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Reasonable Size Design and Influencing Factors Analysis of the Coal Pillar Dam of an Underground Reservoir in Daliuta Mine

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Abstract: Underground reservoir water storage technology has become one important way to achieve efficient coal mining and water resource protection in the western mining areas of China, and the width of coal pillar dams is an important factor affecting the safe operation of underground reservoirs. In order to study the limitations on the reasonable size of a coal pillar dam, Daliuta Mine was selected as the engineering background and a theoretical formula for the reasonable width of a coal pillar dam was proposed. By combining theoretical analysis with numerical simulation analysis, the main influencing factors of the coal pillar dam were compared and analyzed. The research results indicated that changes in the mining height and coal parameters can cause a sharp change in the width of the plastic zone of the dam body. Then, mine water will have an impact on the width of the plastic zone and the width of the elastic core. Moreover, when the width of the coal pillar is smaller than the theoretically calculated width of the coal pillar dam body, the deviator stress and vertical stress inside the dam will significantly increase, and the plastic zone of the dam will significantly expand.

Keywords: coal pillar width; coal pillar dam; underground reservoir; mine water

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1. Introduction

The western regions of China are rich in coal resources, accounting for 62.7% of the country's proven coal reserves, and their coal production accounts for about 70% of the country's total, making them an important coal production base to ensure China's energy security [1,2]. However, these regions are located in the arid water-deficient zone and semi-arid water-deficient zone of China. Coal mining leads to the waste of water resources and destruction of the ecological environment due to drought and water shortage. Therefore, water resources have become the dominant factor for regional coal resource development and ecological protection [3]. In order to solve the problem of the low water resource utilization of coal mining in the western mining areas, and to ensure more efficient use of water resources in mining areas, Gu et al. [4,5] have creatively proposed the concept of distributed underground reservoirs in coal mines in combination with on-site practices and conducted research on engineering practices. Cao et al. [6,7] also proposed constructing underground reservoirs by constructing coal pillar dams and artificial dams to recycle mine water.

Distributed underground reservoirs in coal mines represent a new type of underground water conservancy project pioneered in China. Their main body consists of a working face goaf, a protective coal pillar, and an artificial dam body. The protective coal pillar is the main component of the dam body of a coal mine's underground reservoir, and its reasonable size is not only directly related to the stability of the dam body itself but is also related to the long-term stable and safe operation of the underground reservoir and the safe and efficient production of the coal mine [8]. The stress environment of underground reservoir dams in coal mines is complex and differs from the dam stability of ordinary ground reservoirs. It is not only affected by the pressure of overlying strata and water pressure, as there is also a strong weakening effect on coal pillar dams due to water intrusion [9,10]. In addition, the underground reservoirs of coal mines will affect the seepage flow of underground water, and the mine water will cause the creep of the coal body and influence its mechanical properties [11,12]. The research on coal pillar stability at home and abroad has mostly considered coal pillar stability in coal mine sections, and the research results included the limit equilibrium theory, etc. However, there have been few studies on the stability of underground reservoir dams in coal mines.

Wang et al. [13] studied the lateral abutment pressure distribution caused by multi-face mining and the response law of the coal pillar dam under a dynamic load by analyzing the complex stress environment characteristics of the coal pillar dam in a coal mine underground reservoir under dynamic and static load superpositions. Gu et al. [14] conducted dynamic damage experiments for underground reservoirs under different intensity conditions, and they carried out numerical calculations and studies on the dynamic response of coal pillar dams under earthquake action, exploring dam failure forms, seismic weaknesses, and influencing factors, before proposing a safety coefficient for underground reservoir coal pillar dams. In order to study the safety of underground reservoir water-retaining dams and analyze the relevant factors affecting their stability, Zhang [15] conducted a stress analysis of water-retaining dams, established a mathematical model for safety analysis of the dam, and conducted a safety analysis of the water-retaining dam combined with a typical coal mine—namely, Wulanmulun Mine in Shendong Mining Area. Taking Daliuta Coal Mine as the engineering background, Wu [16] analyzed and studied the retention and stability of coal pillar dams with distributed underground reservoirs in coal mines by constructing a similar model, and Wu also divided the coal pillar layout methods of distributed underground reservoirs. Chen [17] used finite element software to conduct finite element calculations based on three different types of underground reservoir water-retaining dams to obtain the seepage field around the water-retaining dams, calculate the seepage flow around them, and evaluate the seepage prevention effect of the underground reservoir water-retaining dams. At present, there is still a lack of systematic research on the factors affecting the stability of coal pillar dams in reservoirs and their reasonable size design.

