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Study on the Slope Stability of Mine Wall in Open Pit Mines for Paste Backfill of Cut-and-Backfill Mining

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Abstract

The paper presents studies on the slope stability of mine wall in open pit mines for paste backfill of Cut-and-Backfill mining. The simulation of coal seam excavation under the mine wall, which has studied the slope stability of the coal was excavated and then uses paste backfilling, by using the Cut-and-Backfill mining method and analysis of the influence of coal mining under the mine wall that affecting the slope. Studying distortion and stress distribution and is clouding the properties of the reclamation materials that are suitable to support the mine wall from the failure of slope and reduced surface subsidence. Subsequently, the paper uses the Shenyi coal mine to study and develop research on Cut-and-Backfill mining technology, how to efficiently use the remaining coal resources under the mine wall. By creating a small model and numerical model using the Abaqus / CAE program to compare the characteristics of the movement and distribution of stress received from the roof of the mine wall. Including evaluating the stability of the slope during the coal seam excavation and the paste backfill period. The research conclusion indicated that Cut-and-Backfill mining is a method that can reduce the failure of the mine wall and prevent the slope stability of the mine wall that causing displacement and acceptable subsidence. Compared between digging coal seam by leaving coal pillars and digging coal pillars and then paste backfill.

Keywords: open pit coal mine; slope stability; replacement mining and paste backfill mining; evaluation of slope failure

Introduction

Presently, the energy development that is an important factor in various development of China, which most important energy resource is coal and likely to increase. According to the policy of the Chinese government, the importance of using coal resources to the maximum, reduce the loss of coal resources, and reduce environmental pollution. To solve these problems, the coal mines should use clean digging technology in the production process, improving safety and recovery rates of coal mines. (Zhou, Hou & Sun, 2004). However, open mining cannot dig coal beneath the mine walls, resulting is not being able to use the remaining coal resources under slope mine wall. Therefore, the development of research on technology and methods of using remaining coal resources under the mine wall in open-pit mine has occurred to efficiently use coal under the mine wall, which will have minimal impact on geographic and environmental. (Chen, Li & Chang, 2015) Whether the principles of underground mining under mine wall, the suitability of the materials for paste backfill mining, slope stability analysis, and estimation of the failure of mine wall, etc.

The excavation of coal to the final pit. Causes a large amount of coal under mine wall cannot be utilized, resulting in the loss of high-quality coal resources. Consequently, the Shenyi coal mine designed and used the method of recovering coal under mine wall, by excluding many coal pillars to prevent the stability of the mine wall. That was not to cause the failure of the settlement of the slope of mine wall and the surface. By using the digging technology of Cut-and-Backfill mining. (Xuejie et al., 2016) It can achieve high output, maximize the recycling of mine resources, and reduce production costs. It is suitable for mines with multiple coal seams, thin coal seams, complex topography, and large stripping ratio. Especially for the open-pit mine to help cover the coal resources, it can be effectively recovered and improved the recovery rate of the entire mine resources.

The use of the Cut-and-Backfill mining method is important because it is the digging of the remaining

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coal pillars under the mine wall to protecting stability. Which must consider the importance of the slope stability of mine wall and the safety caused by the slope slides failure or the settlement of mine wall. (Chang, 2009) Therefore, it is an interesting issue for studying the slope stability of mine wall in the open pit after completed paste backfill mining.

In which this knowledge and principles must be integrated into the study experimental design and using as a reason correctly analyze. Its purpose is to study the slope stability of mine wall after digging coal under the mine wall. And use paste backfilling mining to study the movement of the mine wall. Compare the displacement and the distribution of stress for the pressure strength of the mine wall. Between the digging coal seam under the mine wall by leaving the coal pillars. And use paste backfill mining in part of the excavation completed and the digging of the coal pillars all under the mine wall. Study the feasibility and the improvement of properties the materials backfill, which makes the stability of the best stable mine wall. Including impact assessment and prediction of failure, by using the numerical simulation of slope mine wall and paste backfill mining. Which will be used to predict the stability of the slope.

