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Abstract: The rational assessment and determination of strata and surface influence range of underground coal mining is straightly associated to the safe production of the wellbore, the reuse of mine land and the regional development. With the depth of coal mining in the world increasing, if the boundary curve of strata and surface movement continues to be considered as a straight line, there will be a great deviation from the real situation, which will seriously waste the land resources of mining area. To solve this issue, the numerical simulation methods were employed to investigate the stratum and surface movement boundary curves of deep caving and backfilling mining in this paper. The findings indicated that: 1) The strata and surface movement boundary of deep caving and backfilling mining were all curves, and they were in accordance with the exponential function, but the influence range of strata and surface movement of deep different mining methods were different; 2) The backfilling rate of deep backfilling mining had an influence on movement boundary of strata and surface. With the backfilling rate decreasing, the influence range of strata and surface movement boundary were increased. 3) The research results were applied to a case in order to confirm the new methods for determining the influence range of strata and surface movement of deep mining. Example application shows that the safe production of the wellbore not only can be guaranteed, but also the reuse area of the mine field can be enhanced.

Key words：deep mining；internal movement boundary of overlying strata；surface subsidence range；deep backfilling mining；mine land reuse

1 Introduction

Coal plays an important role for the energy consumption in the world, which can promote the world economic development and social progress. However, the negative consequences of ecological environment of coal extensive exploitation also seriously limit the harmonious development of social economy, especially the surface subsidence formed by underground mining truly disturbs the land resource utilization and urbanization (Lechner et al. 2016; Bian et al.2006; Guo et al. 2019; Jing et al. 2018; Lamich et al. 2016; Liu et al. 2019; Marschalko et al. 2015). Thus, the reasonable evaluation and determination of influence range of underground coal mining is directly connected to the reuse of mine field, urbanization and regional development.

Currently, considerable scholars have conducted in-depth research on the influence range of rock strata and surface movement in underground shallow coal mining (Guo and Wang 2014; Zhou 2014; Muller and Preusse 2018; Kratzsch 2012; Liu and Cheng 2019), and proposed the geometric method for determining the influence range of underground coal mining based on boundary angle for practical engineering applications, which have been extensively applied in coal pillar design and surface stability evaluation and wellbore safety assessment (He et al. 1991). Also, the partial researches concluded that the internal movement boundary of the rock strata was not e straight line but a curve based on the practical measurement and simulation. For instance, based on the measured data from the roadway in Yangquan Coal Mine, Wang suggested that the internal movement boundary of rock strata was the curved line that was slow in the bottom and steep in the top (Wang 1994). Zhou studied dynamic movement characteristics of internal rock strata through using the method of similar material simulation and theoretical analysis, and attained the internal movement boundary of rock strata was s curve close to the “S” shape (Zhou 2014). The above research findings have laid solid foundation for determination of the influence range of strata and surface movement in shallow underground coal mining.

The history of coal mining has been for hundreds of years around the world, and the long-term, large-scale and high-intensity mining also has lowered the global coal resource reserves. Moreover, the mining depth of coal resource is gradually from open air, shallow (300-800 meters) to deep (more than 800 meters). Taking China that is the largest coal producing and consuming country as an example, there are currently 141 coal mines with the mining depth exceeding or about 800 m (Lan et al. 2016; Guo 2017), and 47 coal mines exceeding or about 1000m. Besides, the state-owned key coal mines located in Shan, Henan, Anhui, Hebei and other providences have an average mining depth of more than 600m. These mine will generally enter the deep mining stage in the next 100 years according to the average speed of 10-25m/a in mining depth. Therefore, the deep mining is trend of coal resources mining in the world (Malinowska and Hejmanowski 2016; Ye et al. 2018; Ranjith et al. 2017; Guo et al. 2016). Yet, there is no research on the influence range of rock strata and surface movement in deep different mining methods, which leads to lack of scientific basis for field reuse in deep mining areas. Deep mining owns the "three great and one disturbance" phenomenon relative to the shallow mining, that is, deep mining is carried out under great ground stress, great low-temperature, great karst water pressure and mining disturbance, so the influence range of strata and surface movement will be significantly different compared with shallow mining. Therefore, it cannot determine the influence range of deep mining through straightly using the boundary angle of shallow mining. Also, with the increase of mining depth, if the internal movement boundary of rock strata is considered as a straight line, the influence range of underground coal mining will be very large, which will extremely waste mine land resources.

Thus, it is urgent to conduct research on influence range of rock strata and surface of deep different mining methods, and provide the scientific basis for the rational use of mine site. Based on this, this paper analyzed the defects of the current methods for determining the influence range of rock strata and surface in deep mining, and utilized numerical simulation methods to investigate the movement and deformation boundary of deep caving and backfilling mining. Also, this work applied the proposed method to Pingdingshan No. 12 Coal Mine to verify its effectiveness and reliability. The research findings have significant theoretical and practical meanings for field reuse, urbanization construction and regional development in deep mining.

2 The existing determination method of influence range of rock strata and surface movement and its defects.

2.1 Determination method of influence range of rock strata and surface in deep mining

Presently, the influence range of rock strata and surface in deep mining was determined by the boundary angle of bedrock and loose layers (He et al. 1991). Assuming a rectangular working face with endpoints A, B, C, D (Fig. 1). The profile views of I-I' and I-II" along the tendency and trend of coal seam are taken through the center O of the working face to determine the movement range of rock stratum and surface caused by underground coal mining. If it is known that the bedrock boundary angle of downhill direction of coal seam in the area is γ_0, the bedrock boundary angle of uphill direction is β_0, the bedrock boundary angle of the strike direction is δ_0, the boundary angle of loose layer is θ_0, the dip angle of coal seam is α, and the vertical depth at the center of working face is H_0, and then the influence range of strata and surface caused by the mining of working face can be attained.

First, for the trend profile view of I-I', the bedrock boundary angle β_0、γ_0 of uphill and downhill direcetion of coal seam is drew from the c_0 and d_0, respectively the determine the range of c_1 and d_1 on the contact surface of loose layer and bedrock. For the strike profile view of II-II', the bedrock boundary angle δ_0 can be drew from the a_0 and b_0, and then the range of a_1 and b_1 can be obtained on the contact surface of loose layer and bedrock (Fig. 1). Then, for the trend profile view of I-I', the boundary angle of loose layer θ_0 is drew along the uphill and downhill direcetion of coal seam from c_1 and d_1 to get the surface boundaries of c_2 and d_2.

On the strike profile view of II-II', the boundary angle of loose layer θ_0 is drew from a_1 and b_1 to attain the surface boundaris of a_2 and b_2 (Fig. 1). Ultimately, based on the projection geometry method, the influence scope of rock strata and surface can be achieved.

