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Current Status and Future Prospects of Mining Subsidence and Ground Control Technology in China

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CURRENT STATUS AND FUTURE PROSPECTS OF MINING SUBSIDENCE AND GROUND CONTROL TECHNOLOGY IN CHINA*

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ABSTRACT: Mining of coal alters the ground stressfields, causing strata deformation, ultimately leading to surface subsidence. For the past 40 years some significant experience on mine subsidence control technology has been acquired in China, particularly when mining under buildings, railways and water bodies, which are known as "3-bodies". Current emphasis is in the evaluation of appropriate mining methods and other correlative technologies that can control or reduce the ground surface subsidence and protect surface structures. The current status of coal mining subsidence and ground control technology in China are discussed, including partial mining, backfilling, bed separation grouting, and harmonic mining. The partial mining methods include; strip pillar mining, the room and pillar method, and limited mining thickness. The backfilling mining method uses the traditional backfill material, like gypsum, paste-filling, and so on. Bed separation grouting in overburden strata is a new and patented technique which can reduce the surface subsidence to some extent, and is used in some Chinese coalmines.

INTRODUCTION

Coal is the most abundant energy resource in China, supplying about 70% of primary energy consumption (See Figure 1). China is the world's largest coal producer and produces nearly 35 percent of the world's annual coal production.
Due to a great deal of coal resources being extracted from underground, the environmental hazards resulted from mining activities are becoming a serious problem. Coal mining subsidence not only destroys the ecological environment, but also causes surface structure damage (See Figure 2). For example, in Yaojie Mining Bureau of Gansu Province, a large surface area subsided abruptly due to coal mining in 1993 causing fatalities.

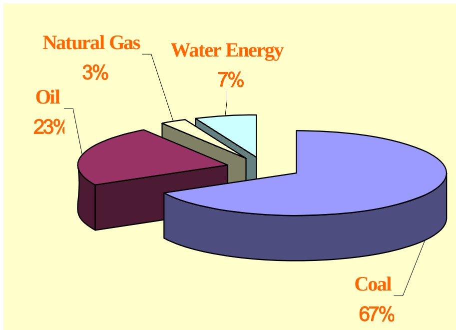

Figure 1 - Energy consumption in China

Reserves of coal under buildings, railway lines and water bodies (called "3- body") are huge in China. Based on the official data, the areas of subsidence prone land due to coal mining are about 600,000 ha, There are more than 1094 villages with 110,000 inhabitants residing in the are situated in the provinces of Henan, Hebei, Shandong, Anhui and Jiangshu . About 10 000 tonnes of coal is mined between 0.2-028 ha. In plain mining area with dense villages, about 2000 persons need to be relocated when 10,000,000 tonnes coal is extracted (Zhang Huaxing et al, 2000). At present, most coal mines that have coal reserves under 3-body conditions have serious problems with mining layout. Although moving villages before mining need not change mining methods, nevertheless, the compensation cost of moving villages away is continuously increasing. Also it is very difficult to find new fertile land to resettle villagers affected by mining subsidence

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In order to control mining subsidence and to protect surface structures, water bodies and railway lines from damages, it is necessary to research mining subsidence and ground control technology. Through several decades of studying and practice, China has accumulated an abundant experience on mining subsidence control technology. The objective is to study appropriate mining methods that reduce or control surface subsidence, and protect structures from damage.

Figure 2 - Farmland and structures damaged by mining

MINING SUBSIDENCE AND GROUND CONTROL TECHNOLOGY

The following underground mining techniques are practiced in China to control subsidence and prevent hazards.

Partial mining methods

Strip pillar mining method

Strip pillar mining is the most widely used method to control mining subsidence in China. In strip pillar mining the coal reserve is divided into regular strips with alternate strips being extracted. The strips left behind, called strip pillars, are designed to support the overburden and prevent surface subsidence. This is one of the important methods in "Green Mining Technology" and has become an effective method to mine those coal reserves lying under village structures (1,2,3,4,5 and 6) (Guo Wenbing, et al. 1998).