Model Foundation of Cut-and-Backfill Mining Under Mine Wall

Due to the method of coal mining under the mine wall in the first phase, the coal pillars are abandoned to help stabilize slope and surface. The second phase is to paste backfill between the coal pillars and digging the coal pillars out to paste backfill along coal seam. Through the experiment, the dynamic movement and deformation of overburden and the evolution of the roof failure by simulated the digging and backfill. According to the actual geological data of the Shenyi Coal Mine, the average depth of the 2-2 medium coal seam is 37 m from surface, the coal seam thickness is 3 m, and every 5 m for protective coal pillars are placed on both sides of the coal excavated and backfill.

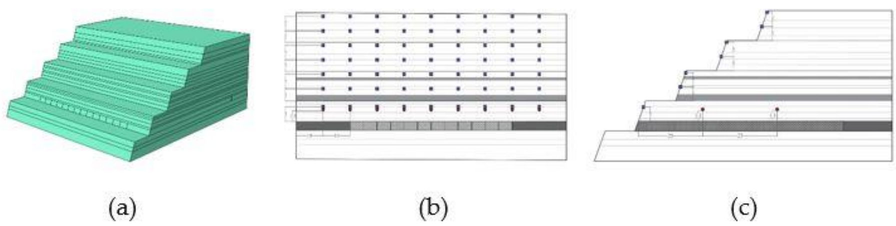


Figure 1. **The model design and layout diagram experiment: (a) Model design and laying; (b) Layout diagram of pressure sensor and measuring point; (c) Layout side view diagram of pressure sensor and measuring point.**

The excavate coal seam and paste filling mining: As shown in Figure 2, the first step simulates mining sequence of the working face and the abandonment of coal pillars to help support roof of the working area as a No. (1), (2), (3), (4), (5) and (6) respectively, which will notice that once the coal has been excavated, leave the coal pillars as designed and will immediately paste backfilling.

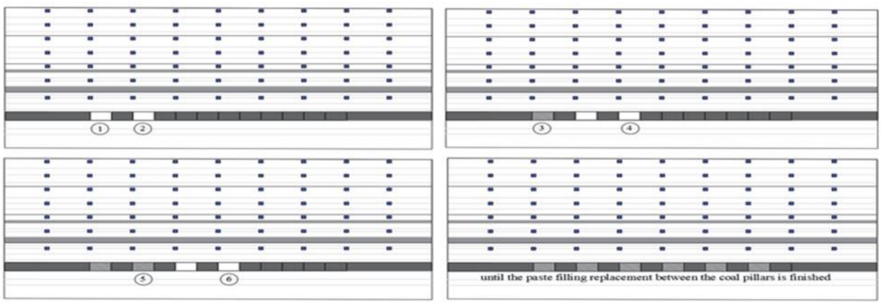


Figure 2. **Step of excavated coal seam and paste backfilling replacement (1) to (6).**

The excavate coal pillars and paste backfilling: As shown in Figure 3, in the second step, the coal pillars 5 cm was left in the first step will be return to excavate out in order to be placed for paste backfilling mining again as a No. (7), (8), (9), (10), (11) and (12) respectively.

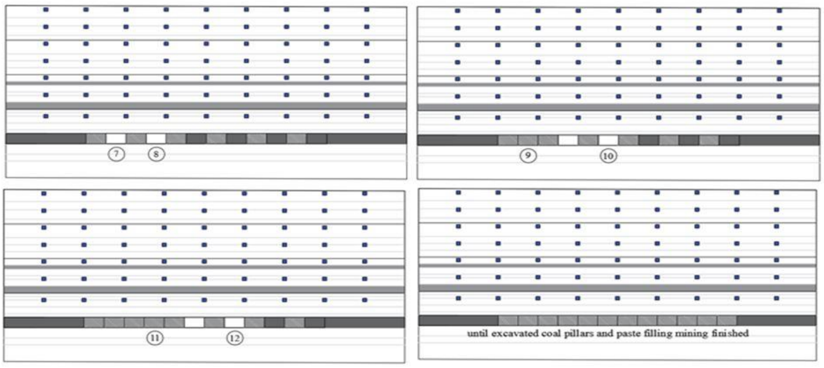


Figure 3. **Step of excavated coal pillars and paste backfilling replacement (7) to (12).**

In the first step of excavating and paste filling mining by leaving the coal pillars. When observing the effects such as crack or displacement of the rock layers and the slope of mine wall, which movement only slightly will move only 50~200 mm.