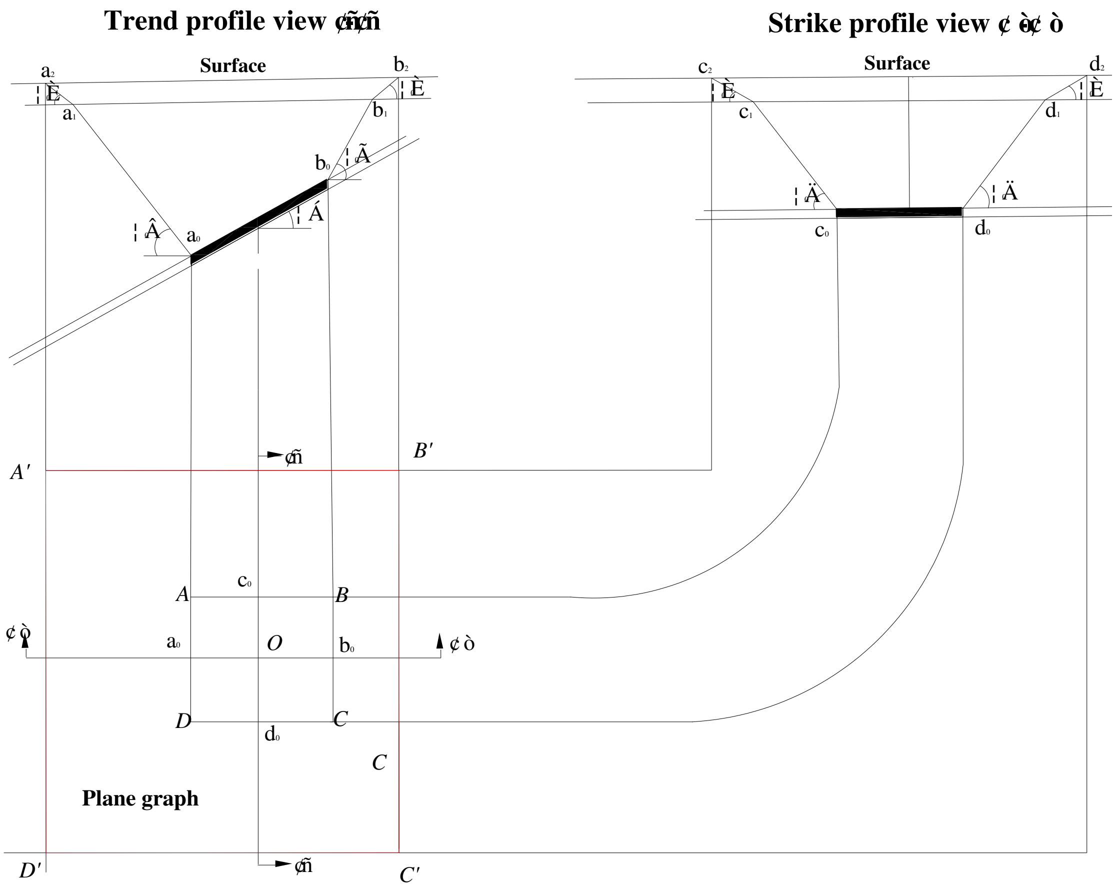

Fig.1 Existing methods for influence scope determination of rock strata and surface in deep mining

2.2 Defects of existing methods

The method for influence range determination of rock strata and surface of deep mining is obtained according to shallow mining. The presented method is proposed on the assumption that influence boundary of rock strata and surface are straight lines, see the red line in Fig .2. However, numerous scholars have computed from the measured data and similar material simulation findings that the internal movement boundary of rock strata is a curve rather than a straight line (Wang 1994; Zhou 2014). During shallow mining, the influence range of rock strata and surface obtained by the straight line is not much different from the actual situation. Under the condition that the precision requirement is not great, the engineering practice can be essentially satisfied.

Nevertheless, when deep mining happens, because of the increase of mining depth, the difference between the rock stratum and surface impact range obtained by the straight line hypothesis will be larger than the practical situation, which will cause a large difference between the assessment of influence scope of rock strata and surface and the actual situation in deep mining, and thus seriously influencing the mine land usage and internal structures construction in rock strata.

Thus, to acquire the more accurate assessment of strata and surface influence range of deep mining can be more consistent with the actual situation and meet the engineering practice requirements, it is necessary to investigate the curves and functions of movement boundary of rock strata and surface in deep mining. This will offer the more scientific and reasonable basis for influence range assessment of rock strata and surface of deep mining.

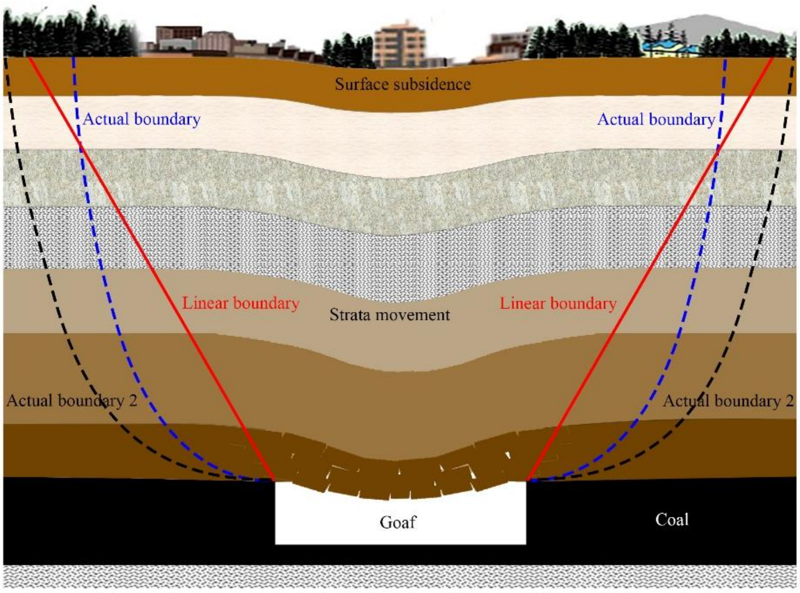

Fig. 2 Comparison between straight line hypothesis of movement boundaries of rock strata and surface and possible practical influence boundaries in deep mining

3 Investigation of movement and deformation boundary of overburden internal in deep mining with different mining methods

From the above analysis, because of the research lack on the movement boundary of overburden and surface in deep mining, the assessment result of influence range is quite different from the actual situation, which can utterly influence the reuse of mine site and structure construction in stratum internal. To resolve the issue, according to a mining area in China, this section applied the numerical simulation to study the curved shape of movement boundary of rock strata and surface of deep mining, and then revealed the movement boundary of rock stratum and surface of deep caving and backfilling mining.

3.1 Building of numerical model

The numerical model was built from the 22-13 borehole data of Pingdingshan 12 Coal Mine. The mining coal seam owned a depth of 833 m, an average mining thickness of 3.4 m and an average inclination of 6°, which was a near horizontal coal seam. The overburden was mainly consisted of mudstone and sandstone and argillaceous sandstone, and the loose layer was thin. Considering that the whole overburden movement in deep mining was the process of coupling of discrete medium and continuous medium, the numerical simulation method according to the discrete-continuous medium coupling has been applied to simulated rock strata and surface movement in deep caving and backfilling mining. The discrete element software PFC2D was employed to simulate the part rock layer above goaf roof, and the overburden was simulated by the finite difference software FLAC2D. The motion calculation code was written by the software built-in FISH language, and the data interface was provided by the two software to achieve the exchange of force and speed, see Fig. 3.

The PFC2D simulated the bottom of the coal seam to the top stratum, with the height of 77.4 m and the width of 2230 m in the numerical model. From the bottom to the top, the fixed wall was 10 m, the coal was 3.4 m, the mudstone was 14 m, the medium sandstone was 15 m, the mudstone was 20 m, the medium sandstone was 4 m, and the mudstone as 7 m, and the sandy mudstone was 14 m. The top of the sandy mudstone was the motion calculation interface, which was constrained by the FLAC transmission speed and the horizontal movement constraint of the left and right sides and bottom, and vertical movement restraint the bottom. The contact between the PFC simulated stratum particles was set as the parallel bonding model with strength features, and the particles between the simulated solid backfilling bodies were set to be linear elastic model that only affected by the friction. The specific rock strata and mechanical parameters are shown in Table 1.

