The Study of Roadway Backfill Coal Mining Technology with Water-Preserved in Western Eco-Environment Frangible Area

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ABSTRACT

In China's western eco-environment frangible area, the traditional fully mechanized caving or room mining method is facing coal pillar instability, mine earthquake, large-area roof subsidence in the goaf, surface subsidence, water and soil loss, vegetation deterioration and other environmental problems. To solve the aforementioned problems and improve coal recovery, the roadway backfill coal mining (RBCM) technology with water-preserved was proposed as a solution and its technical principle, key equipment, roadway layout and backfill mining process were presented in detail in this paper. The mechanical properties of backfilling materials with different ratio of aeolian sand, fly ash and cement are studied in laboratory for a optimum ratio for local coal mines. moreover, a two-dimensional physical simulation model is established to analyze the characteristics of overlying strata movement and effect of water-preserved. Field application results shows that this technology can effectively control the overlying strata movement and improve the recovery rate of coal resources, achieving the coordinated development of the western mining area resources exploitation and environmental protection purposes.

INTRODUCTION

The eco-environment frangible area in western China has huge coal resources, accounting for more than 85% of the total deposit (Xie et al. 2001). Relying on the large quantity, good quality and favorable coal production conditions, coupled with sustainable economic development in recent years, coal output has been increasing annually, making the western coal area the fulcrum or focus of coal mining in China (Qian et al. 2007; Sun et al. 2009). At present, there are lots of small-scale coal mines in the area that account for more than 90% of the total (Liu et al. 2010). Affected by pore phreatic water in quaternary loose soils and thick loose aeolian sand on surface, most mines take room mining method in order to prevent water or sand bursting and severe strata behaviors. The recovery percentage of coal resource is less than 30% and the resources are wasted seriously (e.g., Zeng et al. 2001; Fan et al. 2006). Secondly, observations indicated that the remaining pillars strength are weaken under long-term loading with room mining method in recent years, the pillars are easy to be broken by destabilization, which causes roof caving in the gob, mine earthquake, surface subsidence, water and soil erosion, vegetation deterioration and other natural phenomenon and has a strong influence on local ecological environment and resident’s normal life (Wang et al. 2012; Adibee et al. 2013; Ghasemi et al. 2014; Huang et al. 2014; Dong et al. 2015; Zhang et al. 2015; An et al. 2016). In order to ensure harmonious development of economy and society in western mine, it is very important to search a reasonable mining method.

In recent years, the backfill coal mining technology has been continually popularized in China (Miao et al. 2010b; Bian et al. 2012; Zhang et al. 2012a). This technology has obvious technology advantage on exploiting coal resources under building, body of water, railway and controlling strata movement (Bell et al. 2001; Huang et al. 2011b; Zhang et al. 2014; Kostecki et al. 2015; Jiang et al. 2016). But because of the difference of backfill materials, the choice of backfill mining method and the cost of backfilling, up to now, we do not form a complete set of fast backfill coal mining technology which suits the eco-environment frangible area in western China.

The keys of backfilling coal mining in eco-environment frangible area in western China including: firstly, the selection of reasonable backfilled materials according to the source of backfill materials and geological conditions; Secondly, the selection of appropriate backfill mining method, process and complete sets of equipment according to the different coal mine for the benefit maximization; Thirdly, after backfill coal mining, the backfill body should be stable under the long-term effect of overlying strata, achieving the target of ground control and environment protection in western eco-environment frangible area.

A large number of research work has been carried out to study the backfill coal mining technology and method in western eco-environment frangible area (Huang et al. 2011b; Zhang et al. 2011a; Zhang et al. 2012b). Previous studies predominantly focused on theoretical research of material properties, mining geological analysis or strata movement with fully caving coal mining method. Aiming to different coal mines, a mature backfill coal mining technology suitable for western eco-environment frangible area is not well researched. So there is a need to address this issue for productive and environmental reasons as discussed above.

The major objective of this paper is to provide a new idea and method for shallow coal seam mining in the fragile ecological mining area in western China.

