INTRODUCTION

In virtue of its great technical advantages in various fields for disaster control and prevention, including strata movement control, surface subsidence control, "Three Unders" coal release, solid waste treatment, and disaster control for extremely thick rocks, the solid backfilling mining method has been practically applied in mining-transportation-backfilling integrated mining and mining-dressing-extraction-backfilling-prevention integrated coal-gas comining. Undoubtedly, the application of solid backfilling mining method has been extended to frontier scientific issues in the field of coal resource exploitation such as deep mining, waste-free mining, and safe mining of coal and associated resources. As far as solid backfilling mining is concerned, the relevant theories include the equivalent mining height (mainly for prediction and control) and the "moving set-up room" theory (MSUR). This study provides references for precise control of strata position and status in backfilling mining.
control design of surface subsidence), the key strata stability control (for control of bending deformation of key strata), the main roof control (to determine whether the main roof is critically fractured), and finally the coal body-backfilling support-backfilling body synergistic roof control (for position and status stability control of immediate roof in the backfilling stope). These theories focused on position and status control of key strata, main roof, and immediate roof under the mining pressure, and have basically covered movement analysis and control design of different overlying strata and the ground in backfilling mining. For backfilling stopes, at high backfill ratios, the main roof is exposed to bending deformation only due to the supporting effect of the backfilling body, and the key strata are exposed to slight bending deformations owing to loads by overlying strata. The bending deformations depend on compactness and antideformation performance of the backfilling body; that is, the greater the compactness of the backfilling body, the smaller the crack propagation in overlying strata, and the smaller the bending deformation degree. At low backfill ratios, the main roof exhibits similar ground behavior and strata movements to those of the collapse mining roof management; that is to say, the backfilling body of the backfilling stope in backfilling mining exhibits significant weakening effect on mining, compared to the conventional mining such as collapse mining. Nonetheless, there is no intensive investigation on and effective understanding of mining pressure, and have basically covered movement analysis and control design of different overlying strata and the ground in backfilling mining. For backfilling stopes, at high backfill ratios, the main roof is exposed to bending deformation only due to the supporting effect of the backfilling body, and the key strata are exposed to slight bending deformations owing to loads by overlying strata. The bending deformations depend on compactness and antideformation performance of the backfilling body; that is, the greater the compactness of the backfilling body, the smaller the crack propagation in overlying strata, and the smaller the bending deformation degree. At low backfill ratios, the main roof exhibits similar ground behavior and strata movements to those of the collapse mining roof management; that is to say, the backfilling body of the backfilling stope in backfilling mining exhibits significant weakening effect on mining, compared to the conventional mining such as collapse mining. Nonetheless, there is no intensive investigation on and effective understanding of the mechanism of weakening the mining pressure caused by the backfilling body in the stopes, especially the qualitative characterization and quantitative expression of the weakening degree, the rational determination of critical weakening effect, and appropriate applications of the above said mechanism for the control design of backfilling mining pressure of the stope.

Generally, disturbances and damages of original rocks of the stope caused by set-up room were relatively low, meaning that the effects of set-up room on initial stress field and movement field were relatively small. In collapse mining, the gob range increased as the working face moved forward and the overlying strata support varied significantly. As a result, damages to the original rocks were gradually intensified, and the mining pressure was significant, resulting in roof instability, initial pressure, and periodic pressure. In this case, damages to the original rocks were significantly larger than those at the beginning of set-up room. In backfilling mining, the gob was backfilled by the backfilling body as the working face advanced and the support for overlying strata changed from the original coal body to compact the backfilling body. This resulted into a significant reduction of damages to the original rock. In other words, the backfilling body significantly weakened the mining pressure and variations of damages to the original rock are limited, obviously not as significant as those at the beginning of set-up room.