Table 1 Strata parameters in PFC model

Stratum	Density (kg/m^3)	Friction coefficient u	Contract modulus E (Gpa)	Normal-cut modulus ratio K	Bonding modulus Ep （Gpa）	Bonding modulus ratio Kp	Bonding strength t (MPa)	Bonding cohesion c (Mpa)	Bonding friction angle Φ（°）
Coal	1330	0.2	1.0	1.5	1.0	1.5	15	14	26
Mudstone	2400	0.2	1.5	1.5	1.5	1.5	25	24	34
Medium sandstone	2480	0.2	2.5	1.5	2.5	1.5	35	34	34
Sandy mudstone	2450	0.2	2.5	1.5	2.5	1.5	25	24	34

Filling body	2000	0.2	1.0	1.0	-	-	-	-	-

FlAC2D was applied to simulate the remaining upper strata, with the model size of 2230 m × 759 m, the width of each cell fixed at 10 m. The model was divided into 223 × 87 unit bodies. The bottom boundary of the model was restrained via the PFC transmission force. Both sides of the model are constrained by horizontal movement, and the top was free boundary, and all the elements were Moore-Coulomb models. The specific rock strata and mechanical parameters are shown in Table 2.

Table 2 Strata parameters in FLAC model

Rock stratum	Thickness （m）	Density (kg/m^3)	Internal friction angle Φ（°）	Cohesion c (Mpa)	Bulk modulus (Gpa)	Shear modulus (Gpa)
Surface soil layer	8	1800	10	0.7	0.03	0.01
Mud interbed	65	2310	30	2.0	2.3	1.65
Medium sandstone	52	2380	35	2.5	2.78	2.08
Sandy mudstone	6	2410	30	2.2	2.68	1.84
Mudstone	25	2360	30	1.8	1.79	1.23
Sandy mudstone	84	2400	30	2.2	2.68	1.84
Mudstone	13	2360	30	1.8	1.79	1.23
Sandy mudstone	19	2400	30	2.2	2.68	1.84
Medium sandstone	19	2400	35	2.5	2.78	2.08
Mudstone	10	2360	30	1.8	1.79	1.23
Sandy mudstone	29	2400	30	2.2	2.68	1.84
Mudstone	7	2360	30	1.8	1.79	1.23
Medium sandstone	15	2400	35	2.5	2.78	2.08
Mudstone	8	2360	30	1.8	1.79	1.23
Fine sandstone	34	2480	37	2.5	2.78	2.08
Mudstone	10	2360	30	1.8	1.79	1.23
Sandy mudstone	14	2400	30	2.2	2.68	1.84

Mudstone	13	2360	30	1.8	1.79	1.23
Medium sandstone	5	2480	37	1.8	1.39	1.04
Mudstone	34	2400	30	1.2	0.9	0.6
Medium sandstone	20	2480	37	1.8	1.39	1.04
Mudstone	6	2400	30	1.2	0.9	0.6
Fine sandstone	13	2480	39	1.6	1.39	1.04
Mudstone	42	2400	30	1.2	0.9	0.6
Medium sandstone	18	2480	37	1.8	1.39	1.04
Mudstone	40	2400	30	1.2	0.9	0.6
Mud interbed	27	2380	30	1.5	1.34	0.92
Fine sandstone	14	2480	39	1.6	1.39	1.04
Mudstone	88	2400	30	1.2	0.9	0.6
Medium sandstone	21	2480	37	1.8	1.39	1.04

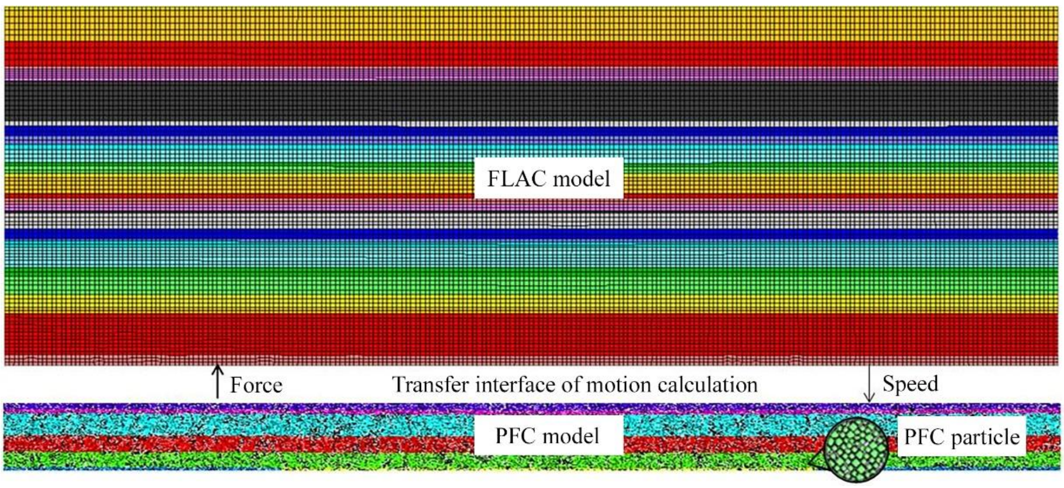

Fig. 3 Numerical model of rock strata and surface movement of deep mining

3.2 Internal movement and deformation boundary of rock strata in deep caving mining

To investigate the boundary shape of internal movement and deformation of rock strata in deep caving mining, a numerical model of stratum movement of deep mining was built. Also, to more directly exhibit the internal movement and deformation boundary of rock strata in deep caving mining, the boundary map of rock strata and surface movement in deep caving mining is made according to the simulation results (the subsidence 10 mm is the standard), as shown in Fig. 4. Considering the symmetry of movement boundary of rock strata and surface, only the movement boundary of rock stratum and surface on the right side in deep caving mining are shown here.

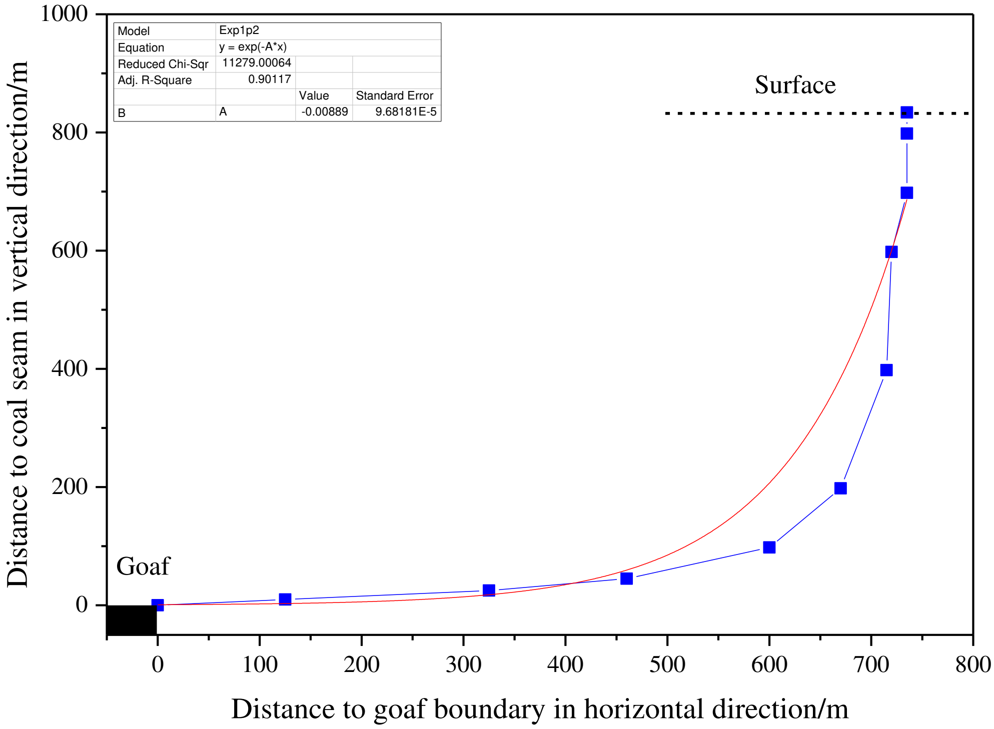

Fig. 4 Movement boundary of rock strata and surface in deep caving mining

From Fig. 4, it can be known that the movement boundary of rock stratum and surface in deep caving mining was a curve rather than a straight line. In the depth of 100 m near the goaf, the curve altered slowly; When the distance was more than 100 m from the goaf on the vertical direction, the curve changed steeply. Meanwhile, the movement boundary curve of rock stratum and surface of deep caving mining was fitted, and the fitting outcome indicated that the movement boundary of rock stratum and surface in deep caving mining consisted with the exponential function $y = \exp(-A * x)$, and the fitting degree $R^2 = 0.90$. The specific value of A was correlated to the properties of regional strata.

