Study on Numerical Simulation of Roadway Backfill under Freeway Based on FLAC\textsuperscript{3D}

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Abstract. Based on the paste-like roadway backfill technology in the study of coal mining under the freeway in Tang'an Mine, the mining scheme of coal under the freeway is described. In order to grasp the change law of the stress and damage degree of coal pillars and surrounding rocks during the coal mining process of roadway backfill, analyze the stability of coal pillars and the amount of roof subsidence, using FLAC3D numerical simulation method, select the width of coal pillar elastic plastic zone, the vertical stress of the column and the vertical displacement of the roof are used as indicators. The influence of the 15m temporary coal pillar width on the stability of the coal pillar, the stress distribution of the surrounding rock and the sinking of the roof under the mining method are studied to verify the feasibility of the mining scheme.

1. Introduction
With the large-scale construction of expressways, the amount of coal resources overlaid on highways is increasing, and how to extract some coal resources overlaid under highways with reasonable security pillars is a very significant subject [1]. In order to solve the contradiction between the basic construction and safe operation of the expressway and the full utilization of underground mineral resources, the research work of coal mining under the expressway is urgently needed.

On the left side of the third panel of the Tang'an Coal Mine, the newly constructed Gaoqin Freeway passes through the east-west direction. The coal pressure of coal seam 3 under the expressway in the third panel of Tang'an coal mine is 4-5 million tons. If the coal pillars are mined by the filling method, not only wastes such as coal gangue can be consumed to improve the mining area environment, but also economic benefits of adding several hundred million yuan to the mine. Considering that the roadway backfill method can not only be flexibly arranged, but also reduce the investment in filling equipment and increase the filling rate [2], the roadway coal mining with paste-like backfill method is adopted to liberate the coal under the freeway.
2. Coal pillar mining design
The average coal thickness of No. 3 coal seam in the coal pillar area is 6m. The coal pillar filling mining under the freeway is a partial backfill for Tang'an Mine. Specially invested comprehensive mining filling brackets for long-wall working face backfill will increase investment in coal mining equipment and complicate production management. Considering synthetically, for partial backfill mining, the use of roadway backfill mining has the advantages of small investment and flexible technology [3]. Therefore, it was determined that the coal pillar under the freeway was mined using the roadway mining with paste-like backfill method.

2.1. Section size of filling roadway
With reference to the technical data of the working roadway provided by the mine, combined with the actual situation and taking into account the conditions of the roadway support and driving equipment, the initial design of the filling roadway width is 5m. In addition, the thickness of the coal seam in the working face is 6.0m. In order to maximize the mining coal resources, the height of the backfill lane is set to 6.0m. The filling roadway section is designed to be rectangular: 5m wide and 6m high.

2.2. Excavation and backfill sequence of filling roadway
According to theoretical analysis and filling construction experience of other mines, the width of the coal (filling body) column between the two roadways should be between 10~20m. Comprehensive consideration, when the width of the coal pillar is 15m, it can not only ensure the long-term stability of the coal pillar, but also minimize the number of cycles and improve the efficiency of mining and filling [4].

In the process of excavation, the bolt net combined support filling roadway is used to reduce the closing amount of surrounding rock. After the first roadway is excavated, the filling begins. At the same time, the second roadway is excavated at an interval of 15m. The first roadway is successively excavated and filled at the same time. After the first round of filling mining is completed, the first roadway adjacent to the first round begins to be excavated at the right side of the second round. According to the first round of filling mining, the second round of filling mining is completed by the first round driving and filling method. After that, the third and fourth round of filling mining will be carried out successively, and finally all the coal in the pillar area will be recovered.

3. Establishment of Numerical Model for roadway Backfill Mining
FLAC3D is mainly used to simulate the mechanical behavior of geological materials and geotechnical engineering, especially the plastic flow after the material reaches the yield limit [5]. Because of the co-supporting effect of coal pillar and filling body, the overlying strata in roadway filling mining generally only appear fracture zone and bending subsidence zone, and the rock mass still has high continuity. Therefore, the paper selects FLAC3D software to carry out the simulation calculation of filling roadway mining, which will get more accurate and practical results.