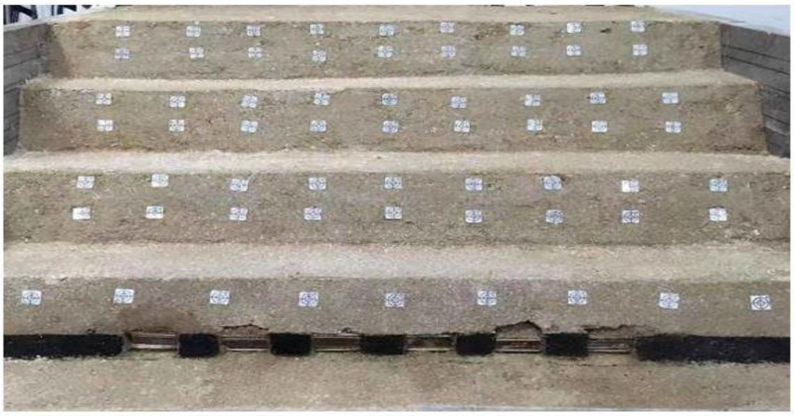


Figure 4. **Displacement of slope mine wall in the first step of cut and backfill by leaving the coal pillars.**

When the coal pillar is digging out and paste filling again in the second step until completion. Observing the effects such as crack or displacement of the rock layers and the slope of mine wall, the movement will be obvious occurs 200~280 mm. So, the original structure began to deform due to stress and pressure acting on the mine wall and the surface.

Figure 5. **Displacement of slope mine wall in the second step of excavating coal pillars and paste backfill mining.**

Numerical Simulation of Deformation Slope Moving of Cut-and-Backfill Mining

ABAQUS finite element simulation software was used for modeling based on the mining geological survey conditions and backfilling mining technology of Shenyi coal mine. The model is established according to the actual size of the slope mine wall. The size of the model space is 100 m × 100 m × 50 m, and a 10 m wide safety platform is added slope for each 10 m increase. The overall dimensions of the numerical simulation model are shown in Figure 6.

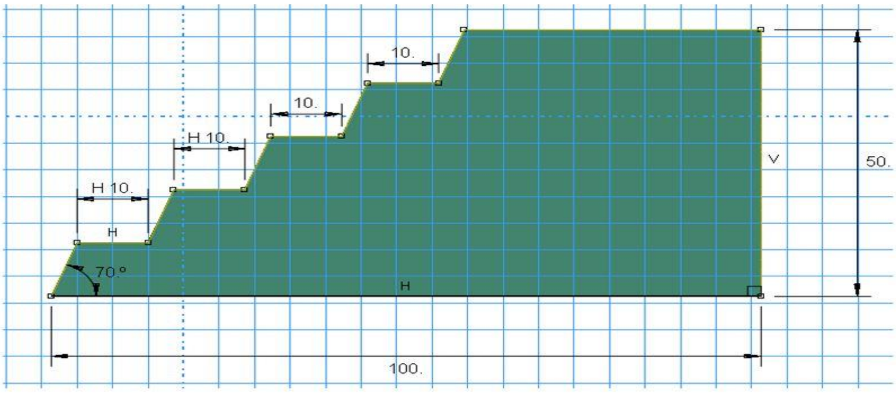


Figure 6. **The overall dimensions of the numerical simulation model.**

The physical and mechanical parameters of each rock formation are obtained from the rock mechanical parameters of each rock formation rock sample measured in the laboratory.