3.3 Movement boundary of rock stratum and surface in deep backfilling mining

1) Stratum and surface movement boundaries of deep backfilling mining

To learn movement boundary of rock stratum and surface of deep backfilling mining, a numerical model of stratum movement in deep backfilling mining was built based on Section 3.1, and the design backfilling rate was 80%. Also, to more straightly show the movement and deformation boundary of rock strata and surface in deep backfilling mining, the boundary map was plotted (the subsidence 10 mm as the standard) according to the simulation findings, as shown in Fig. 5.

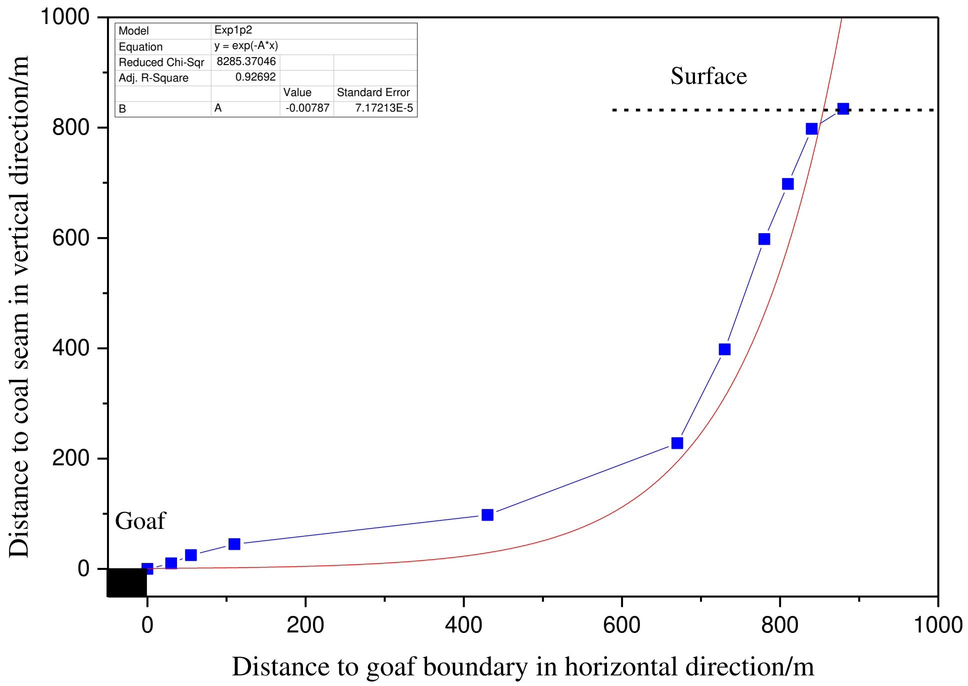

Fig. 5 Movement boundaries of rock stratum and surface in deep backfilling mining

For Fig. 5, it suggested that the movement boundary of rock stratum and surface in deep backfilling mining was curve line and not straight. For the depth of 100 m near the goaf, the curve altered gently; When the distance was more than 100 m from the goaf on the vertical direction, the curve changed noticeably. Meanwhile, the curve fitting was adopted to the movement boundary of rock stratum and surface of deep backfilling mining. The fitting outcomes gave that the movement boundary of rock stratum and surface of deep backfilling mining was also consistent with the exponential function $y = \exp(-A * x)$, and the fitting degree $R^2 = 0.93$. The specific value of A was also correlated to the feature of regional stratum.

2) Movement boundaries of rock stratum and surface under different backfilling rates

To acquire the movement boundary shape of rock stratum and surface under different backfilling rates in deep backfilling mining, the simulation schemes with backfilling rates of 90%、85%、80%、75% and 70% were designed. To see the movement and deformation boundary of stratum with different backfilling rates in deep mining, the influence of backfilling rate on stratum and surface movement boundary was analyzed. In Fig. 6, the stratum and surface movement boundary map of deep backfilling mining under different filling rates (the subsidence 10 mm as the standard) was drawn based on the simulation findings.

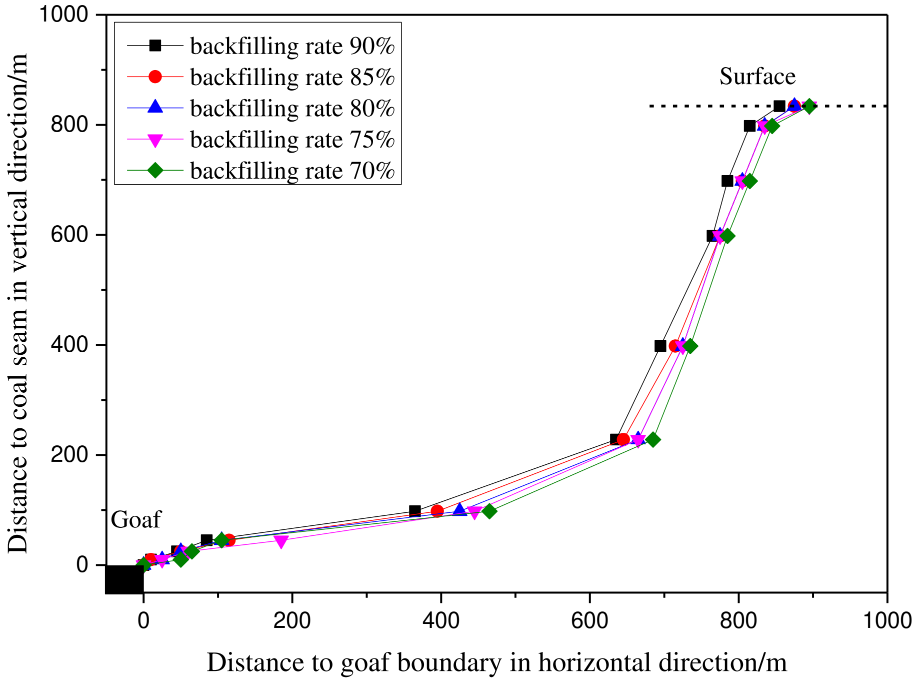

Fig. 6 Movement boundary of stratum and surface under different filling rates in deep backfilling mining

It can be known from Fig. 6 that the stratum and surface movement boundary curves of deep backfilling mining with different filling rates were similar in shape and conformed to the exponential function $y = \exp(-A * x)$. Similarly, the curve changed gradually in the depth of 100 m near the goaf. When the longitudinal direction was more than 100 m from the goaf, the curve altered steeply. However, the backfilling rate had an influence on the boundary scope of rock stratum and surface movement. As the backfilling rate reduced, the boundary scope of rock stratum and surface of deep backfilling mining was increased. When the backfilling rate was lowered from 90% to 80%, the maximum difference distance of movement boundary in the overburden was about 30 m, and the maximum distance between surface movement boundaries was about 15 m. When the backfilling rate was decreased from 90% to 70%, the maximum different distance of movement boundary in the overburden was about 45 m, and the distance between surface movement boundaries was about 30 m. This was because of the fact that the movement and deformation of rock strata caused by backfilling mining were more significant with lower filling rate, leading to an increase in values and scope of strata movement and deformation.