Therefore, to fully understand the mechanism of reducing the mining pressure caused by the backfilling body in the stope, this paper proposes the MSUR theory to characterize this introduced mechanism. Based on qualitative analysis of the control characteristics of backfilling mining pressure in the stope, a stress-movement analysis model was established to focus on the backfilling stopes and used for studying the evolution characteristic of stress and movement in the backfilling stope, and hence clarify the concept and characteristics of moving set-up room. At the same time, by analyzing scientific characterization of moving set-up room based on its effect, the critical conditions of the moving set-up room effect and the design of mining stope pressure were developed to provide references to industrial applications of the moving set-up room theory.

2 | SUPPORTING SYSTEM FOR THE SURROUNDING ROCK OF THE STOPE AND CHARACTERISTICS OF WEAKENING THE MINING PRESSURE IN BACKFILLING MINING

2.1 | Supporting system for the surrounding rock of the stope in backfilling mining

The solid backfilling mining is a kind of mining method that uses solid waste such as gangue to fill the goaf and control the roof from the perspective of mining damage or ground control, its remarkable feature is that it changes the overburden support system of the stope.

In collapse mining, the supporting system for overlying strata of the working face stope consists of coal walls only before roof fractures. After the gob is formed, a cantilever beam structure was observed on roof and its length continuously expanded as the working face was advancing. Meanwhile, area of the bare and suspended part of the roof increased gradually, the flexural rigidity was insufficient to support the load of overlying strata, and fractures occurred. As a matter of fact, the supporting system was converted into the coal wall-hydraulic support-collapsed and broken gangues in the gob structure (Figure 1). The collapsed and broken gangues in gob can barely resist initial subsidence of roof, and periodic fractures were observed for the roof as the working face advanced, resulting in severe variations of abutment stress and overlying strata movement; which produced a significant mining pressure. For the backfilling mining face represented in Figure 2, the gob was continuously backfilled by backfilling materials, and the supporting system for overlying strata in the stope consisted of coal wall, backfilling mining hydraulic support, and backfilling body during the entire process. Indeed, the backfilling body can provide a certain resistance to prevent the roof bending and subsidence from the beginning. Hence, no cantilever beams would be observed on the
immediate roof as the working face was advancing and no periodic fractures would be observed for the main roof. In this case, the abutment stress in the stope and overlying strata movement exhibited slight variations and the mining pressure was not significant.

2.2 Characteristics of the weakening the mining pressure caused by backfilling mining

Before the roof is disturbed by mining, the supporting system for overlying strata in the backfilling stope is composed only of coal walls. After backfilling, the gob was controlled by coal body, backfilling mining hydraulic supports, and backfilling body. The supporting effect of the backfilling body reduced the mining pressure and exhibited a significant weakening effect on it and on the movement of overlying strata. The basic characteristics of weakening the mining pressure caused by backfilling body were as follows.26-30

2.2.1 Ground behavior

Compared with roof management by collapse mining, the degree of movement and stress concentration of overlying strata in the backfilling stope obviously weakened. At high compactness of the backfilling body, no significant first or periodic weighting was observed and the stress concentration coefficient was significantly lower than that in collapse mining. However, when the compactness of the backfilling body was low, the ground behavior of the backfilling stope was similar to that in collapse mining. It also showed initial and periodic weighting, and the stress concentration coefficient was consistent with that in collapse mining.

2.2.2 Mining pressure control

The movement of overlying strata in backfilling stope is controlled by coal wall, backfilling support, and backfilling body, with the backfilling body being the key factor. The backfilling rate or the compaction of the backfilling body relieves the ground behavior, and this is indeed the reduction of mining pressure caused by backfilling body. Different weakening states correspond to different ground behavior characteristics, which can be characterized by direct parameters reflecting the mining pressure such as overlying strata movement, peak abutment stress, stress concentration coefficient, and other incurring mining pressures. The weakening effects were affected by various factors including the structure of overlying strata, backfilling body compactness, size of the working face, gob size, and backfilling space.