In the numerical analysis of geotechnical engineering stability, for mining engineering problems involving mining and paste backfilling, the initial stress field is a prerequisite for correctly simulating its construction engineering. To simulate the initial original rock stress field of the rock formation under the original geological conditions, the model is subjected to in-situ stress analysis in the first step of each simulation. Using the analysis step in ABAQUS numerical simulation software, the initial stress field is simulated under the action of vertical downward gravity acceleration, and then the coal seam mining and paste backfilling simulation are performed.

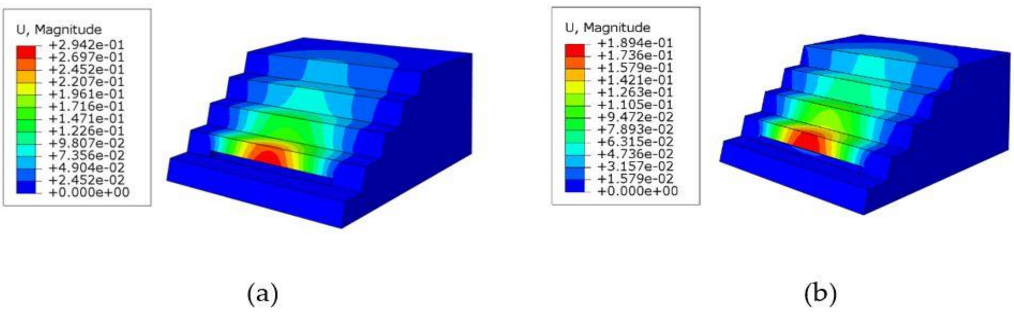


Figure 7. **Changes in displacement of the slope mine wall: (a) Overall displacement cloud diagram of without paste backfill; (b) Overall displacement cloud diagram of paste backfill.**

According to the results of numerical simulation of paste backfilling mining, the vertical displacements and stress changes of mining unfilled and paste backfilling mining are listed separately to compare and analyze the superiority of paste backfill mining technology. The change curve of the path displacement of the roof of the mine. The maximum settlement of displacement occurs in the middle of the roof of the mine, where blue is the vertical displacement curve of the 70 m excavated mine with paste backfill, the maximum settlement is 189.4 mm; green is the vertical displacement curve of the 70 m excavated mine without paste backfill, the maximum The amount of sedimentation was 294.2 mm. It can be seen from the figure that the paste backfilling body can effectively suppress the settlement of the roof of the mining area and slope of mine wall during mining and ensure safety during mining.

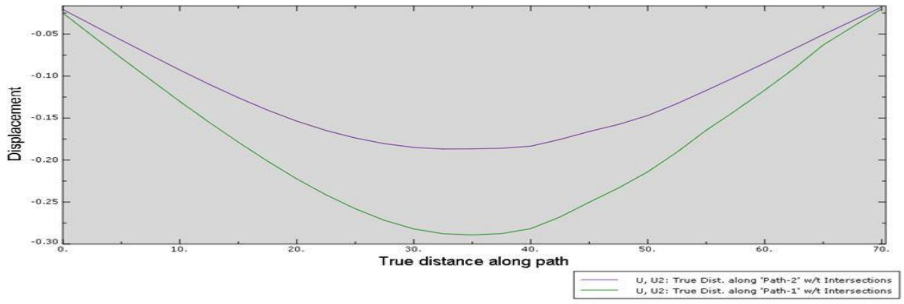
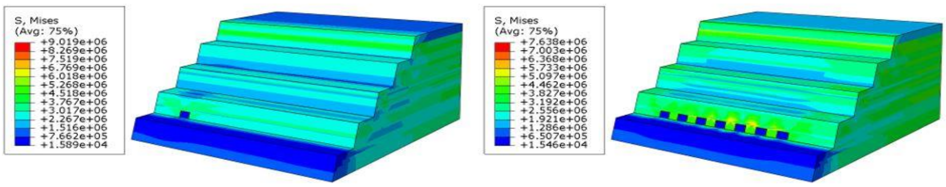


Figure 8. **Roof displacement curve when without paste backfill and paste backfill.**

The end of the first paste backfill mining and the end of the seventh paste backfill mining to illustrate the stress characteristics of the mining surrounding rock during the filling of the working space. Taking the filling body where the working space is located as a plane the stress of the working space at the end of the first paste backfilling mining and the stress of the working space at the end of the seventh paste backfilling mining as examples, the analysis of the influence of the single filling body working space on the stress of the surrounding rock is continued.