In order to provide a safe and reliable calculation method for the width retention of coal pillars, and to provide guidance and a basis for the retention of coal pillars in the underground reservoirs of mines, this paper analyzed the factors affecting the size of coal pillars in underground reservoirs, combined the plastic zone size under the influence of mine water with the reasonable reserved size of waterproof coal pillars, proposed a calculation equation for the reserved size of coal pillar dams in underground reservoirs, and analyzed the changes in the sizes of coal pillar dams under the influence of mining factors, mine water factors, and geological conditions. The stability and stress state of dam bodies with different widths under the influence of mine water were analyzed using Flac3D numerical simulation software to provide a reference for the design of the dam body widths of underground reservoirs.

2. Engineering Background

Daliuta Mine is located to the northwest of Shenmu City. Most of the area consists of windblown sand accumulation landforms, with sand dunes, sand ridges, and sand flats crisscrossed. Vegetation and water resources are scarce in this area. In order to solve the problems of regional water shortages and industrial water shortages in the mining area, Daliuta Mine plans to turn the goaf of Working Face 52503 into an underground reservoir in the later stage of the mine. Working Face 52503 is located in the fifth panel of Coal Seam 5-2, with a dip length of 168.5 m and an advancing length of 4383.4 m. The coal thickness of the seam is 7.0–7.5 m, with an average of 7.15 m. The design mining height is 6.8 m, the ground elevation is 1082.7–1216.4 m, and the floor elevation of the coal seam is 957.5–996.9 m. The comprehensive mechanized mining method of fully caving and retreating at one mining height is adopted. Working Face 52503 and Working Faces 52505 and 52504 on both sides that have not yet been mined are separated by large faults, with a drop of about 25–40 m. Both fault layers are normal faults and are basically parallel to the strike direction of the working faces, extending from the cutting hole to the withdrawal passage. The mine plans to connect the high-level working face with the mined-out area of Working Face 52503 through drainage tunnels and drainage boreholes, so that the accumulated water in the mined-out areas of Working Faces 52505 and 52504 at the high level will flow automatically to the goaf of Working Face 52503 through the boreholes. The surface reservoirs of Boniuchuan River Gully and Guojiawan can provide seepage recharge for the underground reservoir and ensure that the underground reservoir continuously, stably, and efficiently serves the mining area.

In order to ensure the stability and safety of the surrounding rock during the service period of the main roadway in the coal seam and to maximize the recovery of coal resources, this study was conducted on the reasonable size of the coal pillars left in the underground reservoir.

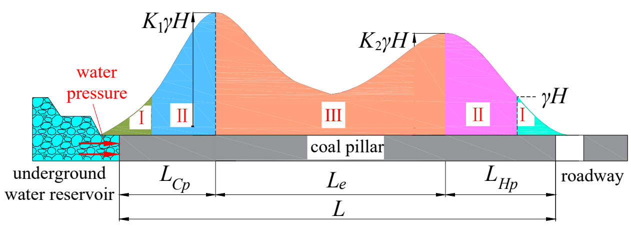
3. Reasonable Size Design of Coal Pillar Dams

The dam stability of underground reservoirs is a key link in the design of underground reservoirs. As a water-retaining dam of a goaf reservoir, the coal pillar on one side of the reservoir is affected by the reservoir water pressure over time, and its stability is closely related to the impact of the water. Therefore, in the process of studying the reasonable size of a coal pillar dam, it is necessary to consider both the overburden action and the water pressure action, as well as to comprehensively analyze and obtain the reasonable size of the coal pillar dam under the influence of these two factors.

