Study on Mechanism of In-Situ Stress Control on the Coal Floor Damage During Deep Coal Seam Mining

Gan Tian

ABSTRACT

In order to study on mechanism of in-situ stress control on the coal floor damage during deep coal seam mining, the internal relationship among ground stress, mine pressure and floor water inrush was analyzed base on the increasing distribution rule of ground stress with the increasing depth of stratum. It is shown that the stress on the deep coal seam has obvious control effect on the depth of the floor damage and failure through the numerical simulation and the statistical analysis of the measured data of the mining damage depth of the coal seam floor. And the calculation formula for the depth of the floor failure in the deep seam mining and the influence coefficient of the ground stress were put forward.¹

INTRODUCTION

It is imperative to mine deep coal resources along with the upper part coal seam dried up gradually in our country. The dangerousness and destructiveness of water inrush from coal seam floor is more and more serious in mining deep coal seam with the increasing depth of coal seam excavation [1]. This is also intimate relationship with the high in-situ stress environment of deep coal seam roof and floor in addition to the reason of the increasing pressure of aquifer water under the coal seam floor. It is the key technology of safely mining deep coal resources that how to safely and effectively develop the deep coal resources from the condition of high geo-stress and high confined water pressure. We usually focus on water filling source, water filling way and water filling strength about shallow coal seam safely mining under water pressure. We didn’t focus too much attention to the control function and control mechanism of the ground stress size on coal seam floor water inrush in the working

¹Gan Tian, Xi’an Research Institute of China Coal Technology & Engineering Group
face, even we ignore them. But the original rock stress of surrounding rock increases rapidly with the increase of buried depth of coal seam. The mechanical properties of surrounding rock, the mechanical response characteristics after coal seam mining and the fracture mechanism of water inrush under high water pressure have different special properties from that of the shallow buried coal seam. The ground stress state becomes the important controlling factors of coal seam floor water-inrush. Therefore, from theory to engineering applications, it is the key scientific and technical problems to systematically study the inherent law of in-situ stress size and the buried depth of coal seam, to research the in-situ stress state of surrounding rock, the control mechanism of the high ground stress on mechanical property of coal seam surrounding rock, and damage characteristics of coal seam floor strata under the effect of mining disturbance and water pressure in high ground stress environment and its control effect coal seam floor water inrush, and then obtain the internal relation among the buried depth of coal seam, the size of the ground stress and hazard assessment index. That is the great demand of realizing safety mining deep coal seam under water pressure and in the deep high stress environment.

**THE RELATIONSHIP BETWEEN THE GROUND STRESS AND THE WATER INRUSH OF THE FLOOR**

**Earth Stress Distribution Law**

Ground stress is the primary rock stress in the earth's crust that is not disturbed by mining engineering. It is mainly formed under the joint action of gravitational field and Structural stress field, and is related to various dynamic processes of the earth. The tectonic stress field and the self-weighted stress field are the main components of the geo-stress field. [2] Generally, the Structural stress changes little in the same mining area, so the geo-stress we study here is mainly vertical stress.

![Figure 1. Relation between vertical stress and buried depth in Shanxi mining area.](image-url)
In general, the vertical stress is basically equal to the weight of the overlying rock mass. In 1978, E. Brown and E. Hoek[3] based on the data fitting, it is concluded that the vertical stress is proportional to the buried depth of the strata. In recent years, many scholars have conducted a large number of tests and studies on the stress in China.

Figure 1 is the results of stress testing in mining areas such as Lu'an, Yangquan, Huozhou and Fenxi in Shanxi Province[4]. The vertical stress of the strata is mapped with the variation of the depth of the strata. It can be clearly seen from the curve that vertical stress has a good linear relationship with the buried depth of the formation, and the vertical stress gradually increases with the buried depth of the formation. The vertical stress is basically equal to the weight of the overlying rock.

**Relationship between Geo-Stress and Mine Pressure**

In the process of coal seam mining, the stress field balance of the original rock in the mining field will be broken and redistributed, and the surrounding rock stress of the corresponding coal seam floor will also change. As a result, displacement, deformation, and even destruction of the floor rock mass will occur. It is called mine pressure that the force generated by underground coal mining activities on surrounding coal masses and related supporting materials such as well lanes, Chambers, and mining face. The supporting pressure is an important part of mine pressure.