RBCM TECHNOLOGY

Technical Principle

The RBCM method uses roadheader other than shearer for coal cutting on the basis of the traditional production system in longwall mining (Zhang et al. 2011b; Zhang et al. 2012b; Zhang et al. 2011a). In other words, it is an underground coal mining method, which involves excavating cross-cut between two entries of the working face using a fully-mechanized coal mining header. After excavating cross-cut, the gangue, loess, aeolian sand and other solid material are used as the main bacfill materials, with the action of binder, and then a certain proportion of high concentration slurry without dehydration treatment is made. The backfill materials will be transport through a pipeline to the mined roadway underground by pumping. The technology can effectively controlling roof in the goaf, preventing surface subsidence, mining three-under coal (coal trapped under buildings, waters-bodies and railways) and disposing solid wastes. The technical principle of RBCM technology can be seen in Fig. 1.

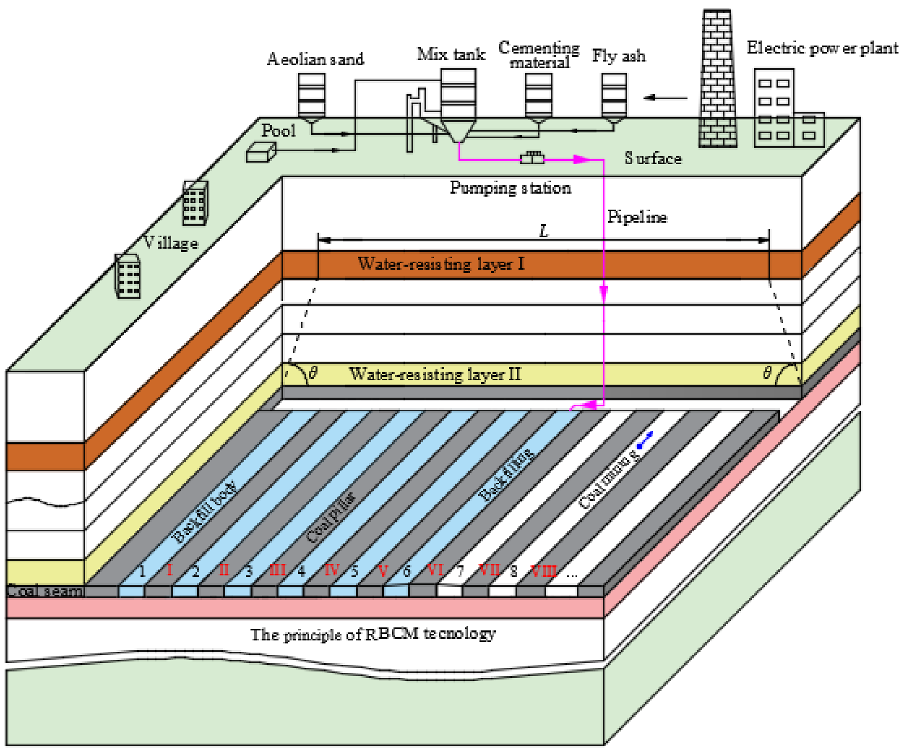


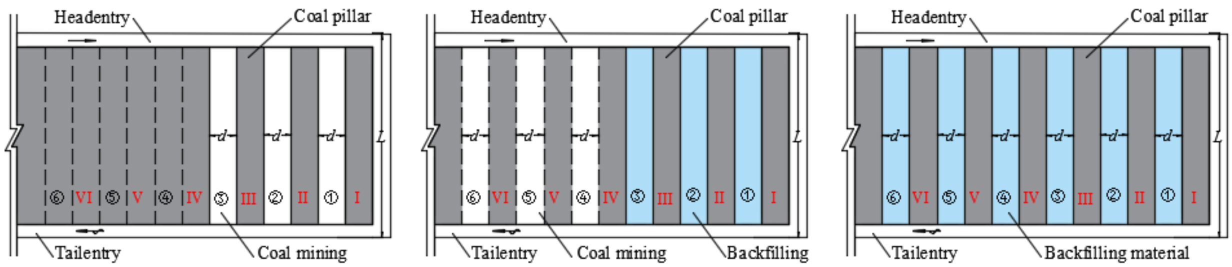
Figure 1. The technical principle of RBCM technology