2.2.3 Definition of weakening

Critical conditions are present for weakening the mining pressure caused by the backfilling body, meaning that
significant differences in ground behavior could not be observed until weakening reached a critical state and its effect was negligible at weak weakening state compared to the roof management in collapse mining. In other words, the weakening status can be clearly defined by tuning parameters such as compactness of backfilling body.

Therefore, it is necessary to conduct in-depth studies on the movement and stress concentration of overlying strata in the backfilling stope in order to clarify the basic contents of the proposed MSUR theory.

3 | ANALYSIS MODEL FOR SET-UP ROOM AND WEAKENING THE MINING PRESSURE CAUSED BY THE BACKFILLING BODY IN THE STOPE

3.1 | Numerical modeling method

Based on fundamental engineering data and experimental tests of backfilling materials and strata parameters, a dynamic analysis model was established by ABAQUS for the overlying strata movement in backfilling mining and a support entity model was established by Pro/E. Afterward, a constitutive analysis model was established for experimental testing of the backfilling body and measured compactness of the stope. Eventually, the support entity and constitutive models of the backfilling body were introduced into the dynamic analysis model of the overlying strata movement in solid backfilling mining. The trends of bearing stress and movement of the stope as a function of work face recovery were obtained by comparing dealing with the gob in backfilling mining and collapse mining, in order to investigate the movement characteristics of the surrounding rock of stope in solid backfilling mining.

3.2 | Backfilling body model

According to the backfilling body stress-strain trends in the backfilling stope at the compacted forming stage and the overlying strata loading stage, the backfilling body can be regarded as an isotropic elastoplastic model, and the stress-strain curve was divided into two stages of elasticity and plasticity, which were fitted in segments by the following equation:

\[
\sigma = \begin{cases} 
A\varepsilon, & 0 \leq \varepsilon \leq \varepsilon_0 \\
\exp(B\varepsilon + C) + D, & \varepsilon > \varepsilon_0 
\end{cases}
\] (1)

When the backfilling body was at the elastic stage, the elastic modulus E was directly given (deduced according to measured stress-strain curve of the backfilling body). In case the backfilling body was at the plastic stage, 50 groups of discrete stresses and corresponding plastic strain values were input in the form of a list and \(\varepsilon_0, A, B, C,\) and \(D\) in Equation (1) were determined by the UMAT program in ABAQUS using the FORTRAN77 Language. In this way, stress-strain functions of the backfilling body at elastic and plastic stages were obtained and the numerical model of the backfilling body was established.

3.3 | Hydraulic support model in backfilling mining

A component model was established for hydraulic support in backfilling mining using Pro/E 5.0 software and assembled into an entity model based on the mutual constraints (Figure 3A); then, the model was imported into ABAQUS in the Stp file format, and segments, curved surface, and entity with small-sized supporting structures were restrained by geometric repair. Each element was defined as a set defining the material properties of different components in the support, and attributes were given to components in the support, respectively. Finally, a finite element analysis model was established for the support by gridding (Figure 3B).

3.4 | Backfilling working face recovery model

This paper is based on the 7203W working face in Zhaizhen Coal Mine. The vertical depth of the working face was 517.1-565.8 m. The corresponding ground elevation at the working face was +177.1 to +181.2 m, while the underground elevation was −340 to −384.6 m. Its average strike length was 286 m. The average inclined length was 92.8 m. The
coal seam on working face had a thickness of 2.73 m with an average inclination angle of 10.5°. Gangue was used as solid backfill material on the working face.