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The advantage of strip pillar mining is to reduce the surface subsidence effectively without changing mining technology. The strip pillar mining method was first employed in 1976, and currently a large amount of coal reserves under" 3-body" have been extracted by the strip pillar mining method. In China, the roof control method of strip pillar mining is almost by caving method. The mining depth of strip pillar mining is less than 500 m; mining height is mostly less than 6m, and the recovery ratio ranges between 40% and 68%. The surface subsidence factor depending on the recovery ratio is mostly less than 0.2, (See Table 1) (Guo Wenbing, Deng Kazhong, Zou Youfeng. 2004).

Table 1 - Relationship between surface subsidence factor and recovery ratio of strip pillar mining

recovery/%	hard stratum	medium-hard stratum	soft stratum
60	0.09□0.11	0.13□0.17	0.17□0.21
50	0.05□0.06	0.08□0.10	0.10□0.12
40	0.026□0.032	0.03□0.05	0.05□0.06

Room and pillar method

The room and pillar method is widely used in America, Australia, Canada, India, and South Africa. Its subsidence factor ranges between 0.35 and 0.68. This method has also been employed in recent years in China, but on a small scale. Huangling Coalmine of Shanxi province is the first coal mine to employ room and pillar mining using continuous miners. Other mines with room and pillar mining include those at Nantun coal mine of Yanzhou Mining Group and Daliuta mine of Dongsheng mining district.

Limiting thickness mining
Limiting thickness-mining method can reduce the effects of surface subsidence on the surface structures. It is rarely used, because its recovery ratio will be low if no surface structure damage is allowed. The permitted mining height (thickness) *M* is calculated by,

$$M \le \frac{\varepsilon_y \cdot H}{1.52 \cdot b \cdot q \cdot \tan \beta}$$

Where: ε_y is the permitted surface horizontal strain; *H*-mining depth in meters; *q*- subsidence factor; *b*,-horizontal movement coefficient; and tanβ- tangent of major affected angle.

Backfilling mining methods

Traditional backfilling method
The traditional backfilling method includes hydraulic backfilling, pneumatic backfilling, mechanical backfilling, and coal gangue sliding backfilling. In the process of mining, filling materials such as sands, coal gangue or fly ashes are filled in the gob behind the working face in order to support the overburden strata.

The hydraulic backfilling method is the most effective way to control surface subsidence. Its subsidence factor in general ranges from 0.1to 0.3 . When water supply is lacking or underground working face is damp or watery, the pneumatic backfilling method should be employed. Coal gangue sliding backfilling method is only used in steeply inclined and inclined coal seams; The subsidence factor of the coal gangue sliding filling method is roughly 0.3~0.4.

Table 2 shows different gob backfilling methods used in some coalmine, such as Fushun, Jiaohe, Jixi, Liaoyuan, Jiaozuo, and Huainan in China (Sui Huiquan, WANG Shaojun, Wang Hu. 2004).

Paste backfilling method
Backfilling materials and backfilling technology have made great progress in China in recent years. The paste backfilling method is a new method in China, and one of the key measures in "green mining technology". This method can increase the coal recovery ratio, protect groundwater and surface structures from damages, improve mining area environment and make use of solid waste materials. Jinchuan Company in China set up the paste backfilling production system in 1996. Now some coalmines in Shandong province are using this method.