Key Equipment

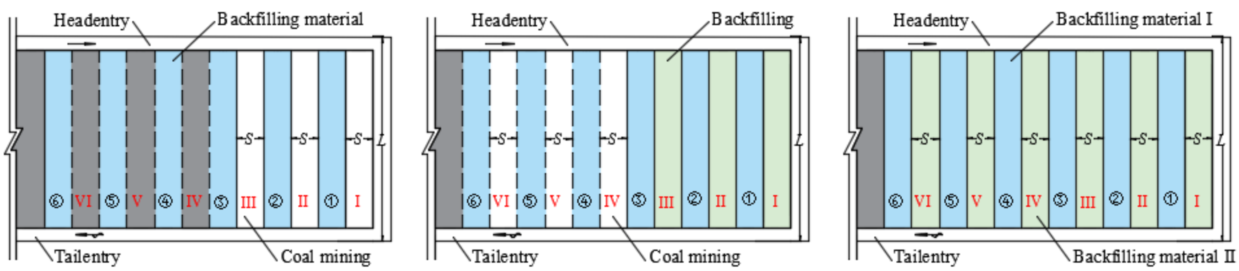
The equipment of RBCM technology is mainly composed of mining, backfilling and transportation equipment. The mining equipment mainly includes the roadheader, local fan and so on; the backfilling equipment mainly includes backfill pump, crusher, vibrating screen, mixer, mixing machine, pipeline; the transport equipment including scraper conveyor, belt conveyor, etc.

Roadway Layout and Process Design

The roadway length of RBCM is generally 100~300m, and the width of the roadway is 5~10m. The process design mainly includes the mining technology and the backfilling technology. According to the different mechanical properties of backfill material and the geological conditions, there are some differences in the backfill process. According to technical principle and the mining processes, the RBCM is divided into two stages: (1) roadway coal pillars with a certain width are formed by mining a certain width of roadway, and then the roadways are backfilled one by one to finish the first stage of mining and backfilling; (2) when surrounding rock of the working face in the first stage of the mining operations become stable, the coal pillars which forms part of the backfilling roadway during the first stage are mined and backfilled again to form the remaining backfill body. Roadway layout and mining process of RBCM are shown in Fig. 2.



(a) The first stage of RBCM



(b) The second stage of RBCM

Figure 2. Roadway layout and mining process of RBCM

MINE OVERVIEW

The Ershike Coal Mine is located in Poluo town, the northeast of Hengshan county. It is about 33km away from the center of Poluo town. The field boundary is 1.9km long and 1.6km wide. There are eight coal seams in this area, among them, the 3# coal seam is the primary mineable coal seam. 3# coal seam is located in Yan'an Formation. Its thickness is from 2.22m to 2.42m and the average thickness is 2.30m with average burial depth of 130m. Over the past years, the room mining method was adopted, resulting in serious coal resource waste, the recovery ratio is less than 30%. Up to now, the remaining coal resources are about 4 million tons, which is mainly under the village. So a solution is urgently needed to ensure harmonious development of the Ershike Coal Mine. The plan view of the study site and lithologic histogram are shown in Fig. 3.