Based on the actual geological and engineering conditions of the 7203W working face in Zhaizhen Coal Mine, the proposed simulation model for the backfilling hydraulic support was imported into the ABAQUS to develop a synergistic roof control model of the backfilling body and hydraulic support (Figure 4). The C3D8I unit and asymmetric solver were used for the proposed model, a uniform pressure of 11.05 MPa was applied in the initial crustal stress analysis step (Geostatic) in ABAQUS to replace the weight of the strata at 428 m, and a vertical acceleration of 9.8 m·s\(^{-2}\) was applied to simulate the initial stress field. The model has a size of 300 × 190 m × 189.7 m, and the horizontal movements were restrained by the surroundings and translational movements were restrained by the base, leaving 50 m of protective coal pillars at each side, which means the actual length, propagation step, and backfilling step of working face in the simulation were 90, 200, 8.0, and 8.0 m, respectively. A total of 25 steps of excavation and backfilling were involved. The upper and lower roof beams of the backfilling hydraulic support were in contact with the top and bottom of the coal seam, and the backfilling body model was implanted in real time during the backfilling process, thus achieving simulation analysis of the dynamic excavation of solid backfilling mining stope, support moving, and backfilling recycling.

3.5 Simulation scheme and monitoring parameters

In order to quantitatively study the trends of stope stress and overlying strata movement as a function of the working face recovery in backfilling mining and collapse mining, the specific parameters were taken as follows: Elastic...
The foundation coefficients of the backfilling body were $0.0 \times 10^6$, $4.0 \times 10^6$, $10.0 \times 10^6$, and $16.0 \times 10^6$ N·m$^{-3}$, which was equivalent to collapse mining and backfilling mining with different backfill ratios. The support used was a six columns backfilling mining hydraulic support; the monitoring parameters included the subsidence of overlying strata, stresses on the backfilling body, and coal rocks. Table 1 summarizes the four simulation analysis plans involved in this study.

### Table 1 Simulation analysis plans

| Plan | Type of support | Elastic foundation coefficient (kg/10^6 N·m$^{-3}$) | Gob treatment method | Monitoring parameters |
|------|-----------------|---------------------------------------------------|---------------------|-----------------------|
| 1    | Six columns     | 0                                                 | Collapse mining     | I. Subsidence of overlying strata |
| 2    |                 | 4                                                 | Backfilling mining (backfill ratio 70%) | II. Stress on the backfilling body and coal rocks |
| 3    |                 | 10                                                | Backfilling mining (backfill ratio 82%) |                       |
| 4    |                 | 16                                                | Backfilling mining (backfill ratio 90%) |                       |

4 | ANALYSIS OF CHARACTERISTICS OF SET-UP ROOM AND WEAKENING THE MINING PRESSURE CAUSED BY THE BACKFILLING MINING STOPE

#### 4.1 Evolution of the stress field with the working face

According to the results of schemes 1 and 4, the distributions of abutment stress under the condition of collapse mining and backfilling mining are respectively obtained as shown in Figure 5 and Figure 6. The following are observations:

1. A significant abutment stress zone was formed around the working face stope at the early stage in collapse mining, and the peak stress showed a significant change by increasing from 32 MPa to 46 MPa as the working face advancement reached 96 m;
2. No significant abutment stress zone was observed around the working face stope during the entire process in backfilling mining, and the abutment stress showed no significant change with the advancement of the working face. Indeed, the peak stress increased from 17.0 to 18.0 MPa as the working face advanced to 96 m.
3. Compared with that in collapse mining, the working face stope in backfilling mining was in a relatively weak abutment stress environment, and the overall damage degree of the surrounding rock was obviously weakened.

Based on further analysis of data of Figures 5 and 6, the abutment stresses at different recovery positions along the working face axis were obtained according to the central part of the face (Figure 7), while the peak stresses are shown in Figure 8.

It can be clearly observed in Figures 7 and 8 that:

1. The stress in the backfilling body gradually increased as the working face advanced and reached the maximum

![Figure 5](image-url) Distribution of abutment pressure in collapse mining as a function of working face location. A, At the initial stage of moving set-up room. B, Working face advances to 96 m
value when the face advanced to 200 m. Along the working face recovery direction, stress in the backfilling body was distributed in the form of an inverted basin, which means that the stress position in the middle is high and low at both ends.