The root cause of mine pressure lies in the existence of ground stress, and its essence is the result of superimposed and self-balanced coal seams in the process of mining that caused the stress field of the surrounding rock to be destroyed. The forming expansion zone, compression zone and shear zone of the bottom plate of the remining face lead to the deformation, destruction, collapse, deformation, damage, and other dynamic phenomena of the surrounding rock mass. The disturbance caused by mine pressure will have a direct impact on the development and occurrence of water inrush on the bottom plate. Therefore, it is of great theoretical and practical significance to study and predict the stress distribution and variation of the surrounding rock in the deep coal seam mining field under different stress conditions.

**Relationship between Geo-Stress and Floor Water Inrush**

With the increasing of coal seam depth, the effect of ground stress on deep coal seam mining becomes more and more prominent. The greater the depth of the coal seam, the greater the pressure of the bottom rock, the smaller the cracks and pores of the bottom rock mass. Then the permeability of the rock mass will be reduced and its ability to resist high-pressure water will increase. Therefore, under the condition of primary rock stress, the ground stress has a certain inhibitory effect on the original intrusion and development height of coal bed aquifer.
With the increase of the depth of coal seam burial, the vertical stress generated by the overlying strata gradually increases, which causes the mine pressure generated by the mining disturbance in the layer of the floor to increase, and the mineral pressure becomes more obvious. Mining disturbance is more serious to coal seam floor shear and tensile deformation and damage depth of floor disturbance damage is increasing, bottom layer interface high pressure water intrusion damage development height is also increased, resulting in floor water intrusion is possible [5][6][7]. Therefore, the ground stress in the process of coal seam mining has a certain induced effect on the floor water inrush.

**NUMERICAL SIMULATION STUDY ON CONTROL EFFECT OF GROUND STRESS ON THE DAMAGE DEPTH OF COAL SEAM FLOOR IN DEEP COAL SEAM MINING**

In order to study the control effect of the ground stress on water inrush of the coal seam floor, according to the coal strata data of a coal mine, the stress distribution of coal seam floor along the direction of coal seam orientation, the influence of the original rock stress on the coal seam floor damage depth and the damage morphology are further analyzed by means of numerical simulation.

The numerical simulation model is as shown in Figure 2. The model size is width(X) × thickness(Y) × height(Z) = 600 × 400 × 340 m. The brick unit is used to simulate the coal formation and the work surface along the positive direction of the X axis. The number of model units generated is 304,000 and the number of points is 318857.

![Figure 2. Numerical model diagram.](image-url)
In order to analyze and study the stress distribution, disturbance failure depth and morphology of coal seam floor surrounding rock mass with different original rock stress under different buried depth conditions, the calculation scheme is set as follows:

(1) The width of the working face is 200m. The thickness of the coal seam is 3m. The thickness of the layer of the coal seam floor is 50m, and the pressure of the floor water is 3MPa.

(2) A total of 400m is advanced. Each time 20m is advanced, and the calculation results are preserved once every 40m.

(3) To simulate the original rock stress with a depth of 500m, 600m, ..., 900m, and 1000m in coal seams (initial vertical should be 12MPa, 14.5 MPa, 17 MPa, 19 MPa, 22 MPa, and 24 MPa, respectively). Law of stress distribution, damage depth and damage form of disturbance damage of bottom floor rock during coal seam excavation. [8]

**Simulation Study on Ground Stress Size and the Variation Law of Rock Floor Stress of Coal Seam Remining Face**

In order to study the variation characteristics of the surrounding rock stress after coal seam mining under different depth conditions, we did numerical simulation of coal seam mining under different depth conditions, and analyzed the vertical stress cloud characteristics of coal floor rock formation in mining field. [8]

Figure 3 shows the distribution of vertical stress in the bottom layer of the coal seam after remining under the conditions of underground stress of 500m, 600m, 700m, 800m, 900m and 1000m.
Figure 3. Vertical stress cloud map of coal seam floor under the conditions of different buried deep.

![Cloud Maps](image)

Figure 4. Variation curve of maximum vertical stress with depth in coal bed floor.