Table 2 - Examples of backfilling mining method in China

No.	Mining method and backfilling method	Site	Coal condition	Protection object	Subsidence factor
1	Longwall mining along the dip with ascending hydraulic backfilling method	Shengli Coalmine, Fushun	Inclined very thick coal seams	Structures	0.1~0.22
2	Longwall mining along the strike with hydraulic backfilling method	Suncun Coalmine, Xinwen	Gently inclined medium thick coal seam	River (water)	0.15~0.2
3	Longwall mining along the strike with hydraulic and gangue backfilling	Wulin Shaft, Jiaohe	Gently inclined thick coal seam	Riceland	0.21
4	Longwall mining along the strike with pneumatic backfilling method	Yanmazhuang Coalmine, Jiaozuo	Gently inclined thick coal seam	Villages	0.3~0.4

After paste backfilling materials are filled in the gob, they become non-water-yielding material aggregate, and its solid constituents, commonly varies from 76% to 85% (Qian, Minggao, Xu, Jialin, Miu, Xiexing. 2003). The preparation process of paste filling is as follows: first, materials such as coal gangue, fly ash, industrial slag, bank sand are processed into hydrated paste like toothpaste. Then the toothpaste mixture is transported underground and pump filled into the gob. Once the paste fill is hardened and set in the gob, the cementation fill body can support overburden strata and control surface subsidence.

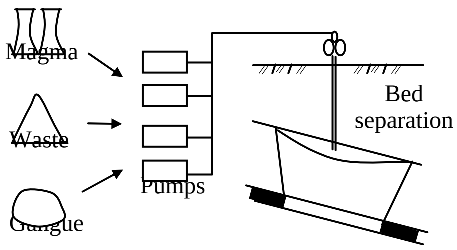
The main features of the past filling method are: the concentration of slurry made by solid waste material is high; the paste can segregate before setting. The paste doesn't pollute the underground working face and thus no drainage equipment is needed at the working face. Paste filling provides good support to Guo Wenbing, Deng Kazhong control overburden strata and surface subsidence, thus contributing to improvement in production and efficiency.

Grouting of bed separations in overburden strata

During mining, strata separations occur frequently in the overburden especially under strong and thick strata. Industrial waste materials such as fly ash are injected into the voids of strata separations under high pressure.

Introduction of bed separation in overburden strata

In recent years, a number of journal articles have published papers on ground subsidence by bed separations and grouting technology. Grouting of the bed separation caused by mining is achieved by injecting into fractured strata, a mixture of fly ash and industrial waste materials based slurry. The injection is carried out from surface boreholes as shown in Figures 3 and 4. The extent of the slurry injection depends on the structure and characteristics of overburden strata. In general, bed separations in overburden strata are formed under competent and thick strata (so called the key strata).



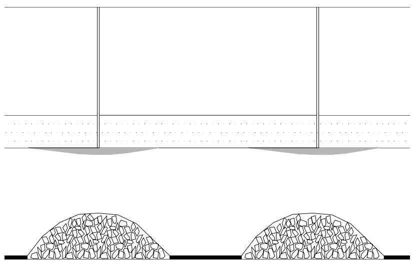


Figure 3 - Bed separation grouting technology under

Figure 4 - Bed separation grouting the key strata

Mechanism of reducing subsidence by bed separation grouting

There are various reasons that bed separation grouting can reduce surface subsidence subsidence (Sui Huiquan, Wang Zhonglin. 2001). First, fly ash slurry material has better binding strength. When injected into the bed separation, fly ash can occupy the fractured space and slowly bind the separated layers, thus preventing the overburden strata from subsiding thus minimising surface subsidence. Thus grouting of the fractured weak layers will cement, reinforce, and improve the strength of strata.\

In comparison with gob backfilling, bed separation grouting is conducted in upper overburden strata and will have less filling effect. Grout location should be in accordance with the following conditions.

(1) Grouting slurry should not reach the working face from the overburden strata. Therefore, the grouting location must be above the caved zone caused by mining.
(2) The depth from the surface of the grouted separation space must not be less than 0.4~ 0.6*H* (*H* is mining depth). Also for longwall mining, the length of the working face must be less than 0.3 *H*.
(3) Where the overburden strata is strong and thick, the lower interface layer will be the best place for grouting.

Table 3 shows some examples of bed separation grouting in China. It can slow down surface subsidence to some degree (Zhao Deshen, Su Zhongjie, Sui Huiquan. 1998).

