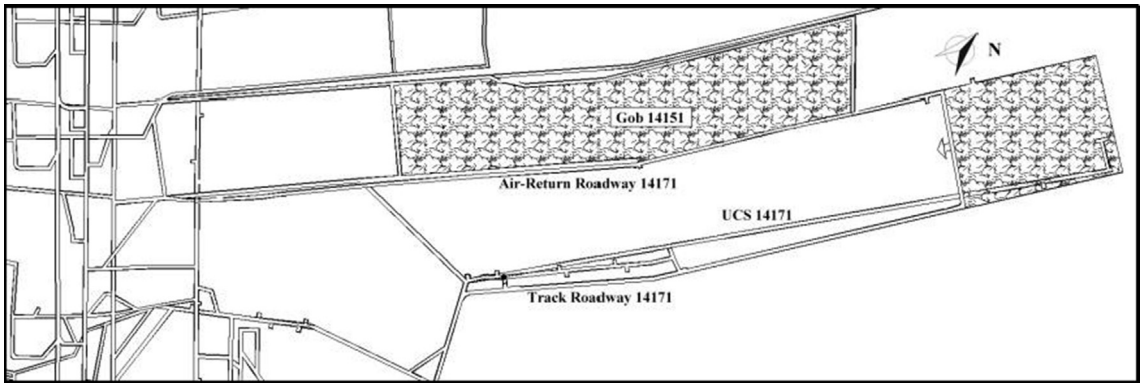

Fig. 5. Mining panel 14,171 of a coal mine in China.

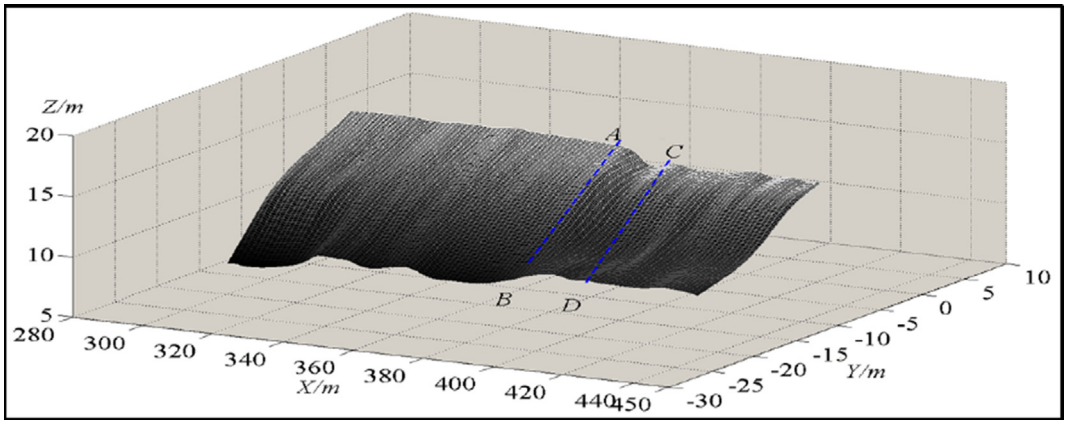

Fig. 6. 3D map of coal seam floor.