2. For collapse mining, the stress concentration coefficient in coal wall gradually increased as the working face was advanced, and the distribution values were 2.08, 2.44, 2.81, 2.97, and 2.60 as the working face approached 32, 48, 96, 152, and 200 m, respectively. Moreover, the stress concentration was ranging between 2.0 and 3.0, which indicated high stress concentration and slight variations of the stress field during the mining process of the solid backfilling coal mining. This was observed under the condition that the gob was densely backfilled (compact backfilling) by the

3. For backfilling mining, the stress concentration coefficient in coal wall remained basically unchanged with the advancement of the working face. When the working face advanced to 32, 48, 96, 152, and 200 m, the stress concentration coefficient in coal wall was 1.07, 1.09, 1.11, 1.11, and 1.09, respectively, concentrated around 1.1, indicating the relatively low stress concentration and slight variations of the stress field during the mining process of the solid backfilling coal mining. This was observed under the condition that the gob was densely backfilled (compact backfilling) by the

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**FIGURE 6** Distribution of abutment pressure in backfilling mining as a function of working face location. A, At the initial stage of moving set-up room. B, Working face advances to 96 m

**FIGURE 7** Abutment stress at different recovery positions in the axial direction of the working face. A, Collapse mining. B, Backfilling mining

**FIGURE 8** Stress concentration coefficient comparison in backfilling mining and collapse mining
backfilling body, meaning that damages to the stress field of original rock were relatively low.

4. According to the above rules, it can be obtained that if the backfill ratio is further reduced from 70%, the stress concentration coefficient of coal wall increases significantly until it is similar to the working face with caving method.

4.2 | Evolution of movement field with the working face

According to the results of plans 1-4, the cloud charts of movement were not illustrated and movements of immediate roof were directly extracted to investigate the movement of surrounding rock in the stope in collapse mining and backfilling mining (Figure 9). Based on that, peak movements of immediate roof in collapse mining and backfilling mining with different conditions were obtained (Figure 10).

Figures 9 and 10 clarify the situation as follows:

1. The immediate roof subsidence gradually moved forward with the advancement of the working face, and the overall subsidence increased significantly with the increase in backfilling distance of the working face in collapse mining. The immediate roof movements were 500.00, 956.37, 1526.07, 1920.39, and 2128.53 mm when the working face advanced to 32, 48, 96, 152, and 200 m, respectively.

2. In backfilling mining, the immediate roof subsidence gradually moved with the advancement of the working face, while the overall subsidence remained independent of the backfilling distance. With foundation coefficient of backfilling body of $16.0 \times 10^6$ N·m$^{-3}$ as an example (compact backfilling), the movement of immediate roof was 213.38, 234.36, 265.63, 281.54, and 288.78 mm as the working face advanced to 32, 48, 96, 152, and 200 m, respectively. Moreover, the peak subsidence of immediate roof is related to the backfill ratio, although the variation is small.

3. The movement of the working face stope in backfilling mining can be regarded as the movement of a set-up room, while that in collapse mining leads to continuously expanding the gob and continuously exacerbating damages to the surrounding rock.

5 | BASIC CONTENTS OF THE MSUR THEORY IN BACKFILLING COAL MINING

5.1 | Basic concept of the moving set-up room theory

Based on the trends of stress and movement of the stope, the moving set-up room theory for backfilling stope is proposed. In this theory, the increase in the backfilling gob in the
compact backfilling mining face with high backfill ratios will not exacerbate damages to the overlying strata. Instead, in collapse mining, damages to the overlying strata were characterized by stress in the stope and movement of the roof. As a result, the maximum movement point of the overlying strata gradually moved forward with the advancement of the working face, while the overall subsidence was independent of the backfilling distance of the working face. Meanwhile, no significant changes in the stress concentration coefficient of the stope were observed; it remained at a level between 1.1 and 1.3 as the working face moved forward, and a low stress concentration degree (weak damages to the stress status of the original rock).

