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Mining subsidence control by solid backfilling under buildings

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Abstract: Solid backfilling mining can reduce the buildings' damage caused by mining greatly. The reduction of subsidence value, the slow advancing speed and the subsidence caused by backfilling body compaction are the main reasons that solid backfilling mining velocity decreases significantly. Based on the research of mechanism, some principles on subsidence control of solid backfilling mining under buildings were proposed. The equivalent mining height was designed according to the fortification criteria of buildings and their attachment structures, which enables the ground movement and deformation caused by mining to be less than the corresponding fortification criteria.

Key words: solid backfilling mining; subsidence control; mining under buildings

1 Introduction

Coal resources exploitation leads to a series of environmental problems, such as solid waste pollution, farmland reduction, and buildings damage. Meanwhile, plenty of coals under buildings, water and railways are not exploited in China. According to the data from China Coal Ministry, coal under buildings accounts for 63.5% of the total buried 13.79 billion tons coal [1]. Conventional mining technologies (caving method, strip mining, etc) usually cause contradiction between coal mine and local residents in addition to loss of resources.

Solid backfilling mining is the technology which uses equipment to fill gangue, coal ashes and other solid waste into goaf to occupy the space caused by coal exploitation. Therefore, the roof and floor movement space decrease, and the surface subsidence decreases. Meanwhile, during the process of filling, large numbers of gangue, coal ashes and other solid wastes are consumed. So, we can call the solid backfilling mining a green technology which integrates subsidence control with environment protection.

Now, environment pollution and mining under buildings, water and railways are big problem in China. More coal mines pay attentions to solid backfilling method due to its successful industry experiments. Recently, several coal mines, such as Xingtai [2], Jining No.3 [3], Zhaizhen [4] have successfully applied this new method.

Based on the analysis on subsidence control mechanism of solid backfilling mining, principles of solid backfilling mining design are given in this work. Moreover, for the aim of subsidence control, design methods of solid backfilling mining are also proposed.

2 Subsidence control mechanism

2.1 Solid backfilling mining technology

Solid backfilling mining technology contains three classes: fully mechanized solid backfilling mining technology, conventional mechanized solid backfilling mining technology and roadway excavation solid backfilling mining technology. Among them, fully

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mechanized solid backfilling mining, whose working face layout mode is similar to fully mechanized mining, is the most widely used one. In the case of solid backfilling technology, the filling working face is deployed on one side of the goaf (i.e., at the back of mining working face), and a transportation belt, which shifts the solid material to scraper chain conveyor, is set in the headentry of working face. Two scraper chain conveyors with the same direction are set at the front and rear of hydraulic support. The rear of hydraulic one is called solid backfilling conveyor, which hangs under the horizontal rear canopy and several dropping holes are made on it. Solid backfilling conveyor is connected with the transportation belt, then solid materials can be transported to solid backfilling conveyor and fall from dropping holes, until the goaf is full of solid filling material. All the backfilling tasks can be done at the shield of horizontal tail beam (Fig. 1).

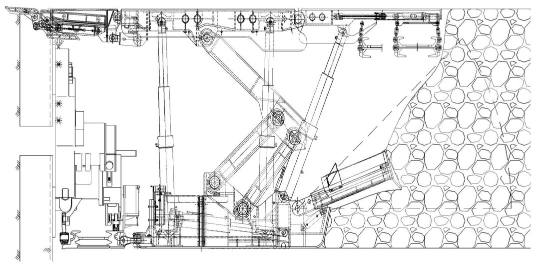

Fig. 1 New solid backfilling hydraulic support [5]

As shown in Fig. 1, solid filling materials fall into goaf through dropping holes on solid backfilling conveyor, and then they are compacted by the push-tamp equipment which is set at the rear of hydraulic support, finally the density and ratio of backfilling body can be increased.

2.2 Subsidence reduction mechanism

From the description of solid backfilling mining technology, the goaf is occupied by compacted solid material. The common solid backfilling materials (gangue, coal ashes, loess) are discrete medium. While the ground pressure is added, backfilling materials will be compacted, broken and the particle gradation can be improved, which can enhance the anti-compact capability significantly. Figure 2 shows the stress—strain curve of the gangue compression in the cylinder compression test.