Limit equilibrium theory and a large number of engineering practices have shown that there exist a certain range of bearing stress elevation areas on both the sides of the goaf and the roadway, and the stress concentration coefficient represents the degree of bearing stress elevation. The coal pillar is divided into the fracture zone, plastic zone, and elastic zone from the goaf and roadway edge to the interior. The strength of the coal pillar in the fracture zone decreases significantly, and the existing fractures will be gradually enriched by the mine water. The coal pillars in the plastic zone bear large vertical stresses, and some of the developed microcracks will also become potential channels for mine water infiltration. Therefore, it is necessary to analyze the width of the plastic zone on the side of the goaf and the roadway. The calculation model of the coal pillar is shown in Figure 1 below.

$$L = L_{Cp} + L_e + L_{Hp} \tag{1}$$

where L_{Cp} is the width of the plastic zone on the reservoir side, Le is the width of the elastic zone, L_{Hp} is the width of the plastic zone on the roadway side, L is the total width of the coal pillar dam, K_1 is the coefficient of the vertical stress concentration of the reservoir, K_2 is the coefficient of the vertical stress concentration of the roadway, and H is the depth of the coal seam.



Ⅰ: Rock crushing area; Ⅱ: Plastic zone area; Ⅲ: elastic zone area

Figure 1. Calculation model of the coal pillar size in an underground reservoir.

3.1. Calculation of the Plastic Zone Width of a Coal Pillar Dam

Field research has shown that the coal pillar dam body is subject to the combined action of overlying rock pressure, interlayer friction, and water pressure. A mechanical model of the coal pillar dam can be obtained by analyzing the coal pillar dam as a plane strain model, treating the coal body as a continuous uniform medium, and treating the water pressure as a uniform pressure, as shown in Figure 2.

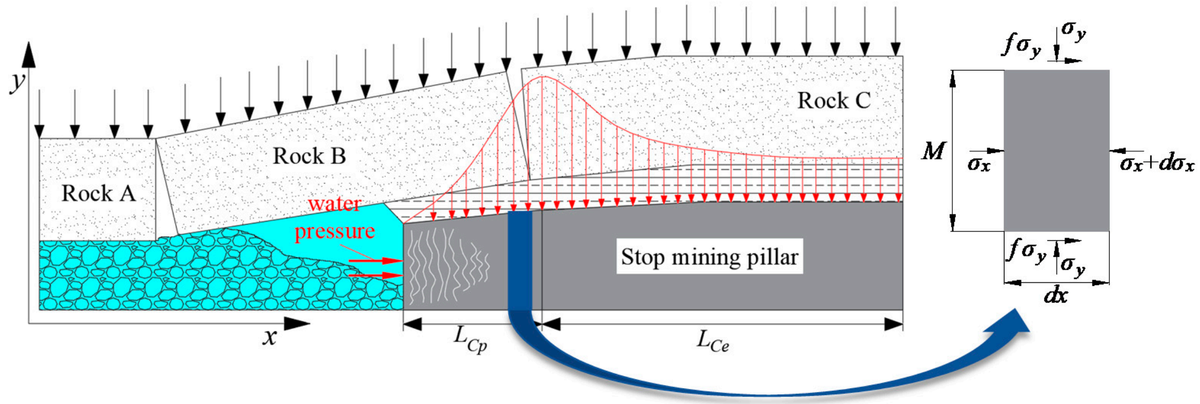


Figure 2. Mechanical model of the goaf side of a coal pillar in an underground reservoir.

Based on the mechanical model of the underground reservoir coal pillar dam, a small unit with a width of dx in the coal pillar dam was taken for mechanical analysis. Due to the lateral horizontal compressive force of the coal seam, the unit tended to extrude toward the goaf, so it is subject to interlayer friction in the opposite direction. A physical model of the unit is shown in Figure 2. The force balance expression of the unit body is as follows:

$$M\sigma_x - M(\sigma_x + \mathrm{d}\sigma_x) + 2f\sigma_y \mathrm{d}x = 0 \tag{2}$$

where M is the thickness of the coal seam, m; f is the friction factor of the interface between the coal seam and the roof and floor; σ_y is the vertical stress of coal, MPa; σ_x is the horizontal stress of the coal body, MPa; and $\lambda = \frac{1+\sin\varphi}{1-\sin\varphi}$, φ is the effective internal friction angle of coal.