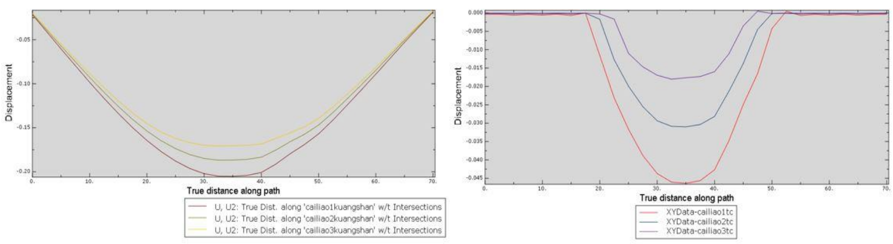


(a) (b)

Figure 9. **Changes in the stress of slope mine wall: (a) Stress distribution at the end of the First digging working space and paste backfill; (b) Stress distribution at the end of the seventh digging working space and paste backfill.**

After the excavation is simulated, the stress distribution of the surrounding rock mass can be seen and occurs at the four corners of the stope. The paste filling body is added, due to the existence of the internal friction angle inside the paste filling body, when the displacement occurs under the effect of the weight, there will be a friction force on the mine wall of the surrounding rock. The stress distribution is arched and not evenly distributed.

During the mining process, the material properties of the filling directly affect the paste backfilling effect. In this simulation, the filling different physical parameters are used to fill the mining coal seam, and the displacement change curve of the roof and the filling are obtained.



(a) (b)

Figure 10. **Changes in displacement of the physical type material of the paste backfilling: (a) The displacement change curve of the top plate under different filler materials; (b) The displacement change curve for different filling materials.**

In Graph 1, The maximum displacement settlement occurs in the middle of the roof of the mine. The red curve is the vertical displacement curve of the mine when the physical paste backfills material parameters of the filling body type one, and had the maximum settlement is 208.3 mm. The green curve is the vertical displacement curve of the mine when the physical paste backfills material parameters of the filling type two, and had the maximum settlement is 189.4 mm. The yellow curve is the vertical displacement curve of the mine when the physical paste backfills material parameters of the filling body type three, and had the maximum settlement is 172.9 mm. It can be known from the curve that as the density, elastic modulus, cohesion, and tensile strength of the filler increase, the effect of the filler on resisting the settlement of the mine roof is better.

In Graph 2, the maximum displacement of the displacement occurs in the middle of the filling body. The red curve is the vertical displacement curve of the filling body when the physical paste backfills material parameters of the filling body type one and had the maximum settlement amount is 47.7 mm. The blue curve is the vertical displacement curve of the mine when the physical paste backfills material parameters of the filling body type two and had the maximum settlement is 32.4 mm. The brown curve is the vertical displacement curve of the mine when the physical paste backfills material parameters of the filling body type three, and had the maximum settlement is 18.9 mm.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

Results

The paper takes it as the example that is the mining stop line of united surface mining and undermine wall mining in Shenyi coal mine. Shenyi Coal Mine is located on the west edge of the Zhungeer Call of Dongsheng Coalfield. There are five coal seams: 2-1middle, 2-2upper, 2-2middle, 3-1 and 4-1. The actual production capacity of surface mine has reached 0.6 Mt/a. The undermine wall coal mining exploits 2-2middle coal seam mainly and the raw coal output reaches 0.16 Mt/a.