When the subsidence increases, the reaction of overburden strata suffered from backfilling body raises until it is balanced with the overburden strata's pressure, and then strata movement stops. A lot of similar materials and numerical simulation result show that [6−7] the overburden strata usually develops fracturing zones and bending zones when the solid backfilling technology

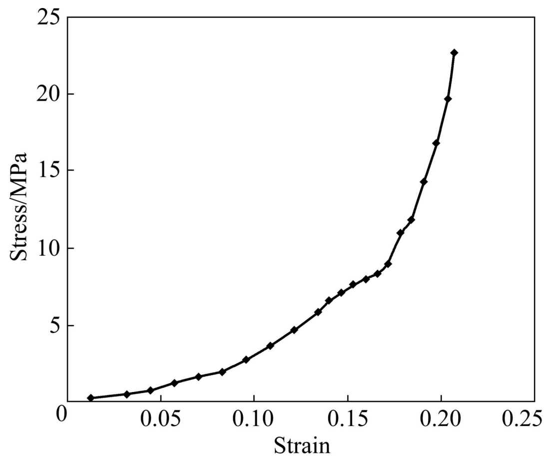

Fig. 2 Stress—strain curve of gangue cylinder compression test [6]

is used, and the overlying strata subsides heterogeneously. Therefore, in the critical mining conditions, the surface subsidence value of solid backfilling mining depends mainly on the subsidence of roof which is determined by mining height and final compression value of the backfilling body. Compared with the caving method, the roof subsidence space, which is the difference between the mining height and the final compression height of backfilling material, decreases significantly. This is the main reason why solid backfilling mining can reduce subsidence.

2.3 Slow down subsidence velocity mechanism

In fact, strata movement of solid backfilling mining is a process that overburden strata moves towards goaf and compacts the filling body, then the filling body is consolidated and the anti-compression ability of it increases until the reaction is balanced with the press of overburden strata. After coal exploitation, the ground pressure at the top of coal seam diverts to the wings, and at this time, the filling body is unloaded. While the working face is advancing, the stress on the filling body will recover to the original rock stress, with the filling body compressed to "release" subsidence space correspondently. The subsidence space of roof decreases and it derives from the "release" space of backfilling body's compaction which is the big difference between solid backfilling mining and caving method. The subsidence velocity depends on the advancing speed of working face, the depth of mining, the maximum subsidence value, the inclined length of mine area, etc. The results show that subsidence velocity has a positive correlation with the advancing speed of working face, the mining height and the maximum subsidence value, while it has a negative correlation with the depth of mining [8−9].

The subsidence of solid backfilling mining can reduce greatly. Meanwhile, the advancing speed of solid backfilling mining is slower than that by the caving method for its technological characteristics. Moreover, the subsidence space is caused by backfilling body compaction. These are the main causes that solid backfilling mining velocity decreases significantly.

3 Subsidence prediction method

Through the analysis on subsidence control mechanism of solid backfilling mining, it can be concluded that subsidence reduces greatly because backfilling body occupies the mining space, which means that it decreases the mining height. Actually, the mining height of solid backfilling mining, which is called equivalent mining height, is the difference between the mining height and the height of backfilling body after long time compaction and rheology by overburden strata. Similar material simulation and in-situ measurements of solid backfilling mining show that the subsidence basin by solid backfilling mining is the same as caving method with equivalent mining height. So, the subsidence prediction of solid backfilling mining can be switched to the subsidence prediction by caving method with equivalent mining height. The subsidence prediction parameters and methods of thin coal seams could be used for it.

In the subsidence prediction of solid backfilling method, how to determine the equivalent mining height is the key issue. The analysis of subsidence influence factors by solid backfilling mining shows that the elements affecting the equivalent height are: the thickness of coal seam, the movement of roof and floor before filling, the backfilling rate, the prime compression of the backfilling body, the residual compression of the backfilling body, etc. Then the calculation of equivalent height can be divided in two parts:

1) The height of filling body (H_0) filled into the goaf can be calculated with the following formula:

$$H_0=H-\Delta-\delta \quad (1)$$

where δ is the gap between the backfilling body and roof, Δ is the movement of roof and floor before filling, and H is the thickness of coal seam.