The stress of the coal pillar element in the dam body of the reservoir side was consistent with that of the coal pillar element in the roadway side, although the boundary conditions of the two were not consistent. The boundary conditions on the reservoir side and roadway side are shown as follows:

$$① \begin{cases} x = 0, \sigma_x = p \\ x = L_{cp}, \sigma_y = K_1\gamma H \end{cases} \cdot (\text{reservoir side}) \tag{3}$$

$$② \begin{cases} x = 0, \sigma_x = 0 \\ x = L_{Hp}, \sigma_y = K_2\gamma H \end{cases} \cdot (\text{roadway side}) \tag{4}$$

Previous research results have shown that, under different boundary conditions, by combining the mechanical balance expression of the unit body with the coal strength equation of the plastic softening stage and the plastic flow stage, the plastic zone width expression of the coal pillar dam body at the side of the reservoir and the coal pillar at the side of the roadway can be obtained. The force balance equation of the unit body is given in this paper, and the strength equations of coal during the plastic softening stage and plastic flow stage [18] are as follows:

$$\begin{array}{l} \sigma_y = \lambda\sigma_x + \sigma_c + \frac{S_m S_g}{M}(L_{cp} - x) \\ \sigma_y = \lambda\sigma_x + \sigma_r \end{array} \tag{5}$$

After comprehensive consideration of the coal body strength and stress expression of the unit body, combined with the stress boundary conditions, the expression of the plastic zone of the reservoir side and roadway side could be obtained as follows [18]:

$$L_{Cp} = \frac{M}{2\lambda f}\ln\left\{\frac{K_1\gamma H}{\lambda p+\sigma_r} - \frac{S_{\rm m}S_g(1-\eta)}{2\lambda f(\lambda p+\sigma_r)}\right\};\eta = \exp\left(\frac{2\lambda f}{S_{\rm m}S_g}(\sigma_c-\sigma_r)\right) \quad (6)$$

$$L_{Hp} = \frac{M}{2\lambda f}\ln\left\{\frac{K_2\gamma H}{\sigma_r} - S_{\rm m}S_g\left[1-\exp\left(\frac{2\lambda f}{S_{\rm m}S_g}(\sigma_c-\sigma_r)\right)\right]/2\lambda f\sigma_r\right\} \quad (7)$$

where K_1 is the stress concentration coefficient of the reservoir side; K_2 is the stress concentration factor of the roadway side; σ_c is the uniaxial compressive strength of coal, MPa; σ_r is the residual strength of coal, MPa; S_m is the softening modulus of the coal mass, MPa; S_g is the strain gradient of the coal mass in the plastic zone; γ is the volume force, 25·KN·m^{-3}; and p is the water pressure, MPa.

3.2. Calculation of the Elastic Area Width of the Coal Pillar Dam

As the coal pillar of the underground reservoir is subject to the water pressure of the goaf, and as the seepage damage of the goaf water to the coal pillar dam is a process of gradual deepening over time, in order to ensure the safety of the coal pillar dam and its ability to permanently serve the underground reservoir of the coal mine, the width of the elastic area of the coal pillar dam was calculated according to the calculation method of the waterproof coal pillar in the Regulations of Coal Mine Water Control [19]. The calculation formula was as follows:

$$L_e = 0.5kM\sqrt{\frac{3p}{K_p}} \quad (8)$$

where L_e is the width of the elastic zone of the coal pillar, m; and k is the safety factor, usually 2–5. Due to the long service life of the coal pillar dam and considering the issue of safety, the safety factor was 5. Moreover, M is the thickness or mining height of the coal seam, m; p is the water pressure, MPa; and K_p is the tensile strength of coal, MPa.