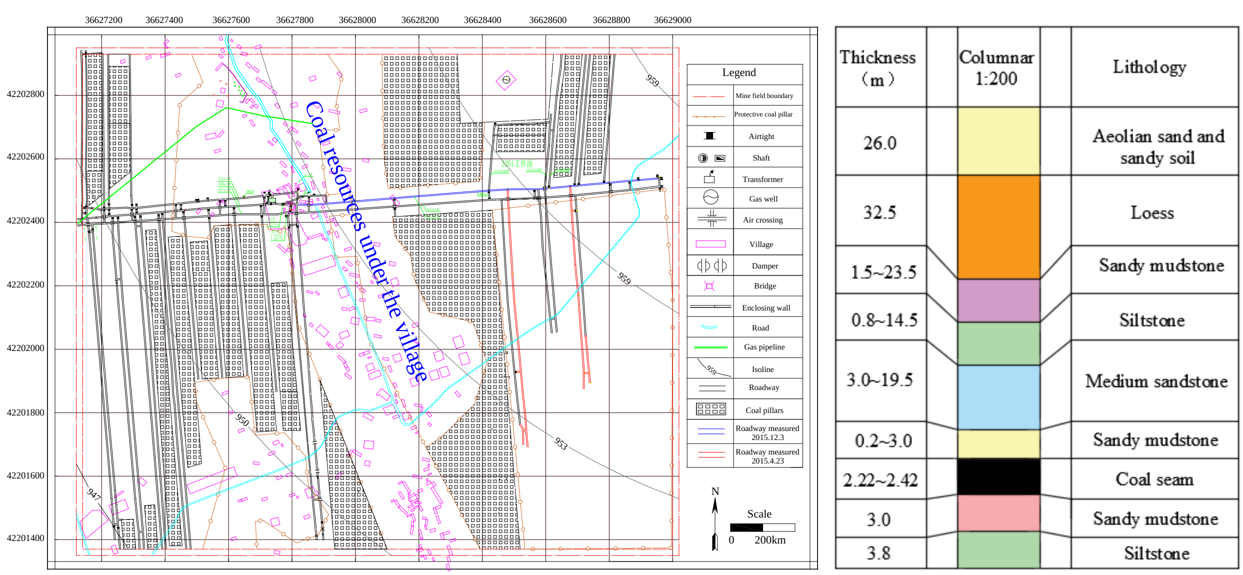


Figure 3. Plan view of the study site and lithologic histogram

BACKFILL MATERIAL SELECTION

Material Composition

According to the actual mining geological conditions of the eco-environment frangible area in western China, considering material source adequacy and the cost of materials, in this paper, aeolian sand which is widespread on the surface in local area is selected as backfill aggregate, the III-level fly ash were collected from Qishan coal mine in Yulin Shaanxi province as fine aggregate, and the ordinary Portland cement 42.5R (GB175-1999) was used as binder in all of the samples from the village of Mao in Xuzhou Jiangsu.

Testing of Material Properties

The fragile ecological mining area is characterized by relatively shallow buried depth (0~200m) with thick aeolian sand layer on the surface (Wang, et al. 2012). Affected by the pore phreatic water in the loose bed of Quaternary system, coal mines with fully caving coal mining method are usually threatened by disasters such as water or sand bursting. Moreover, a large proportion of high-quality coal resources are under the buildings. For these reasons above, the backfill materials should has certain strength possess long term stability to meet the long-term stability of the strata. In this experiment, the mechanical properties testing of material with different ratio of aeolian sand, fly ash, cement under the condition of different curing period is the major studies. The viscosity and flowability of the backfill materials, another important rheological parameter, were not the aim of this research project. The experiment scheme are shown in Table 1. The production, curing, testing and results of backfill materials with mainly aeolian sand are shown in Fig. 4.