2) Equivalent height can be decided by the following formula:

$$H_z=H-H_0+\eta H_0 \quad (2)$$

where η is the residual compression rate of solid filling body.

After that, solid backfilling mining subsidence can be calculated by the equivalent mining height and strata movement parameters in the coal mines.

4 Subsidence control principles and design methods under buildings

4.1 Subsidence control principles

It can be known from the theoretical analysis of equivalent mining height that the key for subsidence reduction by solid backfilling mining is to reduce the mining height of coals. While under a particular geological and mining condition, the strata movement and deformation values can be decided by the equivalent mining height. The task of subsidence control of solid backfilling mining is that the surface movement caused by mining should be less than the fortification criteria of buildings. Thus, subsidence control principles of solid backfilling mining can be described as follows. The equivalent mining height is designed according to the fortification criteria of buildings and their attachment structures, which enables the ground movement and deformation caused by mining to be less than the corresponding fortification criteria. Based on the experience of mining under buildings, subsidence and horizontal deformation are usually selected as the fortification criteria of buildings in coal mines:

$$W_z \le W_c$$

$$\varepsilon_z \le \varepsilon_c$$

where W_z is the maximum subsidence in the building area after mining with the designed working face; W_c is the fortification criterion of ground subsidence value in designed building area; ε_z is the maximum horizontal deformation in the building area after mining with the designed working face; ε_c is the fortification criterion of horizontal deformation value in designed building area.

According to the former analysis, it can be concluded that in a certain working face, the ground subsidence and horizontal deformation are decided by the equivalent height solely, thus the former principles of subsidence control can be illustrated briefly as:

$$H_z \le H_c$$

where H_z is the designed equivalent mining height of working face; H_c is the critical equivalent mining height calculated by fortification criteria of buildings and their attachment structures.

4.2 Subsidence control design methods of mining under buildings

The key part in the application of subsidence control principles by solid backfilling mining is to decide the designed and critical equivalent mining heights. The designed equivalent mining height can be calculated according to Eq. (2). Besides, the critical equivalent mining height can be got by the ground movement and deformation fortification criteria of buildings and their attachment structures. The flowchart is shown in Fig. 3.

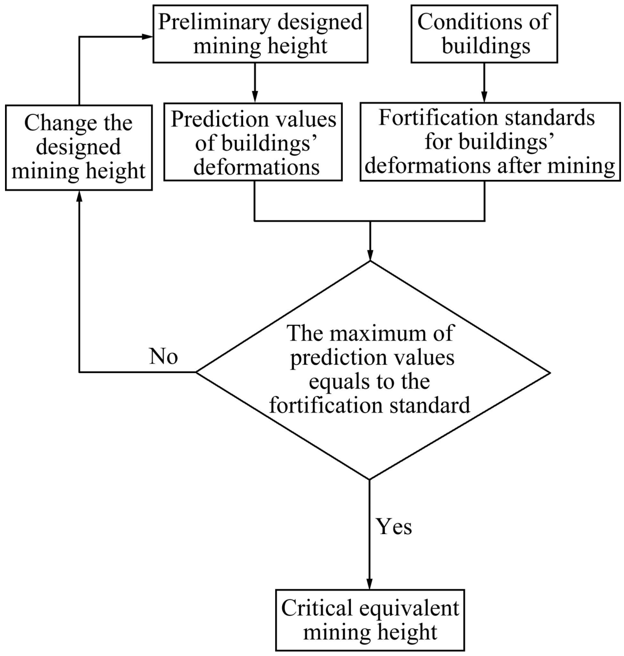

Fig. 3 Flowchart for calculation of critical equivalent mining height

In the process of critical mining height computation, it is difficult to enable the prediction value of deformation to be the same with the fortification criteria. So, if the difference between the prediction value of deformation and the fortification criteria is less than 5%, it is acceptable. The prediction of buildings' deformation is done with the probability integral method based on the equivalent mining height while the thin coal seam parameters are used in the process.