4. Analysis of the Influencing Factors of the Coal Pillar Dam Size and Theoretical Calculation of the Dam Width

4.1. Analysis of the Influencing Factors of the Coal Pillar Dam Size

According to the above analysis, the coal pillar dam body of the reservoir is composed of the reservoir side plastic zone, the elastic zone, and the roadway side plastic zone, and the expression is as follows:

$$\begin{aligned} L = {} & \frac{M}{2\lambda f}\ln\left\{\frac{K_1\gamma H}{\lambda p+\sigma_r} - \frac{S_{\rm m}S_g(1-\eta)}{2\lambda f(\lambda p+\sigma_r)}\right\} + 0.5kM\sqrt{\frac{3p}{K_p}} + \\ & \frac{M}{2\lambda f}\ln\left\{\frac{K_2\gamma H}{\sigma_r} - S_{\rm m}S_g\left[1-\exp\left(\frac{2\lambda f}{S_{\rm m}S_g}(\sigma_c-\sigma_r)\right)\right]/2\lambda f\sigma_r\right\} \end{aligned} \quad (9)$$

As can be seen from the above equation, the factors affecting the size of the coal pillar dam can be divided into three categories: the influence of mining factors, the influence of mine water, and the influence of mine geological conditions. A classification diagram of the influencing factors is shown in Figure 3 below.

In order to study the degree of influence of various factors on the size of the coal pillar dam, the control variable method was adopted to take a certain reference value and change a variable. The reference values are shown in the Table 1 below.

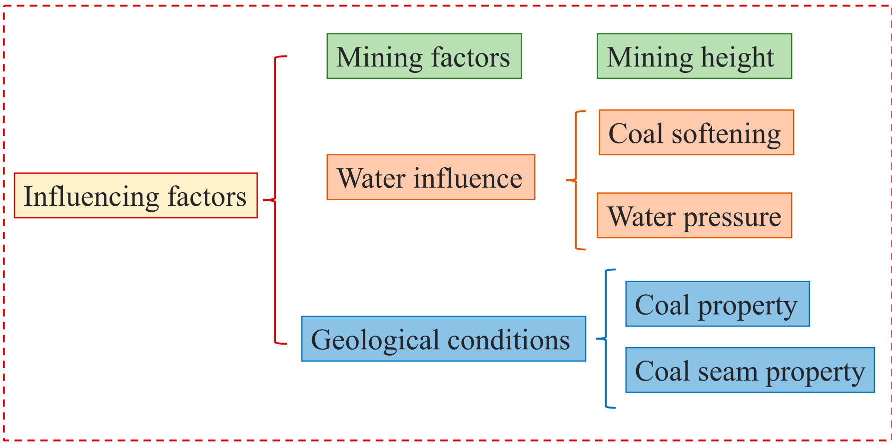


Figure 3. Classification diagram of the influencing factors.

Table 1. Selected reference values.

γ/(kN·m^{-3})	K_1	K_2	k	S_m/MPa	S_g
23.9	3.0	1.8	5	800	0.08

Firstly, the mining factors were analyzed, and the mining height was found to influence the width of the plastic zone, elastic core, and plastic zone of the roadway side. Based on the reference value, the mining height was changed from 2.0 m to 7.0 m, and the change curve and change rate of the coal pillar width are shown in Figure 4.

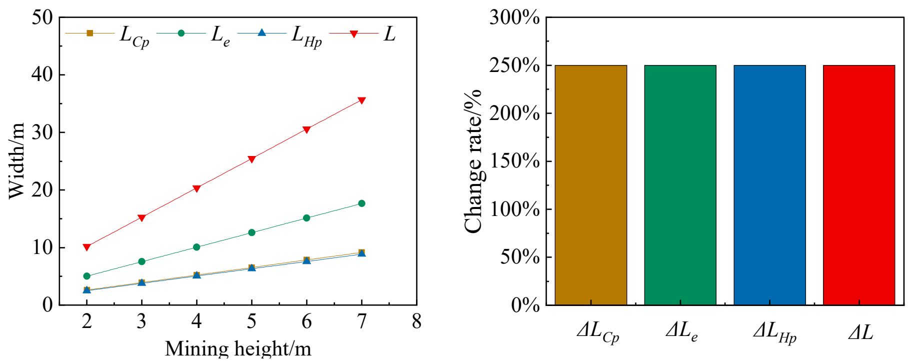


Figure 4. Diagram of the coal pillar affected by the mining factors.