Generally speaking, the disturbance and damage degree of the stope to the original rock of the stope are relatively low; that is to say, it has little influence on the original stress field and displacement field. The mining process of the working face of the backfilling stope is visually expressed as a moving set-up room, and the weakening effect of the dense backfilling body on the mining effect is vividly equivalent to the influence of the moving set-up room on the original stope. Therefore, the effects of the working face on backfilling mining can be visually compared to the effects of a slowing down the moving set-up room on mining of overlying strata (Figure 11), and then, this paper reveals the basic law of strata pressure appearance and overburden movement.

5.2 Basic characteristics of the MSUR theory

Characteristics of the set-up room theory for the stope movement in backfilling mining include the following:

1. A moving set-up room is generated only when the backfill ratio satisfies the critical conditions. Indeed, the moving set-up room effect on weakening of the mining pressure caused by the backfilling body in backfilling mining is proportional to the backfill ratio. Therefore, the greater the backfilling ratio, the more obvious the effect of moving set-up room on the whole backfilling system.

2. The key engineering parameters such as backfilling ratio, working face size, size, and height of mining space all affect the formation of dynamic set-up room effect, meaning that these parameters constitute the influencing factors of critical conditions for the moving set-up room effect. It is hence necessary to combine the above-mentioned influencing factors and analyze specific issues case by case.

3. According to the characterization of stress in the stope and movement of the roof in the moving set-up room theory, the movements were reflected in two aspects. First, the maximum subsidence location of overlying strata moved with the working face, while the peak subsidence was basically not significant. Second, the peak abutment stress point moved as the working face advanced, while the peak stress remained basically unchanged.

4. The moving set-up room theory reflects the weakening effect of backfilling body on the mining pressure, movement characteristics of overlying strata in the backfilling stope, and the significant differences with the mining pressure of stope in the roof management in collapse mining.

5. The moving set-up room theory explains the motivation of strict control of strata movement and surface subsidence in backfilling mining, thus providing references for industrial design of backfilling coal mining (optimization of the working face, surface subsidence control design, and support design for the stope).

6 INDUSTRIAL APPLICATIONS OF THE MSUR THEORY IN THE BACKFILLING STOPE

6.1 Qualitative description and quantitative characterization of moving set-up room

The moving set-up room theory essentially reflects the weakening effect of the mining pressure caused by the backfilling body. However, the moving set-up room effect is affected by the weakening degree. In backfilling mining, the working face can be regarded as a moving set-up room if and only if the mining pressure is sufficiently weakened. In this case, the backfilling stope with no periodic weighting or ground behavior is defined as the critical condition for qualitative description of moving set-up room. Therefore, the moving set-up room can be qualitatively described by the following situation: Unlike the roof management by collapse mining, the backfilling mining activities are equivalent to the set-up room effects on the stope in the absence of significant periodic weighting and ground behaviors in the backfilling stope, owing to the supporting effect created by the backfilling body in roof management by backfilling mining. In this case, the mining pressure is weakened to become the moving set-up room effect status. This is commonly observed in the compactly backfilled stope with the surface subsidence control as the primary objective. Otherwise, the mining pressure is not in the moving set-up room effect status and this is commonly observed in the noncompactly backfilled stope with the treatment of solid wastes but not strata control as
the objective. Furthermore, parameters reflecting the mining pressure, such as the overlying strata movement, peak abutment stress, and stress concentration coefficient, can be quantitatively described by the moving set-up room effect. More specifically, the critical condition of the moving set-up room effect can be solved first, and then, the quantitative expression of the moving set-up room effect under the same condition is given.

In the solid backfilling mining, the quantitative expression is tentatively determined as follows: The overall subsidence degree of the rock layer is basically unchanged with the increase in the mining distance of the working face; the stress concentration coefficient is basically unchanged with the forward movement of the working face, and remains about 1.1-1.3. In other backfilling conditions such as paste backfilling mining and high-water backfilling mining, the quantitative characterization of moving set-up room also needs to consider many factors such as the layout method of backfilling mining system, stope size, mining and backfilling time, loading characteristics of backfilling body.