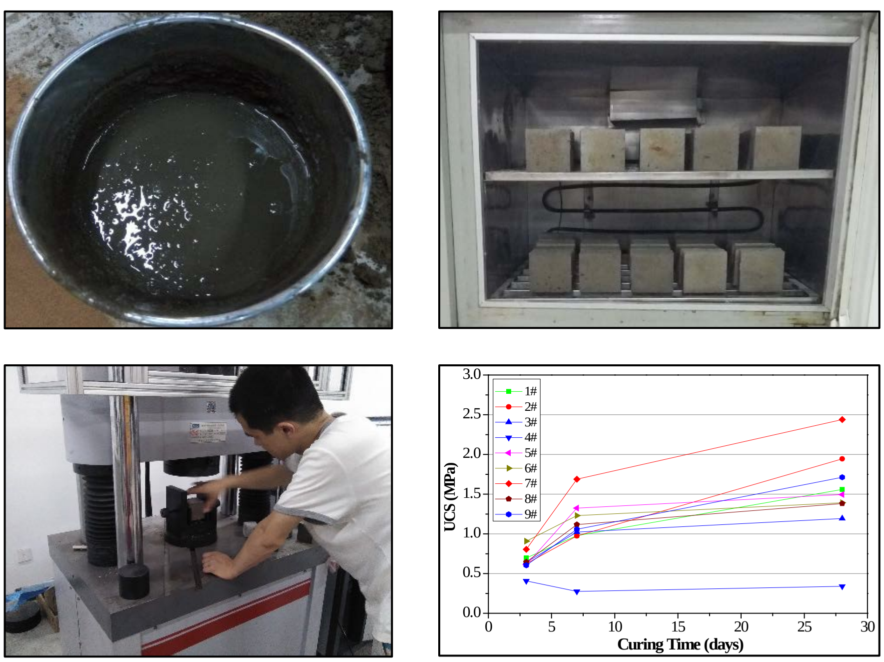


Figure 4. Testing of material properties

Table 1. The experiment scheme

Experiment scheme	Aeolian sand (wt.%)	Fly ash (wt.%)	Binders (wt.%)	Mixing water	Slug concentration (%)	Curing time (days)
I	65%	5.0%	30%	Tap	80	1,3,7,14,28
II	65%	5.0%	30%	Tap	81	1,3,7,14,28
III	65%	5.0%	30%	Tap	82	1,3,7,14,28
IIV	60%	5.0%	30%	Tap	81	1,3,7,14,28
V	70%	5.0%	30%	Tap	81	1,3,7,14,28
VI	65%	5.0%	25%	Tap	81	1,3,7,14,28
VII	65%	5.0%	35%	Tap	81	1,3,7,14,28
VIII	65%	2.5%	30%	Tap	81	1,3,7,14,28
IX	65%	8.5%	30%	Tap	81	1,3,7,14,28

OVERLYING STRATA MOVEMENT CHARACTERISTICS OF RBCM

Experimental Scheme Design

To grasp the characteristics of overlying strata movement of RBCM, the stability of water-resisting layer with RBCM was studied through the experimental to prevent the disaster of water or sand crush at the same time. In this paper, a two-dimensional physical simulation model is established to study the overlying strata movement characteristics (mainly focus on water-resisting layer). The model assumes a length of 1400 mm in the dip direction, a width of 100 mm in the strike direction and a height of 1300mm, and the geometry similarity of physical similar simulation model is 1:100, as shown in Fig. 5. The physical and mechanical parameters of rock are shown in table 2.

The mining scheme of RBCM in this study are designed as follows: roadway coal pillars with 5m width are formed by mining 5m roadway, and then the roadways are backfilled; after the first stage, the 5m coal pillars which forms part of the backfilling roadway during the first stage are mined and backfilled again. What’s more, the interval distance between coal mining face and backfilling face is always 25m to avoid mining-induced stress influence (when mining the fourth roadway, backfilling the first roadway), during the backfill coal mining, the strata movement and fracture development of water-resisting layer are observed.