3）Movement boundary comparison of stratum and surface in deep different mining methods

To compare and analyze the strata and surface movement boundaries of deep different mining methods, the stratum and surface movement boundary maps of deep different mining methods (the subsidence 10 mm as the standard) were plotted based on the above simulation findings, see Fig. 7.

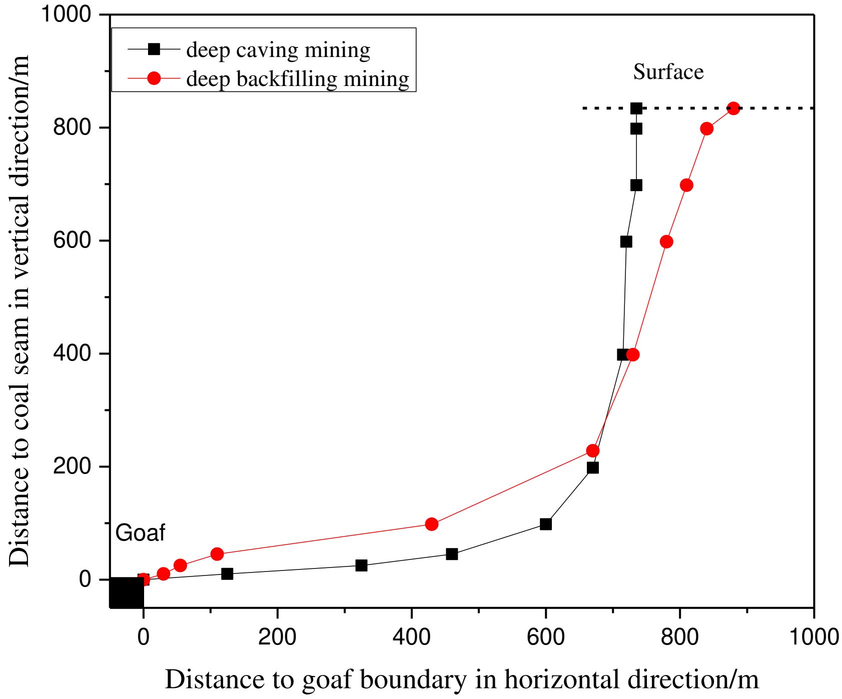

Fig. 7 Stratum and surface movement boundaries in deep different mining methods

Fig. 7 indicated that the stratum and surface movement boundaries of deep caving mining and deep backfilling mining were similar. For the depth of 100 m near the goaf, the curve was more smoothly; When the longitudinal direction was more than 100 m from the goaf, the curve altered dramatically. Meanwhile, the boundary curves of strata and surface movement in deep different mining methods all conform to the exponential function $y = \exp(-A * x)$. However, the influence ranges of stratum and surface movement boundary in deep caving mining and backfilling mining were different. Below the average depth of the surface and goaf, the strata movement boundary of deep caving mining was larger than the deep backfilling mining, and the maximum distance between two boundaries was about 35 m. Above the average depth of surface and goaf, the surface movement boundary of deep backfilling mining was larger than the deep caving mining, and the difference between two methods was about 95 m.

This is because the movement and deformation of rock stratum caused by deep caving mining method was greater than that of deep backfilling mining. In the depth range close to the goaf, the movement and deformation of rock stratum caused by deep caving mining to be more substantial and severe, leading to the movement and deformation values and scope of rock stratum being larger than the corresponding values of deep backfilling mining. With the depth close to the surface, the additional stress caused by deep caving mining was more concentrated and influence of rock stratum structure made the strata movement and deformation value of deep caving mining more than the corresponding values of deep backfilling mining, but stratum and surface influence range from deep caving mining was smaller than the corresponding value of deep backfilling mining.

4 Practical application

This section took the deep backfilling working face of a mine in China as the experimental object, and applied the new proposed method and existing method to determine the stratum and surface influence range of deep backfilling mining, and then analyzed the difference between the two approaches.

4.1 Overview of the research area

Pingdingshan No. 12 Coal Mine is located in the eastern part of Pingdingshan Mine, and is 7.5 km away from the urban area. The administrative area is belonged to Gaohuang Township of Pingdingshan City (Fig. 8). The mine field was about 4 km from north to south and 3 km width from east to west. In the remaining recoverable treatment of the mine, the amount of coal under the building and the water body accounted for about 45%, and 600,000 m^3 of gangue existed on the ground. To treat the buried coal under the buildings and the water body and the environmental issues of gangue pollution, the 15-31010 working face had been mined with the integrated mechanized solid backfilling mining technology. The working face owned a length of 929 m and a face length of 218 m. The average thickness of coal seam was 3.2 m and the average depth was 1085 m, which was a near horizontal coal seam.

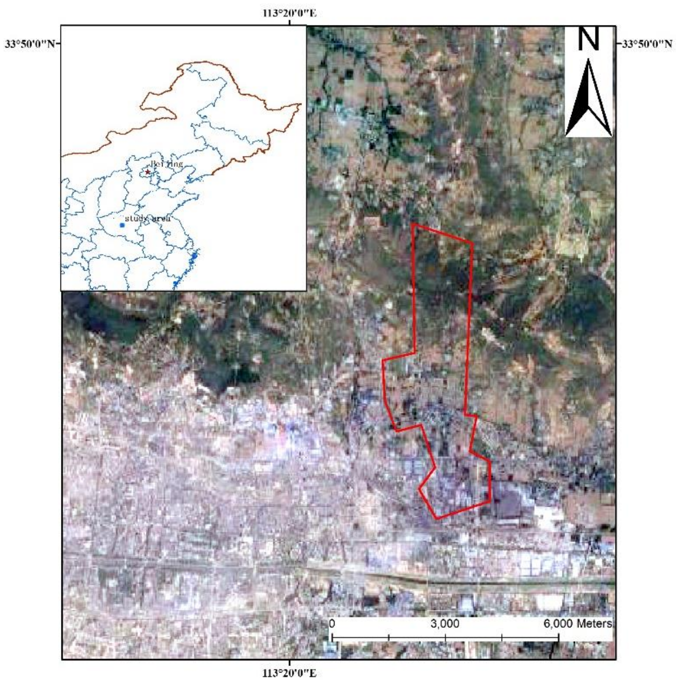

Fig. 8 Research area location

4.2 Influence range determination of strata and surface of deep backfilling based on the new and existed methods

The average depth of 15-31010 working face in Pingdignshan No. 12 Coal Mine was 1085 m, of which the average bedrock thickness was 1075 m, the average thickness of loose layer was 10 m. The working face was 929 m long and the face length was 218 m. The coal seam was near horizontal. The bedrock boundary angle of the strike and tendency was $60°$, and the boundary angle of loose layer was $45°$. This permitted the existed method to acquire influence scope of rock stratum and surface, and the existed method assumed that the internal movement and deformation boundary of rock stratum in deep backfilling mining was straight.

Also, the influence boundary of rock strata and surface of deep backfilling mining were in accordance with the exponential function $y = \exp(-A * x)$ from Section 3, and the value of A was related to the stratum characteristic. Combined with the numerical simulation findings in Section 3 and the overburden properties of 15-31010 working face in Pingdingshan No. 12 Coal Mine, A=-0.013 can be determined. The boundary function of rock stratum and surface of 15-31010 working face was $y = \exp(0.013 * x)$, where x was the distance to the boundary of the goaf on the transverse direction, and y represented the distance to the coal seam in vertical direction. Thus, a comparison diagram of the stratum and surface influence range of 15-31010 working face can be attained based on based on the new and existed methods, as shown in Fig. 9.