As can be seen from Figure 4, an increase in the mining height will cause the linear growth of the width of the plastic zone of the goaf, elastic core, and plastic zone of the roadway. In the process of increasing from 2.0 m to 7.0 m, the growth rate of the three was 250%, and the total width of the coal pillar also increased by 250%, which indicated that the coal pillar width of the reservoir is extremely sensitive to a change in the mining height of the working face. The increase in the mining height of the working face requires the increase in the coal pillar width of the reservoir.

The influence of the mine drainage on the reservoir coal pillar is reflected in two aspects, water pressure and coal softening, which are determined by the coal moisture content. By changing the water pressure and coal body moisture content, the influence curve of the mine water factors could be drawn as follows (Figure 5).

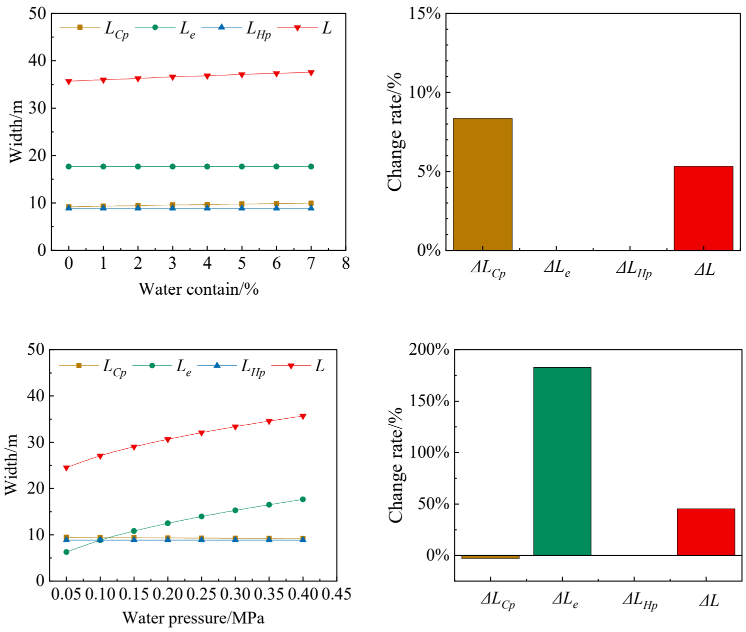


Figure 5. Diagram of the coal pillar affected by the mine water factors.

As can be seen from Figure 5, the softening of the coal mass caused by the change in the water content led to the increase in the plastic zone in the goaf, although the softening of the coal mass had little influence on the expansion of the plastic zone. When the water content increased from 0% to 7%, the total width of the coal pillar in the reservoir only increased by 5.3%. However, the elastic core width was extremely sensitive to the change in the water pressure. When the water pressure increased from 0 MPa to 0.4 MPa, the elastic core width increased by 182.8%, which was also the main reason for the increase in the total width of the coal pillar.

The influence of the geological factors could mainly be divided into two aspects: coal body parameters and coal seam parameters. Among them, the coal body factors affecting the width of the coal pillar in the reservoir included the internal friction angle and tensile strength. The influence curve of the coal body parameters is shown in Figure 6.