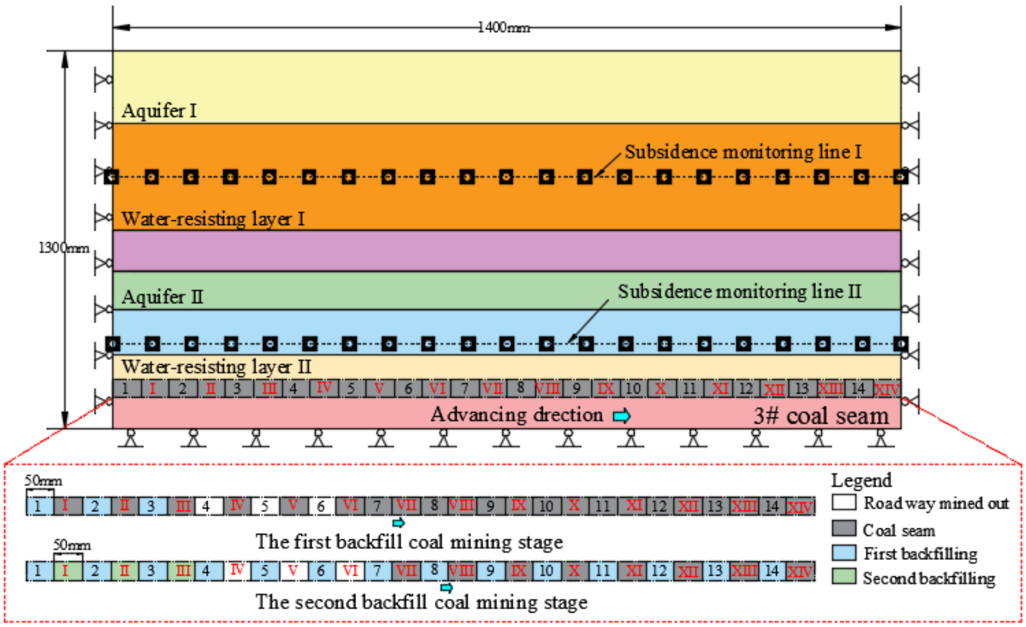


Figure 5. Experimental scheme design of RBCM

Table 2. Mechanical parameters of coal (rock) strata in simulation

Aquifer or Water resisting layer	Lithology	Thickness (m)	Density (kg/cm³)	Tensile strength (MPa)	Cohesion (MPa)	Internal friction angle (°)	Bulk modulus (GPa)	Shear modulus (GPa)
Aquifer I	Aeolian sand and sandy soil	26.0	1870	0	0.5	16	0.08	0.05
Water-resisting layer I	Loess	32.5	1790	0.05	0.5	18	0.12	0.08
	Sandy mudstone	26.4	2200	1.0	1.0	28	0.63	0.5
Aquifer II	Mudstone	11.5	1600	0.8	0.6	27	0.6	0.32
	Siltstone	8.3	2615	1.0	2.0	30	1.87	1.12
Water-resisting layer II	Medium sandstone	13.5	2400	1.2	2.3	32	1.6	1.14
	Sandy mudstone	3.0	2200	0.8	1.0	31	0.65	0.7
	Coal seam	2.42	1400	1.86	0.3	25	0.8	0.41
	Sandy mudstone	3.0	2200	0.6	1.0	28	0.63	0.5
	Siltstone	3.8	2615	1.0	2.0	30	1.87	1.12

Results and Discussion

As shown in figure 5 (a), during the first mining stage, as the roadway mined out and backfilled, the overburden slowly sinks, when the roadway backfilled is 7, 12, 14, the average subsidence of water-resisting layer II is 17.3mm and there are only some horizontal micro-fractures, the overburden is stable. At this stage, during the process of mining coal face advancing, the 5m coal pillars is the main load bearing body, the cementation strength of backfill material is weak, the load-bearing effect is not obvious.

As shown in figure 5 (b), at the second mining stage, when the roadway backfilled is 7, 12, 14, the maximum subsidence of the water-resisting layer II is 105.4 mm, 135.2 mm and 168.0 mm, and the maximum subsidence of the water-resisting layer I is 75.4 mm, 89.2 mm and 144.0 mm respectively. The results also show that, there are roof separation and horizontal fractures during the mining. At this stage, mining-induced stress gradually transfer to backfill material and the support function enhanced gradually. During the process of mining coal face advancing, there are no obvious vertical fractures, the water-resisting layer is not broken all the same, which shows that, after the RBCM, the backfill body can support the overlying load effectively, and achieving the target of water-preserved and environment protection in western eco-environment frangible area. Overlying strata movement characteristics of RBCM is as shown in Fig. 6 and Fig. 7.