6.2 Method of solving the moving set-up room effect under critical conditions (group)

Based on the above discussion, the method for solving the critical conditions for the moving set-up room effect is established. More specifically, the geological conditions of backfilling coal mining are analyzed first and the critical backfilling ratio is determined according to objective and control parameters of backfilling mining. Then, analytical simulation of the mining pressure on the backfilling stope is established by analog simulation or numerical simulation and different plans with combinations of backfilling ratio, working face size, mining space size and mining height are established for inverse simulations of the stope recovery in different plans. Afterward, weakening of the mining pressure caused by the backfilling body at different recovery locations of set-up room and working face is investigated and the parameters reflecting the weakening effect, including the overlying strata movement, abutment stress concentration coefficient, are extracted to determine whether the moving set-up room effect is achieved. Finally, the critical conditions (groups) of moving set-up room under the specific geological conditions are obtained based on the measured mining pressure on the backfilling stope under similar geological conditions. The design process is shown in Figure 12.
6.3 Control design of mining pressure of stope based on MSUR theory

The core of backfilling mining is to weakening the mining pressure in order to achieve precise control of strata position and status. The weakening effect of the backfilling body on the mining influence is reflected by the moving set-up room status. The working face in backfilling mining can be defined as a moving set-up room only when the mining pressure is weakened to a critical level. Based on that and according to its critical status, the backfilling stope can be divided into moving set-up room and nonmoving set-up room.

In the moving set-up room state, the mining pressure is weakened and easy to control; in the nonmoving set-up room state, the mine pressure is strong, and the mining pressure control is similar to the caving method.

The main controlling factors for the weakening of mining pressure caused by the backfilling body include the materials, equipment, and techniques of backfilling, and monitoring of the backfilling effect. Therefore, the fundamental principles of control design of mining pressure in the stope based on the moving set-up room theory are obtained; that is, the precise control of rock strata position and status is achieved by controlling major factors affecting the weakening of mining pressure so that the backfilling stope is in definite moving set-up room effect. It consists of four aspects as follows:

1. Selection of backfilling materials: Appropriate backfilling materials and optimized ratio shall be selected to guarantee excellent bearing capacity;
2. Backfilling equipment: The structure and ramming strength of backfilling support shall be optimized to guarantee good compactness of the generated backfilling body;
3. Backfilling technique: The early roof subsidence shall be controlled to guarantee enough space for backfilling and ensure as many compacting cycles as possible to optimize substance backfilling;
4. Monitoring of backfilling effect: A dynamic roof subsidence analyzer was installed for dynamic monitoring of the backfilling ratio to achieve dynamic feedback of compactness of the backfilling body, and data of ground behavior parameters were collected to achieve dynamic feedback of the mining pressure.

7 CONCLUSIONS

1. Based on the fundamental principles that disturbances and damages to the original rocks in the stope caused by the set-up room were relatively low and no significant ground behavior was observed in the backfilling stope, the moving set-up room theory was proposed and the weakening of mining pressure caused by the backfilling body was characterized. The scientific connotation included the qualitative expression and quantitative representation of the weakening status, appropriate definitions of critical conditions for the weakening effect, and control design of mining pressure in the stope based on the weakening effect.
2. The moving set-up room theory can be employed to characterize the mechanism of weakening the mining pressure caused by the backfilling body. Though the qualitative expression of the “moving set-up room” and “nonmoving set-up room” statuses, the parameters such as overlying strata movement, peak abutment stress and stress concentration coefficient were quantitatively characterized.
3. The fundamental principles of mining pressure control design in the stope by the MSUR theory are that the precise strata position and status control are achieved by controlling major factors affecting the weakening of mining pressure so that the backfilling stope is in definite moving set-up room status. This method consists of selection of backfilling materials, backfilling set-up optimization, technical support for backfilling, and backfilling effect monitoring, respectively.

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CONFLICT OF INTEREST
None.

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DATA AVAILABILITY STATEMENT
All data are available within the paper or may be provided by the corresponding author upon request.

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