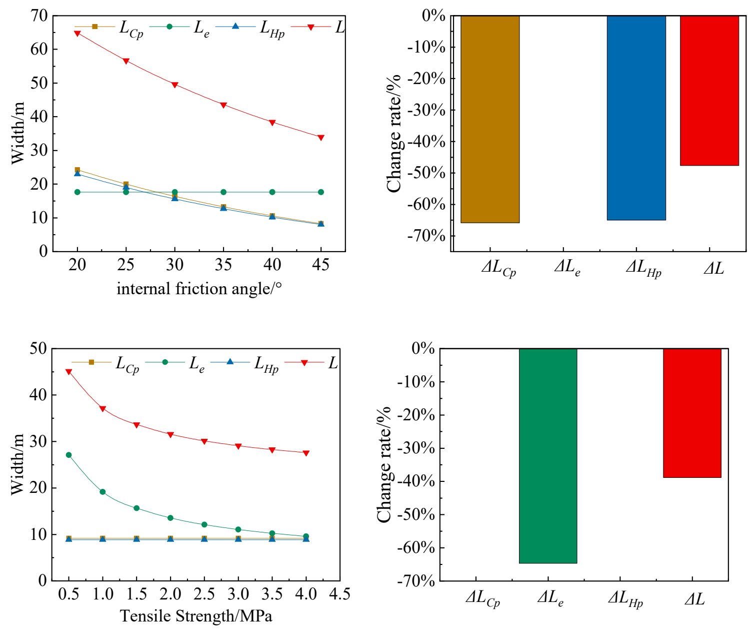


Figure 6. Diagram of the coal pillar affected by the coal body parameters.

As can be seen from Figure 6, the internal friction angle of the coal body had a direct influence on the plastic zone of the working face and the roadway. With the decrease in the internal friction angle, the width of the plastic zone showed an accelerated growth trend. The tensile strength of coal only affected the width of the elastic core. The smaller the tensile strength was, the larger the width of the elastic core needed to be to maintain the stability of the coal pillar. The influence curve shows that the width of the coal pillar is sensitive to the change in the coal parameters. The coal seam factors affecting the width of the coal pillar in the reservoir included the friction coefficient and coal seam depth, and the related influence curve is shown in Figure 7.

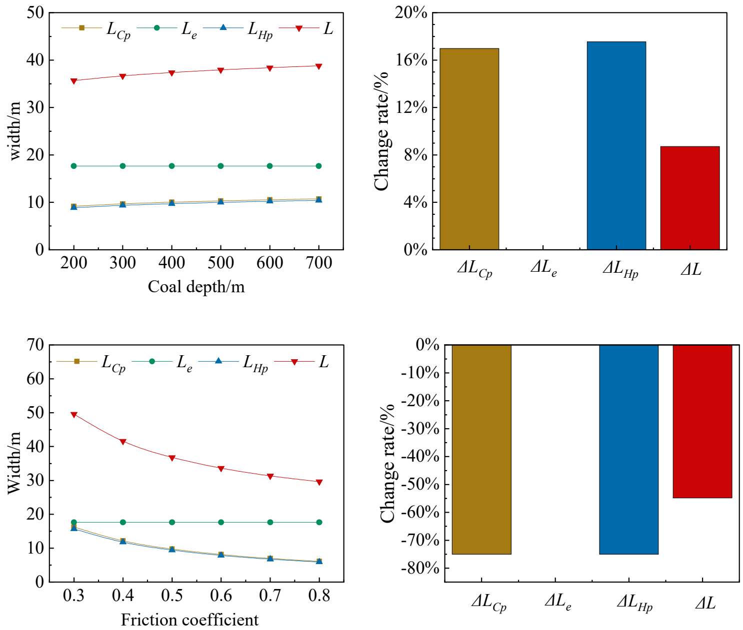


Figure 7. Diagram of the coal pillar affected by the coal seam parameters.

As can be seen from Figure 7, the depth of the plastic zone at the working face and the roadway side increased with the increase in the coal seam depth. However, when the depth of the coal seam increased from 200 m to 700 m, the total width of the coal pillar dam body of the reservoir only increased by 8.7%, so the coal pillar of the reservoir is not greatly affected by the depth of the coal seam. On the other hand, the interlayer friction coefficient has a larger influence on the plastic zone range of the working face and the roadway side. The smaller the interlayer friction coefficient is, the larger the plastic zone range is, and the increasing trend is accelerated. With the increase in the interlayer friction coefficient from 0.2 to 0.8, the total width of the coal pillar in the reservoir decreased by 54.8%, which was far greater than the influence of the depth of the coal seam.