3.1. Numerical model
The coal seam dip angle of Tang'an mine is 0 ~ 5 °, which belongs to near horizontal coal seam. In order to improve the speed and accuracy of computer calculation and analyze the stress of coal seam and its surrounding rock more clearly, the model takes coal seam and its top and bottom six layers as the research object. In order to simplify the simulation, the weight of the overlying strata of the model is equal to the force of the same size, which is loaded on the upper boundary of the model as the stress boundary condition, with the value of \( q = \sum \gamma \cdot gh \), where \( \gamma \) is the unit weight of each overlying strata, \( g \) is the acceleration of gravity, \( h \) is the mining depth, taking 430m.

The immediate roof of the coal seam is siltstone and mudstone of about 2.40m, the main roof is medium-fine-grained sandstone and siltstone of about 3.45m, and the floor is about 3.50m of mudstone and siltstone. The model takes 100m in the X direction and 20m in the Y direction. The
height of the model is 44m, the bottom of the heading face is 12m, and the top is 20m. The thickness of the coal seam is 6.0m, which is located between 12m-18m, and the filling roadway is arranged here.

In the X direction, the working faces of the roadways at the left and right ends are about 30 ~ 35m away from the corresponding boundary of the model, so as to minimize the impact of the boundary effect. Adjust the density of the grid according to the importance of the study area to balance the software operation speed and calculation accuracy. In order to avoid the influence of the front and back boundaries of the model, a section at 10m in the Y direction was taken for research.

A pair of horizontal compressive stresses \( \sigma_x, \sigma_y \) are applied to the model boundary along the x and y directions, the value of which both are \( \lambda \sigma_z \) (\( \lambda \) is the lateral pressure coefficient, \( \sigma_z \) is the sum of the dead weight stress of all overlying rock layers above), and the initial displacement of the boundary is set at The direction is zero. The initial displacement of the bottom boundary of the model is zero in both the horizontal and vertical directions.

3.2. Physical and mechanical parameters of rock mass

According to the geological coal seam histogram of Tang'an mine and the physical and mechanical experimental data of coal seam, the mechanical parameters of each coal seam used in the simulation calculation are listed according to the sequence of strata, as shown in Table 1.

| Lithology parameters | \( \rho \) (kg/m³) | K (bulk modulus) (GPa) | G (shear modulus) (GPa) | C (cohesion) (MPa) | \( \sigma_t \) (tensile strength) (MPa) | \( f \) (internal friction angle) (°) |
|----------------------|-------------------|------------------------|------------------------|-------------------|-------------------------------|----------------------|
| Medium sandstone     | 2610              | 19.4                   | 14.6                   | 7.8               | 4.5                           | 32                   |
| Main roof            | 2660              | 21.0                   | 16.2                   | 7.35              | 4.6                           | 35                   |
| Immediate roof       | 2635              | 6.25                   | 5.08                   | 1.2               | 0.5                           | 28                   |
| Coal                 | 1370              | 2.65                   | 1.37                   | 2.1               | 1.5                           | 30                   |
| Filling body         | 1900              | 2.05                   | 1.07                   | 1.5               | 1.1                           | 28                   |
| Immediate bottom     | 2635              | 8.7                    | 4.20                   | 1.3               | 0.7                           | 28                   |
| Medium sandstone     | 2610              | 19.4                   | 14.6                   | 7.8               | 4.5                           | 32                   |

3.3. Simulation scheme

According to the mining sequence of roadway backfill, the composition of temporary coal pillars will change with the number of mining rounds. This simulation will analyze the range of coal pillar plastic area, roof subsidence, maximum vertical stress of coal (filling body) column when the width of coal (filling body) column is 15m, and the different widths of coal pillar and filling body are combined. The coal (filling body) column width combinations and simulation scenarios are shown in Table 2.

| scheme             | Width of coal (filling body) column / m | Coal (filling body) pillar combination |
|--------------------|----------------------------------------|---------------------------------------|
| Coal pillar width / m | Filling body/m |
|----------------------|-----------------|-----------------|
| First round          | 15              | 15              | 0               |
| Second round         | 15              | 10              | 5               |
| Third round          | 15              | 5               | 10              |
| Fourth round         | 15              | 0               | 15              |
4. Numerical simulation analysis of roadway backfill mining

4.1. Impact Analysis of coal pillar stability

On the premise of ensuring the simplicity and feasibility of mining technology, combined with the geological mining conditions of coal seam and the actual mining conditions of the mine, the plastic zone depth and vertical stress of the 15 m temporary coal pillar are selected to study the influence of the width of the coal pillar on the stability of the coal pillar.