Based on the engineering geological materials that have already been collected, calculation parameters are selected as follows: the density of topsoil is 1,760 kg/m^3, cohesive force is 0.01 MPa, internal friction angle is 20°; the density of mudstone is 2,200 kg/m^3, cohesive force is 7.20 MPa, internal friction angle is 36.7°; the density of medium grain sandstone is 2,450 kg/m^3 cohesive force is 5.75 MPa internal friction angle is 37°; the density of sandy mudstone is 2,550 kg/m^3 cohesive force is 1.74 MPa internal friction angle is 28°; the density of siltstone is 2,550 kg/m^3 cohesive force is 4.00 MPa internal friction angle 34.8°; the density of coal seam is 1,370 kg/m^3 cohesive force is 1.20 MPa internal friction angle is 25.5°; the density of filling body type I is 1,860 kg/m^3 cohesive force is 0.37 MPa internal friction angle is 32°; the density of filling body type II is 1,960 kg/m^3 cohesive force is 0.47 MPa internal friction angle 32°; the density of filling body type III is 2,010 kg/m^3 cohesive force is 0.55 MPa internal friction angle is 32°;

Discussion

From the experiment in the model after finished excavated, the original equilibrium after pass digging all coal pillars. The roof of the rock floor will sink and after contact with the material paste backfilling to the new equilibrium state. Due to the collapse of the roof and the movement of changing the form of compression of the material paste backfilling causes the structure to accumulate in the goaf is unstable. The measurement data of each line after paste backfilling at the coal pillars has the total subsidence of the soil layer increases but as the height increases the subsidence will gradually decrease. (Simon & Franz, 2018)

The analysis of pressure sensor data, the first pressure movement caused by excavated and paste backfilling by leaving coal pillars to receive pressure from the rock layer above and reduce the increase in stress of the soil layers. (Ying & Wei, 2011) The gravity load will be alleviated by coal pillars to maintain and reduce the stability of the soil layer and mine wall. The second period after excavated coal pillars and paste backfilling them with a back drop. (Luo, 2014) The material paste backfilling will be pressure from all rock layers on the roof, causing increased stress to the point of equilibrium of stress. Because the paste backfilling helps to slow down the sinking of the roof until the roof finally touches the filling body, the material is paste backfilling and reacts to the drug, tightening and stabilizing the surrounding rock layers and form a support for prevention Stability of mine wall. (O'Hearn, 2012)

By analyzing the displacement diagram and change curve of the excavation roof, it is concluded that the vertical displacement of the roof will increase with the progress of the excavation process until it reaches a certain value. After the excavation is simulated, the stress distribution of the surrounding rock mass can be seen. After excavation, stress concentration occurs at the four corners of the stope. (Eberhardt, 2003) After the filling body is added, due to the existence of the internal friction angle inside the filling body, when the displacement occurs under the effect of the weight, there will be a friction force on the wall of the surrounding rock. The stress distribution is arched and not evenly distributed.

By Analyzing Shenyi coal mine practice, the conclusion can be drawn as follows: Application of mine wall design theory, combined with the theory of safety factors of slope stability. In which the theories are studied in detail and integrated for the purpose of this research for the research that is the guideline in the design and development of coal mining under the mine walls and can slow down the erosion of the slope stability of the mine walls. (Lee et al., 2002)

The effects of the slope stability of mine wall. Including the design of coal pillars that can support pressure distribution to protect or slow down the movement that may occur after coal excavation and the analysis of paste backfilling materials in accordance with the coal mine design to prevent the stability of the mine walls as well as the prediction of surface subsidence, all have an important influence on the slope stability of the mine wall. (Wang, 2016) The experiment model can be concluded that the impact of coal digging under mine walls and laying substitution for the above important shale will not be deformed and will not fail in the stability of slope mine walls. After the excavation has been completed, the maintenance of the original balance after all excavation of the coal pillar. The roof of the ground will sink and after contact with the material paste backfilling to a new equilibrium state. (Hongge, et al., 2011) By analyzing the observation data of the movement on a slope, the overall vertical displacement and settlement of the mine will increase with the increase of the excavation depth. When mining is used to paste backfill under mine wall, the displacement of the mine will become smaller, compared to the unfilled mining to 85% of the subsided mining, and had settlement relatively reduced by 31.05%. With the increase of the density, elastic modulus, cohesion and tensile strength of the filling body, the better the filling body resists the settlement of the roof of the mine, the smaller the settlement of the roof of the slope mine wall and the mining area.

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