As can be seen from the figure 4, with the increase of the depth of coal seam burial, the influence of the surrounding rock stress of the coal seam floor is increasing, and the maximum vertical stress of the bottom plate is gradually increasing(Figure 6.). At the same time, the stress concentration degree and range of the bottom plate on both sides of the working face also increased. In different depths, the maximum vertical stress of the water-resisting layer near the coal wall of the working face was 30.6 MPa, 33 MPa, 37.8 MPa, 53.79 MPa, 55.85 MPa and 66.96 MPa, respectively.

**Simulation Study on Geo-Stress Size and Deformation and Failure Characteristics of Coal Seam Floor of Remining Face**

In order to study the effect of ground stress on the deformation and failure of coal bed after coal seam mining, we simulated the deformation and failure characteristics of coal bed after back mining under the condition of ground stress of 500 to 1000m.

Fig. 5 shows the characteristic cloud map of plastic deformation and failure of bottom floor after coal seam excavation at different depth of 500 to 1000m.
Figure 5. Characteristic cloud map of plastic failure of coal seam floor under different buried deep stress conditions.

It can be seen from the cloud map that a large plastic damage zone is generated in the floor rock formation after the working face excavated. With increase of the coal seam depth, the stress of the coal seam floor surrounding the rock is constantly increasing, and the stress of the coal floor surrounding the rock is released and concentrated more intense after the coal seam was excavated. The depth and range of the plastic damage zone of the bed floor of the working face also gradually increase. As a result, the damage depth of the coal seam floor also increases.

Relationship curve between plastic failure depth of floor rock layer and coal seam depth (Figure 6.) shows that the plastic damage depth of bed floor increases with the increase of depth. They are proportional. There is a significant relationship between the ground stress control effect and the plastic failure degree of the layer.
Figure 6. Variation curve of the plastic failure depth of floor rock layer with depth in coal bed floor.

**Analysis on the Control Effect of Geo-Stress on the Breakdown Characteristics of Ground Floor of Coal mine Remining Face**

Based on the results of numerical simulation, the control effect of ground stress on deformation and failure of coal bed was analyzed comprehensively.

**CONTROL EFFECTOFVERTICALSTRESSONROCKDEFORMATIONINCOALBED**

It can be seen from the curve chart 7. of vertical stress and shifting deformation of coal bed that there is a good correlation between the maximum vertical stress and the increase of shifting deformation of coal bed under different buried conditions. It shows that vertical stress has a strong control effect on the deformation of coal bed.

Figure 7. The relationship curve between vertical stress of mining and rock deformation in coal bed with different buried depth.
CONTROL EFFECT OF VERTICAL STRESS ON PLASTIC DEFORMATION AND FAILURE OF COAL BED

It can be seen from the graph of the relationship between vertical stress and plastic deformation and failure of coal bed (figure 8.) that the maximum vertical stress and plastic deformation and failure increase in step with the increase of the depth of coal bed under different buried stress conditions. It shows that vertical stress has a strong control effect on the plastic deformation of coal bed floor.

ANALYSIS ON THE EFFECT OF GROUND STRESS ON WATER INRUSH COEFFICIENT

According to the numerical simulation results, we analyze the impact effect of the ground stress on the water coefficient of the mining process with hydraulic pressure under the condition of 50m thickness of the layer and 3MPa water pressure of the floor aquifer.

Figure 9 shows the relationship between the effects of the added value of overburden vertical stress on water-inrush coefficient of the coal seam under the condition of buried depth greater than 500m. It can be seen from the figure 11. that the added value of overburden vertical stress on the roof of the coal seam remining face has a great influence on the water coefficient, and the greater the vertical stress added value, the greater the influence coefficient of the ground stress on the water coefficient. In other words, the greater the vertical stress value on the roof of the coal seam remining face, the faster the effect of the ground stress on the water-inrush coefficient, the greater the risk of water inrush on the bottom plate of the remining face.
Through data fitting, the relationship between the degree of influence of ground stress on the water-inrush coefficient (ground stress impact correction coefficient) $C_d$ obtained by the existing calculation method and the vertical stress of the overlying strata of the mining coal seam is [8]:

$$C_d = 0.1272\Delta\sigma_v + 0.8066$$

(1)

In the equation: $C_d$ — the ground stress influence coefficient;

$\Delta\sigma_v$ — Value added of vertical stress when buried deeper than 500M, MPa.

This formula is only suitable for mining coal seams with a depth of more than 500m.