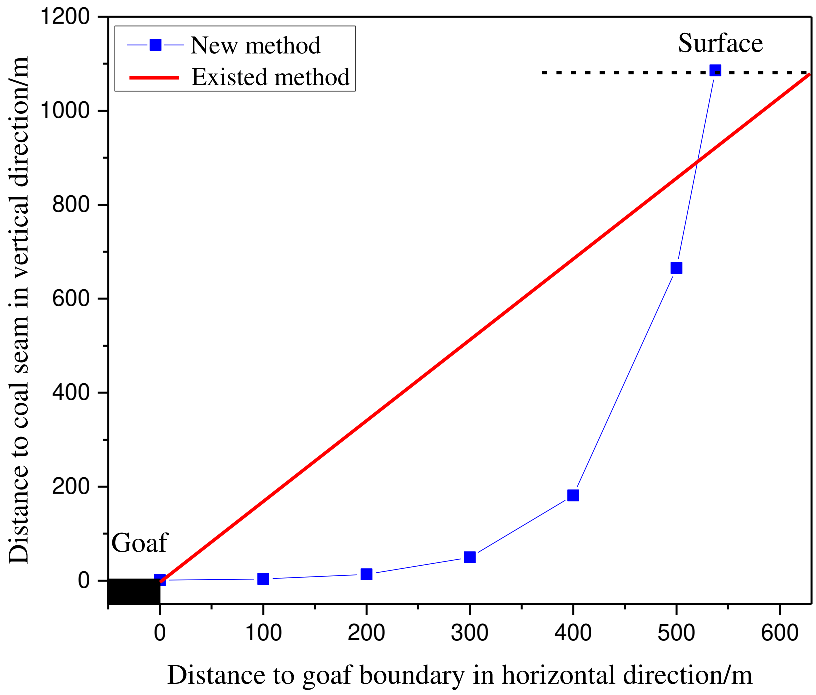

Fig. 9 Comparison of stratum and surface influence range of 15-31010 working face based on the new and existed methods

From Fig. 9, it can be concluded that under a certain critical rock stratum, the stratum movement boundary of deep backfilling mining based on the new method was larger than the existed method. Therefore, the use of the existed method for deep backfilling mining wellbore design will cause wellbore to be within the mining influence range, which will threaten the wellbore safety. Above a certain critical stratum up to the surface, the stratum and surface influence range of deep backfilling mining based on the new method was smaller than the existed method, and the maximum distance difference was on the surface, with a value of 92.9 m. Therefore, the surface movement boundary of deep backfilling mining obtained by the existed method owned a large deviation from the actual situation, which can cause a decrease in the area of mine land not affected by mining, thus utterly impacting the reuse of the field above the goaf.

5 Conclusion

1) The stratum and surface movement boundary of deep caving and backfilling mining was a curve rather than a straight line, and this curve followed to the exponential function of $y = \exp(-A * x)$, and the value of A was associated to the regional geological conditions. Meanwhile, as the filling rate of deep backfilling mining reduced, the influence range of rock stratum and surface was increased. These findings can offer the theoretical basis for determining the influence range of rock stratum and surface in deep different mining methods.

2) The movement boundary curves of stratum and surface of deep caving and backfilling mining had the similar shapes, but the influence range was dissimilar. Below the average depth of the surface and the goaf, the stratum movement influence range of deep caving mining was larger; above the average depth of the surface and the goaf, the stratum and surface movement boundary of deep backfilling mining owned a larger influence range, with the largest difference on the surface.

3) The influence range determination of rock stratum and surface of deep backfilling based on the existed method may result in the design wellbore within the mining impact range, and the surface movement boundary was quite different from the actual situation. Based on the new method to determine the influence range of rock stratum and surface in deep backfilling mining, it can only ensure the safety of the wellbore, but also improve the reuse area of goaf site.

Acknowledgements

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Figures

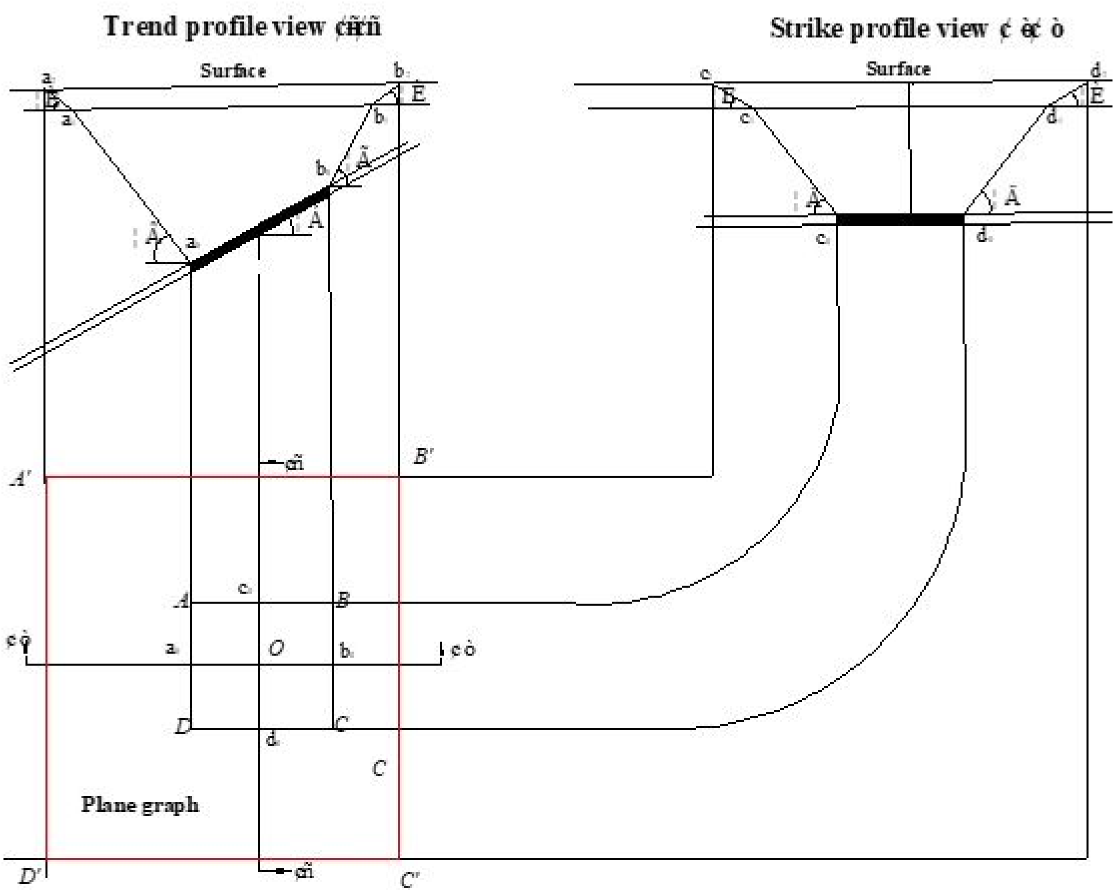

Figure 1

Existing methods for influence scope determination of rock strata and surface in deep mining