When the working face is critical mining and the maximum deformation value locates in the buildings' area, the schedule for calculation of critical equivalent mining height can be simplified. According to principles of probability integral method, the critical equivalent mining height can be expressed in the following formula, while the maximum subsidence in buildings' area should be less than the subsidence criteria.

$$H_z \le \frac{W_c}{q\cos\alpha} \tag{3}$$

While the maximum horizontal deformation in buildings' area should be less than the horizontal deformation criteria. The critical equivalent mining height can be expressed as

$$H_z \le \frac{\varepsilon_c H}{bq\tan\beta\cos\alpha} \tag{4}$$

where q is the subsidence coefficient; H is the depth of mining; $\tan\beta$ is the tangent of the main influenced angle; and α is the incidence angle of coal seam.

In practical, the smaller one of the two values, which are calculated by Eqs. (3) and (4) respectively, can be selected to ensure the safety use of buildings.

5 Engineering example

5.1 Geological and mining conditions of working face

In this case, the working face is 450 m in length, 142 m in inclined width, 335 m in average depth, 8° in inclined angle and 3.3 m in thickness of coal seam. For the roof management, solid backfilling is adopted. The direct roof of working face mainly consists of siltstone-mudstone intercalation and post stone with the average thickness of 7.44 m. Sandy shale is the main part of the floor whose average thickness is 4.81 m. Villages, highways and other buildings locate above the working face and the land is flat.

5.2 Subsidence control design

Above the working face, there are several buildings such as villages, the industry square of coal mine, some roads and the shaft. After researching the buildings' qualities, and referencing to the 27th item of Regulations on Coal Pillar Design and Mining Regulations Under Buildings, Water, Railways [10], it is fixed that the fortification of subsidence in this district is 500 mm and the horizontal deformation criterion is 1.5 mm/m. The subsidence prediction parameters are inversed by the thin coal seam measurement, that are subsidence coefficient 0.73, horizontal movement coefficient 0.34, tangent of main influence angle 1.8, deviation of inflection point 0.1H. While the geological and mining conditions, and filling technology of this case are considered, the roof-to-floor convergence before backfilling is 100 mm and the gap between the backfilling body and roof is zero.

The critical equivalent mining heights are calculated to be 0.69 m and 1.2 m by taking the subsidence and horizontal movement as the fortification standards respectively. According to the principles of subsidence control, the critical equivalent mining height of 0.69 m should be chosen. The residual compression rate should be less than 18.4% from Eq. (2), and the designed residual compression rate should be less than 15% for safety.

Meanwhile, in order to master the strata movement laws of solid backfilling mining, and ensure the safety of buildings, strata movement monitoring stations have been set.

5.3 Subsidence control effect

By using prediction technology of solid backfilling mining, the ground subsidence and horizontal deformation of solid backfilling mining and caving method are calculated respectively. The comparison between the predictions and the true measurements is listed in Table 1.

Table 1 Comparison between prediction value and measurement value

Item	Equivalent mining height/mm	Maximum of subsidence/mm	Maximum of horizontal deformation/(mm·m^{-1})	Classes for buildings' damage
Caving method	3 300	987	−9.5, +4.3	III (serious)
Designed residual compression ratio 15%	580	173	−1.7, +0.8	I (light)
True residual compression ratio 7.8%	350	105	−1.0, +0.5	I (very light)
Measurement value		15	−0.2, +0.1	I (very light)

From Table 1, it can be concluded that solid backfilling mining can reduce the buildings' damages caused by mining to a large extent. At the same time, the true measurement values are far less than the results calculated based on the theory of equivalent mining height, which means that the result calculated by equivalent mining height is safety.

6 Conclusions

1) Solid backfilling mining can reduce the buildings' damages caused by mining greatly. The decrease of overburden strata movement space, which is the difference between the mining height and the height of backfilling body after long time compaction and rheology by overburden strata, is the main reason that solid backfilling mining can reduce ground subsidence.

2) The reduction of subsidence value, the slow advancing speed and the subsidence caused by backfilling body compaction are the main reasons that solid backfilling mining velocity decreases significantly.

3) The fortification principles and technologies for solid backfilling mining under buildings are proposed. The equivalent mining height is designed according to the fortification criteria of buildings and their attachment structures, which enable the ground movement and deformation caused by mining to be less than the corresponding fortification criteria. In the process of designing, the critical mining height can be derived by subsidence prediction model according to the fortification criteria.

4) The case study shows that solid backfilling mining can reduce the buildings' damage caused by mining to a large extent and the result calculated by equivalent mining height is safety.

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