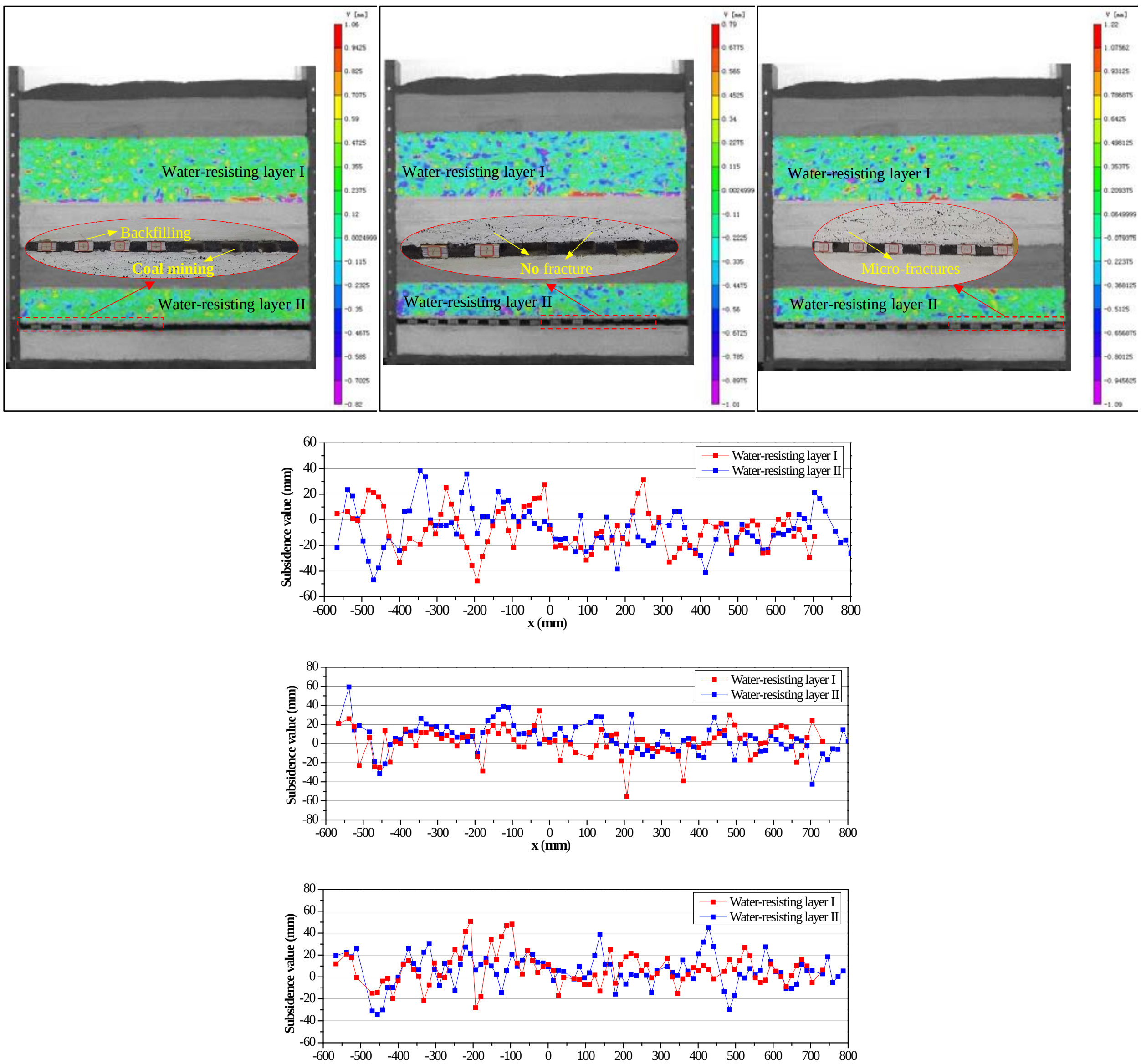


Figure 6. Overlying strata movement characteristics of RBCM: the first mining stage