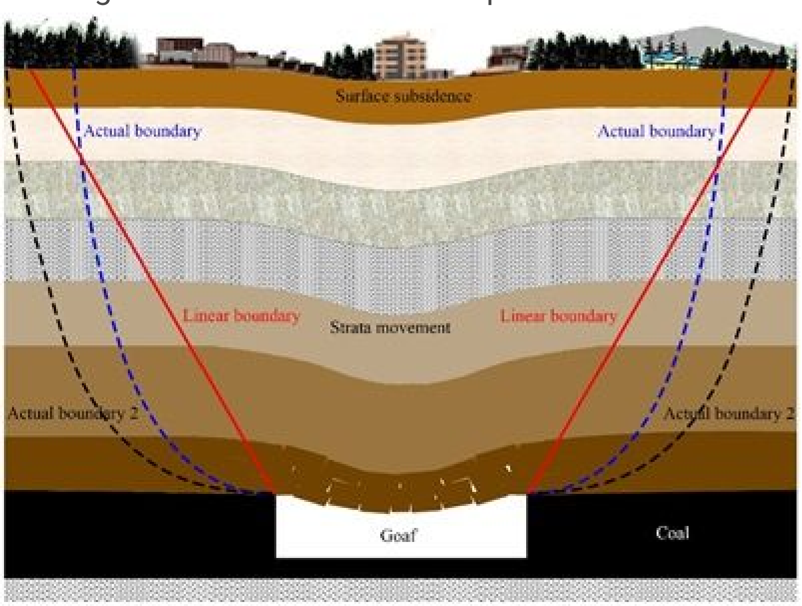

Figure 2

Comparison between straight line hypothesis of movement boundaries of rock strata and surface and possible practical influence boundaries in deep mining