In order to analyze the stability of the temporary coal pillar and reduce the influence of surrounding rock mining, master the influence degree of the temporary coal pillar width of 15 m on its own and surrounding rock stability. In the simulation, the filling rate is 100%, the roadway width is 5 m, and the width of the temporary coal pillar is 15 m to simulate, and study the change of the plastic zone depth and vertical stress of the coal pillar.

Coal pillar width a = 15m, one side of the coal pillar is the filling body, but the filling completion time is short, the strength of the filling slurry is low, and the other side is the roadway being mined. The coal pillar plastic area map and vertical stress cloud diagram are shown in Fig. 1 and Fig. 2.
It can be seen from Fig. 1 and Fig. 2 that the roof and both sides of the filling roadway have plastic failure, and the stress concentration phenomenon has occurred in the temporary coal pillar and surrounding rock. From the data in the figure, it can be seen that the plastic zone depth of the roadway roof is 2.0m, the plastic zone depth of the floor is 1.5m, the plastic zone depth of the two sides is 3.0m, and the maximum vertical stress of the coal pillar is 13.93MPa.

According to the analysis, the width of the elastic zone of the coal pillar is 9.0m, which is between the height of the coal pillar and twice the height of the coal pillar, which can meet the stability requirements of the coal pillar for a long time. The maximum vertical stress of the coal pillar is 13.93 MPa, which is approximately equal to the theoretical analysis of 14.33 MPa, which is much smaller than the strength of the coal pillar in this case. That is, when the width of the temporary coal pillar is 15m, the coal pillar has sufficient elastic zone width during the mining process, and the actual stress value is far less than the strength of the coal pillar. The stability of the temporary coal pillar is better.

4.2. Stress distribution of surrounding rock and roof subsidence law in roadway backfill mining

The vertical stress map and vertical displacement map of the coal pillar area after the four rounds of backfill mining are completed are listed in turn. As shown in Fig. 3 and Fig. 4.

As the backfill mining progresses, the vertical stress on the condensed backfill body continues to increase, that is, as the backfill mining progresses, the backfill body column gradually shares the load
carried by the coal pillar, and eventually bears the overlying rock Full load. During the entire filling and mining process, the maximum stress of the coal pillar is 10 MPa, which is less than the corresponding strength value of the coal pillar. At the same time, during the filling and mining process, the roof of the coal seam will bend and sink, and the maximum sinking amount of the roof is 25mm. It can be seen that with the progress of backfill mining, the subsidence of the coal seam roof gradually increases, but the subsidence is generally small. Therefore, neither coal pillars nor backfill body columns will be damaged during the four rounds roadway backfill mining process, and this solution is feasible.

5. Conclusion
The numerical simulation method is determined according to the geological conditions, mining technology and other factors in the research area of Tang'an Mine. The simplified FLAC3D numerical simulation model is established. The stability of the coal pillar under the width of the 15 m temporary coal pillar, the process of the gradual bearing of the filling body and the law of roof subsidence are studied in the process of roadway filling mining. It mainly includes the following contents:

(1) Based on the simulation results, the plastic zone and vertical stress of the coal pillar in the mining scheme of 15 m temporary coal pillar are analyzed, and the stability of the coal pillar is studied. The width of elastic zone of coal pillar is 9 m, and the stability of coal pillar is better.

(2) Numerical simulation results show that, for a mining scheme with a mining distance of 5m and a temporary retention of 15m, after four rounds of backfill mining, the stresses of the coal pillars and the backfill body columns are less than their respective strengths, and the vertical displacement of the roof is smaller, which verifies the feasibility of the scheme.

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References
[1] Zhang P.G. Selection of coal mining method under the pressure of Expressway [J]. Shanxi Science & Technology of Communications, 2011, (01):7–8.
[2] Lang B, Chen L, Qiu Y.H. Numerical analysis of overlying strata deformation laws in cemented filling mining [J]. Coal Engineering, 2018, 50(4): 92-96.
[3] Dong Y, Huang Y.C, Liu G, Shi J.W. Numerical Simulation on the overlying strata failure law of roadway backfill under strong aquifer [J]. Coal Engineering, 2018,50(10):126-129.
[4] Huang Y.C, Wu Y, Chang J. Application and Technology of Coal Mining with Paste - like Roadway Backfill [J]. Coal Science and Technology, 2014, 42(1) : 37-39.
[5] Zhang N.C, Du X.H, Jiang B.Y, Liu M. Simulation of influencing factors of coal pillar stability by FLAC software [J]. Energy Technology and Management, 2008, (05): 114–115, 120.