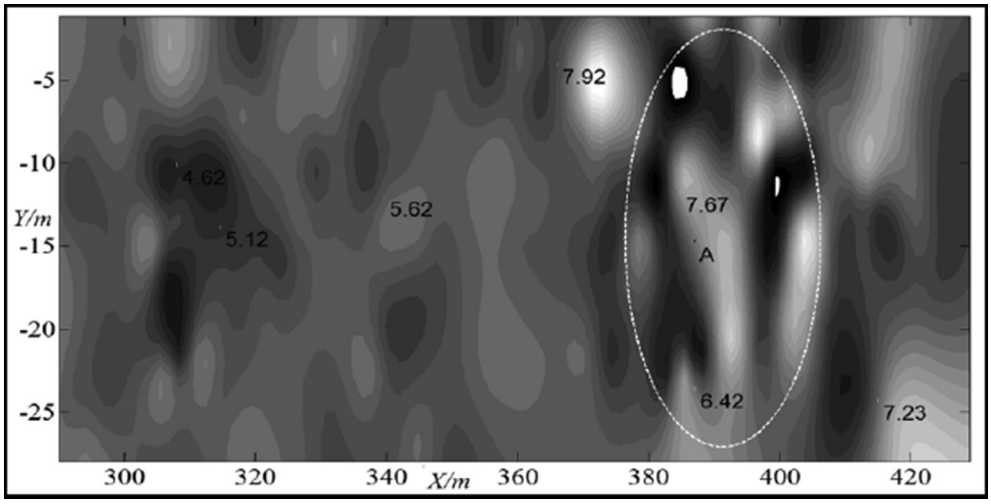

Fig. 7. Isopach map of coal seam.

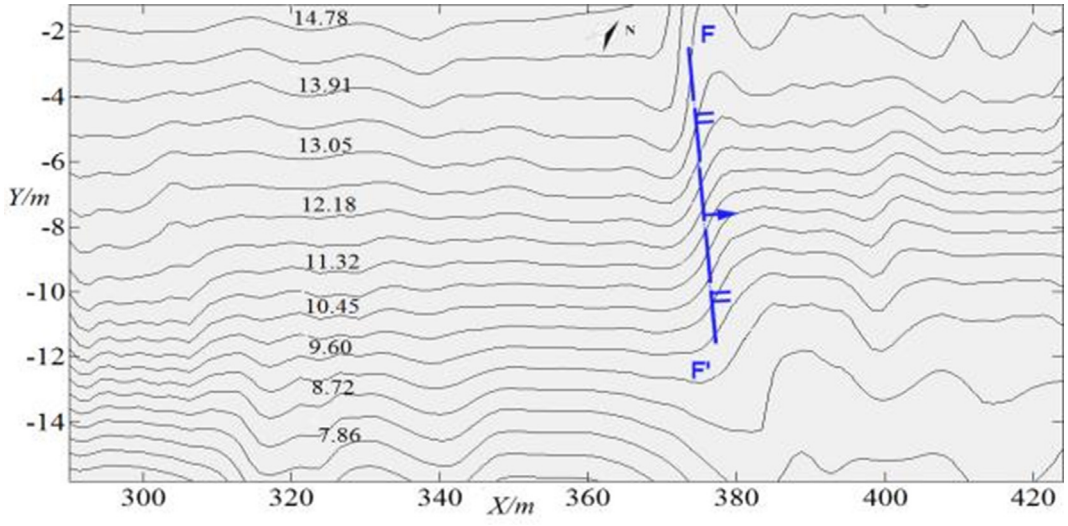

Fig. 8. Contour map of coal seam floor.

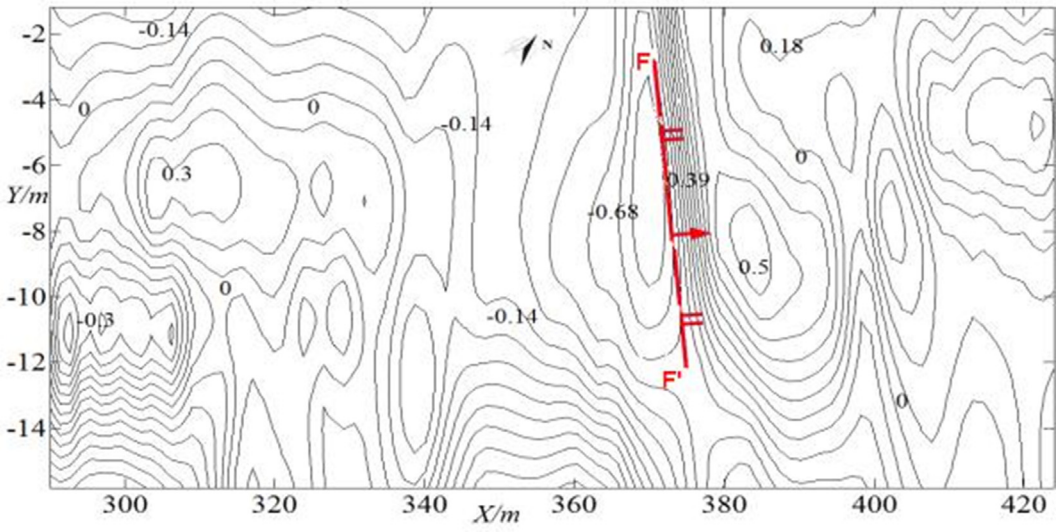

Fig. 9. Third residual error map of coal seam floor.