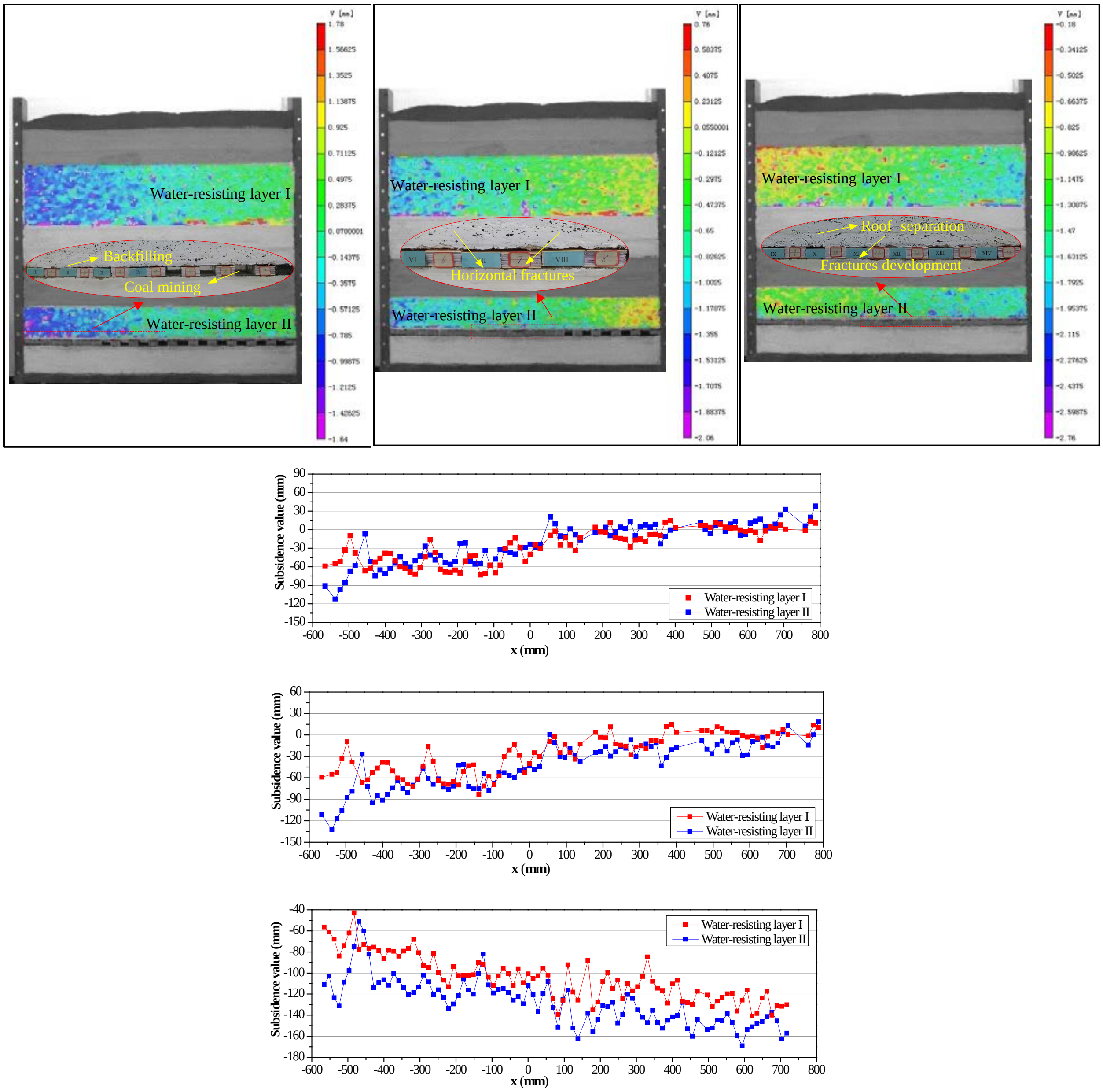


Figure 7. Overlying strata movement characteristics of RBCM: the second mining stage

MAIN CONCLUSIONS

(1) Mining operations in China's western area is often associated with coal pillar instability, mine earthquake, large-area roof subsidence in the goaf, surface subsidence, water and soil loss, vegetation deterioration and other environmental problems. RBCM method can improve the coal recovery and also to protect the environment. The application of this method allows a coal recovery of more than 90%.

(2) The mechanical properties of material with different ratio of aeolian sand, fly ash and cement are studied in laboratory, which will have an important significance to local coal mines for a rational backfill design.

(3) A two-dimensional physical simulation model is established to study the overlying strata movement characteristics and effect of water-preserved. The result shows that the backfill materials can support the overlying load effectively, and achieving the target of water-preserved and environment protection in western eco-environment frangible area.

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