According to the above comprehensive analysis, it has a good correlation between the deformation and failure of coal floor and vertical stress after coal seam mining with. The deformation and failure increases with the increase of vertical stress of coal floor rock. It increases with the continuous advancement of the work surface. The ground stress has obvious control effect on the deformation and failure of coal bed.

**Statistical Analysis of Measured Data of Floor Damage Depth**

In order to further study the relationship between the damage depth of coal seam floor and the ground stress, the measured data of the damage depth of coal seam floor in 67 coal mines in China are calculated. And the distribution map of the relationship between the depth of rock damage and the depth of coal seam burial was drawn (Figure 10.).
Figure 10. The curve of damage depth change with buried depth of bottom plate measured in some coal mines in China.

It can be seen from Figure 10 that the general trend of the damage depth of coal seam floor is increasing with the increase of the depth of coal seam. In addition, from the data distribution in the figure, when the depth of coal seam is less than about 400m, the data distribution of the destruction depth of the floor rock layer is relatively chaotic, the law is not obvious, and the data on the destruction depth are relatively concentrated, and the basic distribution is relatively concentrated at about 10m. This shows that the damage depth of the bottom layer is not obviously controlled by the stress when the depth of coal seam mining is less than 400m.

Figure 11 shows the distribution of the relationship between the damage depth of the floor rock layer and the depth of the coal seam after coal seam mining when the buried depth is greater than 400m. It can be seen from the figure that when the depth of coal seam is 400 to 1000m, as the depth of coal seam is continuously increased, the damage depth of the coal floor is also increased, and the damage depth of the floor rock layer is basically linear with the buried depth. This shows that when the depth of coal seam is greater than 400m, the damage depth of rock floor of coal seam mining is controlled by the stress.

Figure 11. The relationship between rock damage depth and buried depth of coal seam buried greater than 400m floor.
By fitting the measured data, we can obtain the formula for calculating the rock damage depth of deep coal seam mining floor when the depth of coal seam is greater than 400m:

\[ h_t = 0.0316H + 0.6817 \]  

The formula for calculating the damage depth of the bottom layer only considers the influence of the depth of coal seam on the damage depth of the bottom layer, but does not consider the influence of the slope length, height and coal seam inclination of the back mining face on the damage depth of the bottom layer. Therefore, the formula is not perfect enough. However, it has certain guiding significance for coal seam mining in the same mining area. According to the numerical simulation results and the measured statistical data, it can be seen that the disturbance and destruction depth of the watertight rock layer in the coal seam floor of the remining face increases with the increase of the depth of the coal seam and the vertical ground stress. The disturbance failure depth is proportional to the burial depth and vertical stress of the floor layer. The theoretical analysis results are consistent with the measured results.

**MAIN CONCLUSIONS**

The following main conclusions are drawn:

1) Ground stress (vertical stress) increases with the deepening of coal seam mining depth, which is proportional to the depth of coal seam burial.

2) Mine pressure is the result of superposition and self-balancing due to the destruction of the stress field of the surrounding rocks in the mining process, and the greater the buried depth, the greater the mine pressure generated by the recovery of the coal seam. The damage depth of disturbance on coal bed floor is also increasing, and the ground stress in coal seam excavation has a certain induced effect on the water inrush of coal floor.

3) Numerical simulation study of the effect of stress on the deformation and failure characteristics of the bottom floor of the remining face, and the depth of rock excavation disturbance and destruction in the bottom floor of the coal seam increases with the increase of the surrounding rock stress. The stress of surrounding rock has obvious controlling effect on the plastic deformation and failure of coal bed. The higher the vertical stress on the top plate of coal seam remining face, the faster the effect of the ground stress on the water penetration coefficient, the greater the risk of water intrusion on the bottom plate of the remining face. The influence coefficient and calculation formula of geo-stress are put forward.

4) According to statistical data analysis, under the same mining technology, the overall trend of rock damage depth in the coal bed floor is to increase with the increase of coal seam depth, and the damage depth of the ground floor rock layer is
basically linear. The damage depth of rock floor in coal seam mining is controlled by the stress. A formula for calculating the damage depth of bottom plate in deep coal seam mining is presented.

ACKNOWLEDGEMENTS

China Coal Engineering Group Xi'an Institute Fund Project (XAYMS201516).

REFERENCES