structures, there could be high gas hazard potential near them in a coal mining panel. In the process of coal mining, with the continuous advance of the working face, the mining stress field and the additional tectonic stress field of small geological structure are superimposed on each other in front of the working face [31,32], which increases gas disaster risk in coal mining panel. Therefore, to optimally design and efficiently build preventing projects against gas disaster, a 4D analysis of the gas hazard potential of small geological structures in front of the working face should be carried out based on the fine geological survey in coal mining panel. The 4D analysis follows the technical route listed below (Fig. 10).

Firstly, based on the fine exploration and forecast of small geological structures, the dynamic simulation of stress fields (gas fields) near to the small structures in front of working face are carried out by use of numerical simulation technology to understand the characteristics of the small structures; And then, the prediction and evaluation of gas geological anomaly area (zone) and gas disaster risk around the small structures could be made with gas parameter measurement and dynamic phenomenon observation. Following is a 4D analysis example around a small fault with 1 m drop at a coal mining panel in Henan, China (Fig. 11).

There is a small oblique fault beyond mining face. It could result in a local anomalous gas geological area, where additional tectonic stress, tectonically disturbed coal and pressured gas could appear together (Fig. 11a); Based on the 4D analysis, the additional tectonic stress field of the small fault doesn't superimpose with the mining stress field beyond 30 m ahead mining face. However, a superimposed stress field has appeared around the track roadway (Fig. 11b); An obvious superimposed stress field around the small fault appears from 21 m ahead mining face (Fig. 11c), and the most dangerous location could be at the middle of the mining face near to the small fault while recovering coal (Fig. 11d).

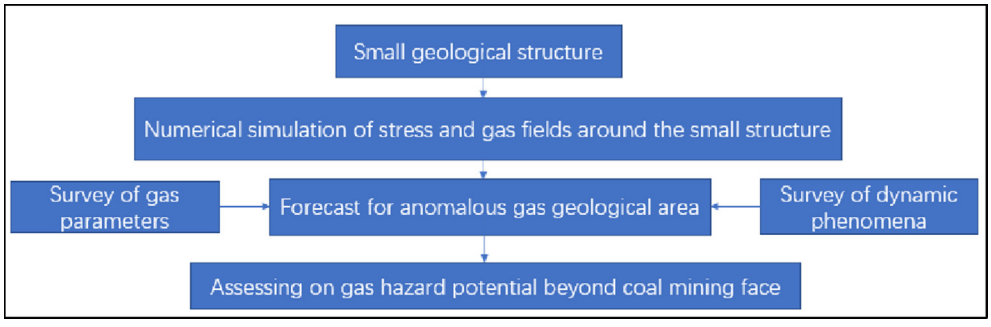

Fig. 10. Technical route of 4D analysis.