Table 3 - Examples of bed separation grouting in China

Mine	Seam thickness	Angle of coal seam	Mining depth	Subsidence factor
Laohutai	25.7m	26°	602m	0.278
Xuzhuan	2.6m	20°	529m	0.24
Dongtan	5.4m	3°	545m	0.032

Harmonic mining method

Harmonic mining is a technical measure to reduce surface deformation, but usually it can't reduce surface subsidence. During mining, adjusting the progress of two or more working faces and making structures to be located at the center of the subsidence trough, so that the structures are only subjected to dynamic deformation and final uniform subsidence. In China, Fengfeng mining group has made an experiment on extracting coal reserves under Sinsi village by harmonic mining technology. Seven longwall faces were simultaneously conducted, and coal reserves under the village was simultaneously extracted by two longwall faces. Because there was no gob edge under the village, the surface deformation in the village was reduced.

THE TREND OF GROUND CONTROL TECHNOLOGY

(1) The paste backfilling method will be the developmental trend of strata and surface movement control technology and mining under "3-body". Paste backfilling is being studied both in the laboratory and field. It represents the development trend of subsidence control technology and mining "under 3-body". As one of the important measures of "green mining technology", it will become an important measure for protection of surface structures from damage. Although the paste backfilling has some disadvantages, this method is a favourite approach to realize "green mining". On the one hand, paste backfilling method can make use of solid waste material so that environmental pollution problem caused by solid waste material is solved to some degree. On the other hand, some problems of mining environment and safety can be solved to some extent. So paste backfilling technology using solid waste material represents the developing direction of strata and surface movement control and mining coal reserves under villages.

(2) The strip pillar mining method can reduce surface subsidence effectively, and protect surface structures from damage. Since strip pillar mining is an important technical measure to control mining subsidence and to extract coal under "3-bodies", it will continue to be widely used in China's coal mines. At present, the research on deep-strip pillar mining is not enough. As the mining depth increases, it is increasingly urgent to research deep strip mining design and surface subsidence prediction. When the mining depth of strip pillar mining is more than 500m, there isn't a good method to select prediction parameters. As to multiple seams, the theory of surface movement and deformation design for strip pillar mining is still not perfect, so it results in larger differences between predictive results and field observation. Therefore, it is necessary to use new theories to study the mechanism and laws of mining subsidence.

(3) There is a series for the difficulties of traditional backfilling method, for example, backfilling technology is complicated, the cost is higher, the coal production decreases, mining production is affected by the backfilling method. Therefore, this method is rarely used at present in China. Bed separated grouting technology can reduce the surface subsidence. But it still needs to be studied in many aspects. Now, its application is not extensive. Although the room and pillar method is employed in many foreign countries, the percentage using room and pillar mining method gradually decreases. Because there are some differences in geologic and mining conditions between China and foreign countries, room and pillar is rarely used. Harmonic mining method has many disadvantages, for example, it can only reduce surface deformation and can't reduce surface subsidence. Thus harmonic mining technology cannot become the main measure of subsidence and ground control, and therefore its application is limited in China

CONCLUSIONS

China is a big country of abundant coal resources and coal production. But the problems of surface subsidence and environmental hazards due to coal mining are becoming increasingly serious. It is necessary to study mining subsidence and damage prevention technology. The current status of the coal mining subsidence and ground control technology in China are analysed and discussed in this paper. The measures to control subsidence and prevent damage in China mainly include: the partial mining method, the backfilling mining method, bed separation grouting in overburden strata and the harmonic mining method. The partial mining methods include the strip pillar mining method, the room and pillar method and the limited thickness (height) mining method. The traditional backfilling mining methods include hydraulic backfilling, pneumatic backfilling, mechanical backfilling, and coal gangue sliding filling.

The Strip pillar mining method is regarded as an important measure to control mining subsidence and to extract coal reserves "under 3-body". It is and will be used widely in China's coal mines. Paste backfilling technology and strip pillar mining technology are both very important measures. They are suitable for mining practice in China. They represent the development trend of damage control technology.

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