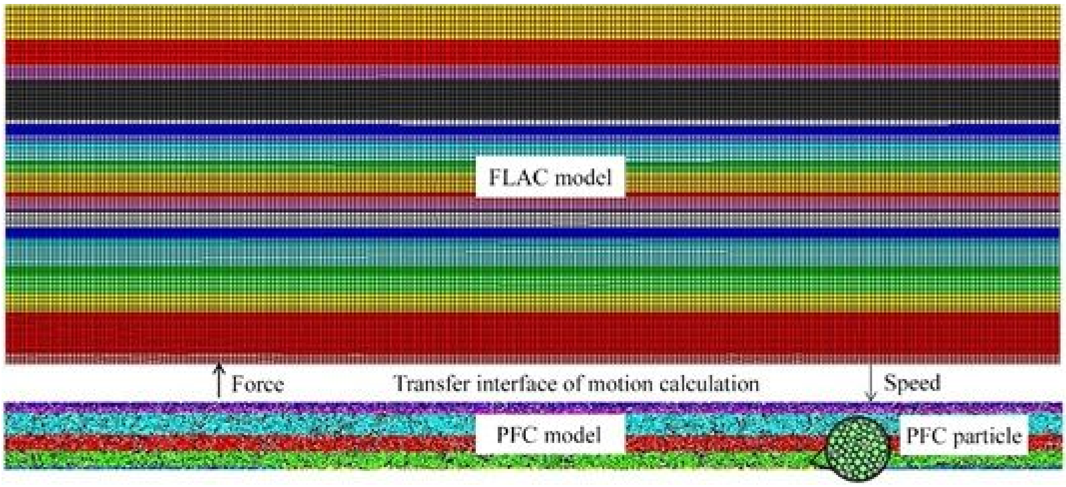

Figure 3

Numerical model of rock strata and surface movement of deep mining

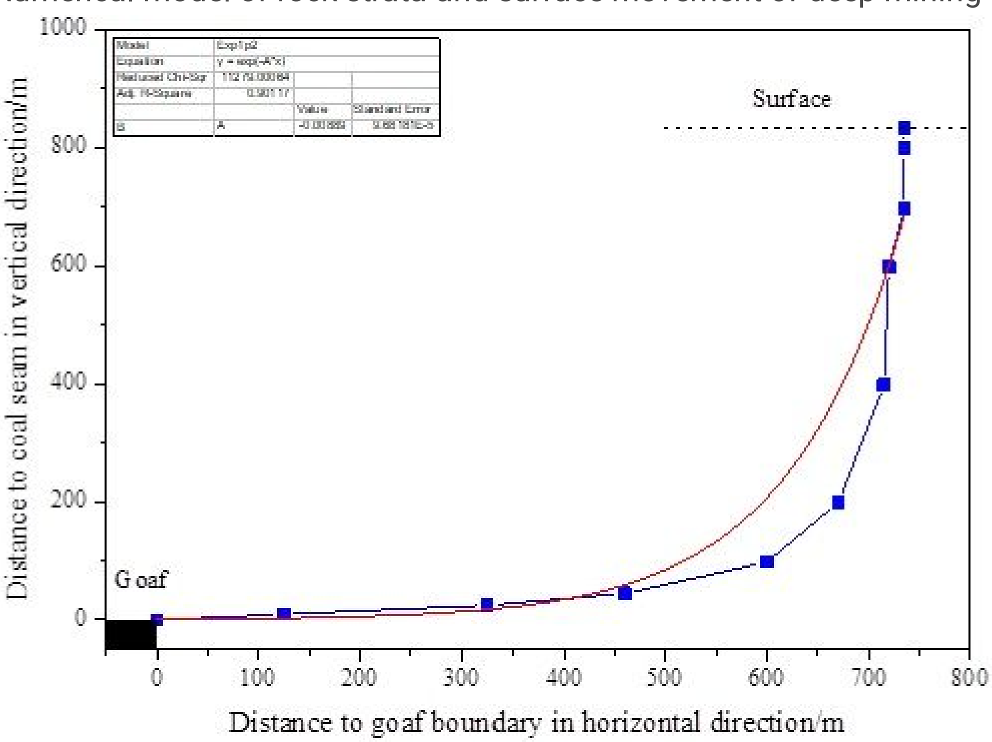

Figure 4

Movement boundary of rock strata and surface in deep caving mining

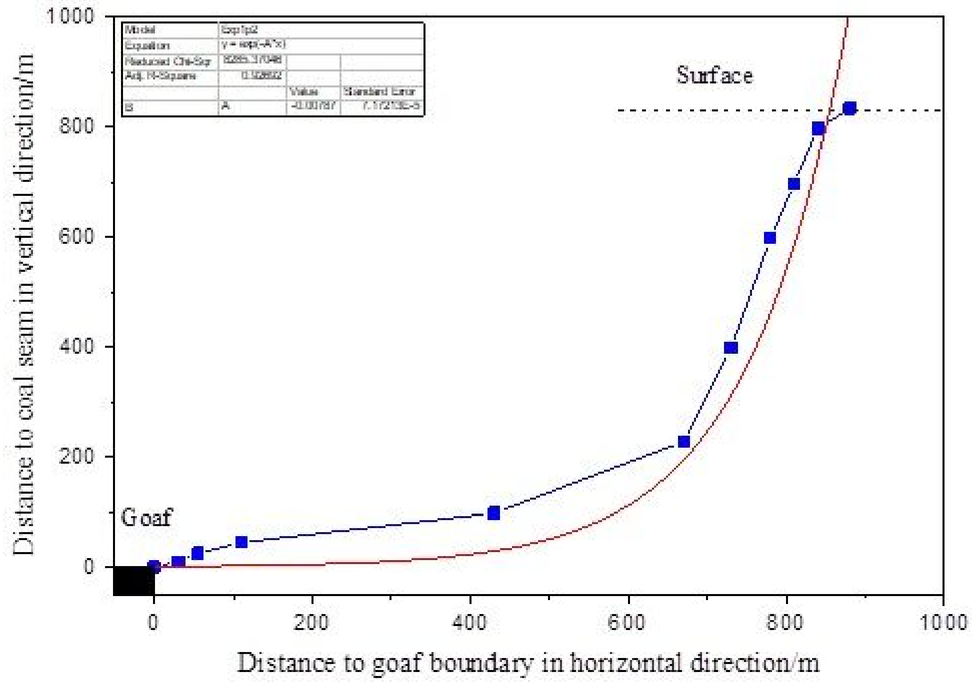

Figure 5

Movement boundaries of rock stratum and surface in deep backfilling mining

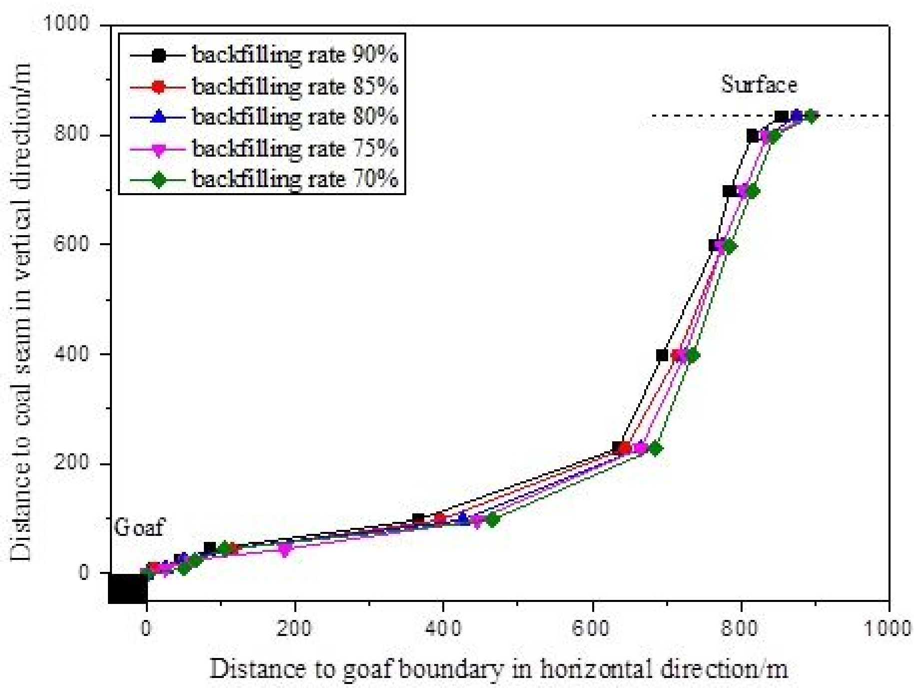

Figure 6

Movement boundary of stratum and surface under different filling rates in deep backfilling mining

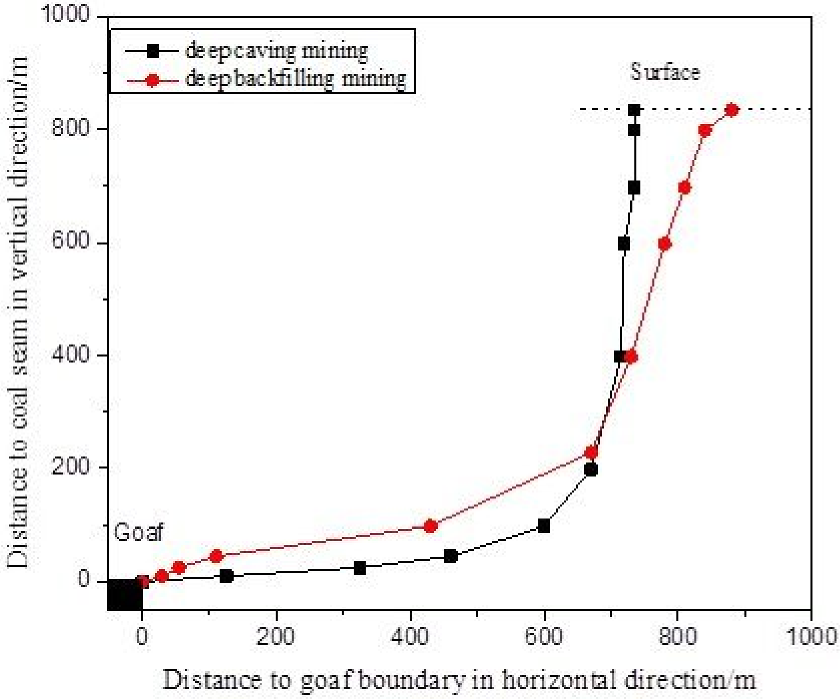

Figure 7

Stratum and surface movement boundaries in deep different mining methods

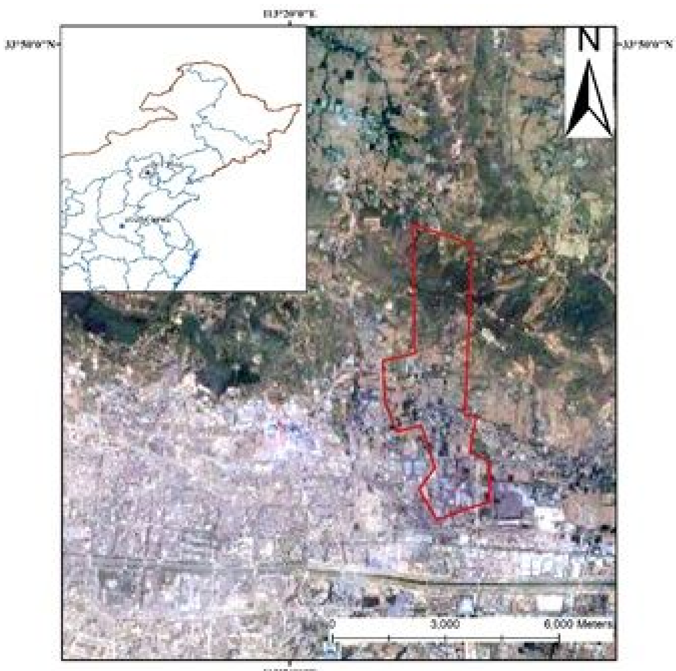

Figure 8

Research area location. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

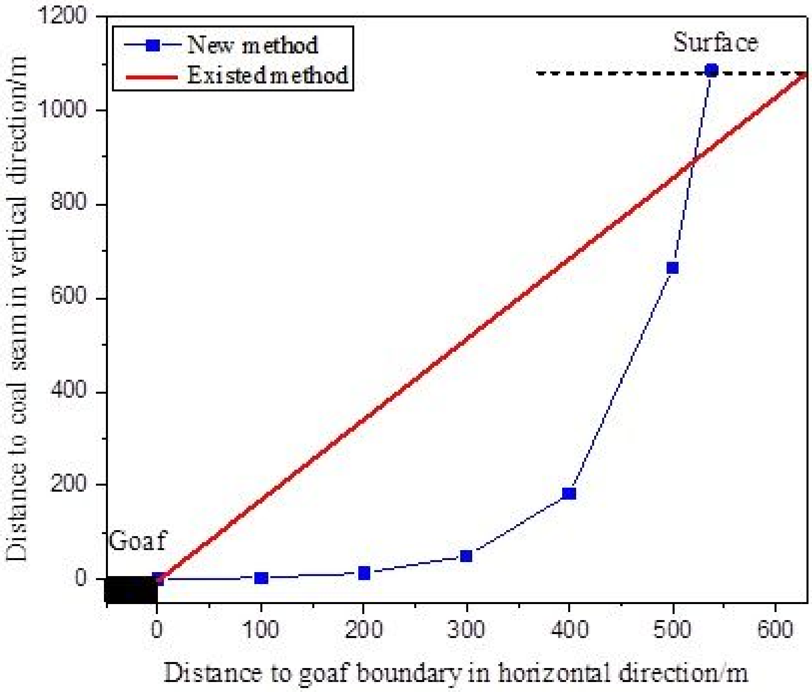

Figure 9

Comparison of stratum and surface influence range of 15-31010 working face based on the new and existed methods