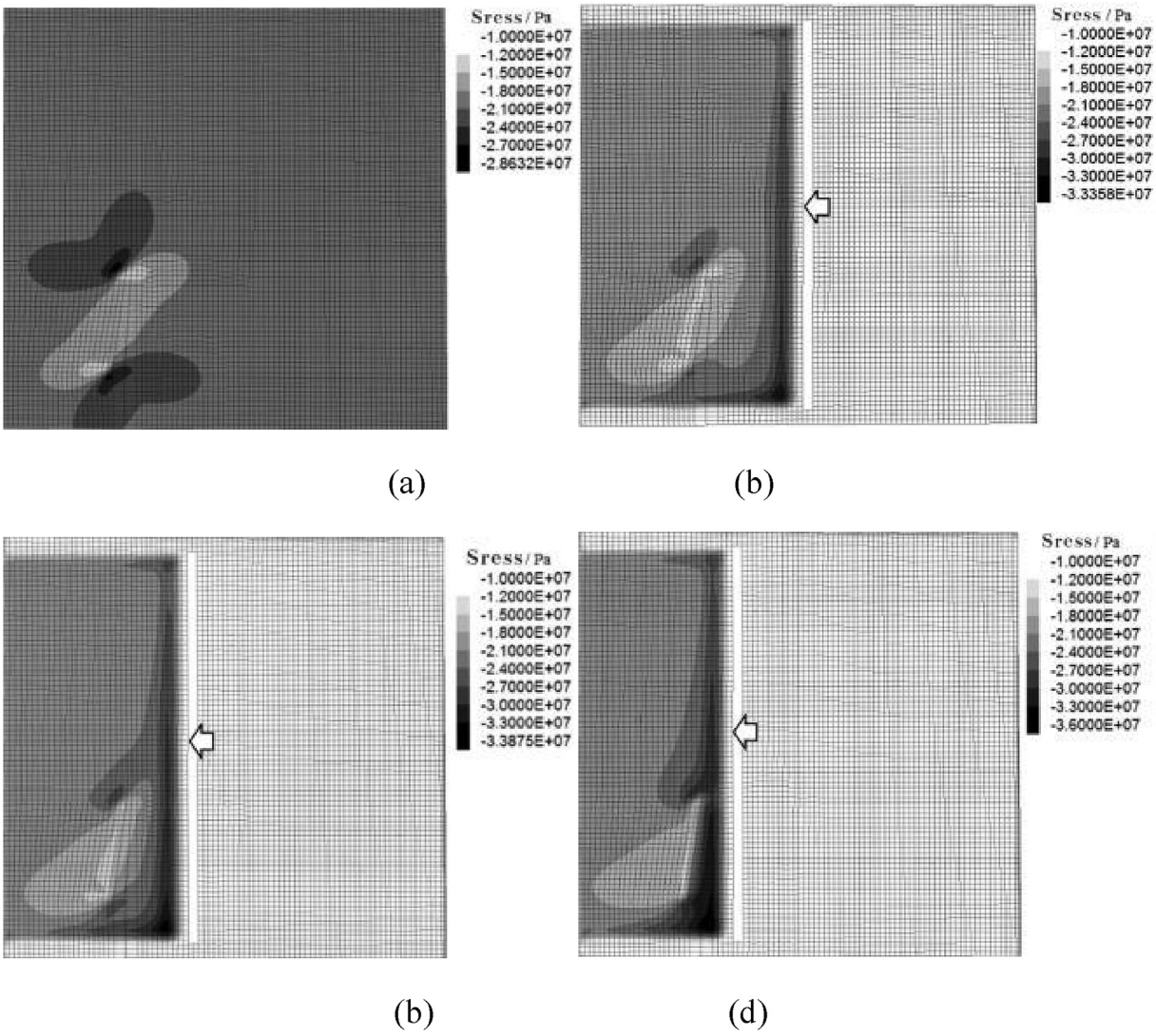

Fig. 11. Numerical simulation of stress fields around a small fault (a) Original tectonic stress field before mining (b) Stress field around the fault 30 m ahead mining face(c) Stress field around the fault 21 m ahead mining face (d) Stress field around the fault 12 m ahead mining face.

5. Conclusion

Since small geological structures could result in the local anomalous gas geological area, it is very important to find them in advance before recovering coal in the mining panel. It could be an economic and efficient way for the fine survey on small geological structures to be carried out using gas drainage holes.

As soon as the small geological structures have been found before coal recovery, the gas hazard potential areas (zones) could be forecasted in time while recovering coal. Furthermore, a numerical simulation of stress and gas fields around the small geological structures could make the forecast more certainly with some other gas geological information, such as abnormal coal thickness variation, dynamic phenomena, unusual gas parameters or gas emission rate.

4D gas geological research could benefit the optimal design and effective implementation of gas hazard prevention measures in coal mining panel with high gas hazard potential.

Conflicts of interest

The authors declare no conflict of interest.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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