The above findings can be summarized as follows. First, the width of the coal pillar in the reservoir is affected by the mining factors, water factors, and geological factors, and the three factors jointly determine the minimum width required to maintain the stability of the coal pillar dam. Second, the width of the coal pillar in the reservoir is very sensitive to changes in the mining height and coal body parameters. The increase in the mining height and changes in the coal body parameters will cause a sharp increase in the coal pillar width. Third, the influence of the mine water on the coal pillar in the reservoir is mainly reflected in the strength weakening of the coal body in the plastic zone and the change in the water pressure. The strength weakening of the coal body will lead to the enlargement of the scope of the plastic zone, while the increase in the water pressure will greatly increase the width of the elastic nucleus needed to maintain the stability of the coal pillar.

4.2. Theoretical Calculation of the Width of the Coal Pillar Dam in Daliuta Mine

According to the geological data concerning Daliuta Mine, there is a 25–40 m fault drop between the goaf of Working Face 52503 and the working face to be mined on both sides, so the possible water storage depth of the goaf is 25 m at most and the maximum water pressure is 0.25 MPa. Considering the weakness of the coal body strength under the influence of the mine water, the relevant parameters of the coal body were substituted, the stress concentration coefficient was measured by field measurements, and the buried depth was taken as the average buried depth of the coal seam. L_{Cp} was 11.12 m, L_e was 15.31 m, L_{Hp} was 6.22 m, and the total theoretical calculation width of the coal pillar in the reservoir was 32.65 m.

5. Numerical Simulation Analysis of the Coal Pillar Dam

5.1. Numerical Modeling and Analysis

In order to obtain a reasonable and safe size for the coal pillar in the reservoir, FLAC^{3D} numerical simulation software was used to establish a three-dimensional numerical simulation model based on the geological conditions of Working Face 52503 of Daliuta Mine, as shown in Figure 8 [20]. The model size was 500 m × 470 m × 99 m. A stress of 5.13 MPa was applied at the top of the model to simulate the overlying rock load. A fixed support was adopted at the bottom, and a roller support was adopted around the model to limit the normal displacement.

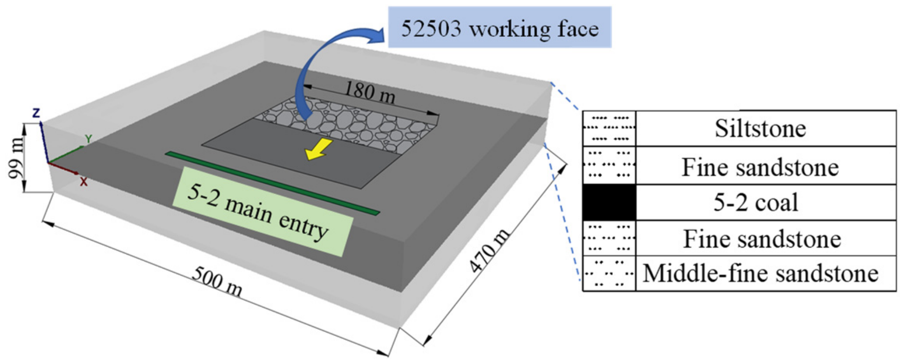


Figure 8. Three-dimensional numerical simulation model.

The rock mechanics parameters of the model were obtained via rock mechanics experiments, and the rock strata with little difference in their physical properties were combined. In order to simulate the softening effect of the mine water on the coal body, the coal body parameters were weakened accordingly, and the coal pillar widths of 20 m, 25 m, 30 m, 35 m, 40 m, 45 m, 50 m, 55 m, and 60 m were calculated, respectively.

5.2. Comprehensive Analysis of the Stresses and Plastic Zones of Different Dam Widths

In order to analyze the stability of the coal pillar in the remaining reservoir, the principal stress and vertical stress data for different coal pillar widths were extracted, respectively, and the deviator stress was calculated. The expression of the deviator stress was as follows, while the internal stress curve of the dam body was drawn as shown in Figure 9.

$$S_1 = \sigma_1 - \frac{(\sigma_1 + \sigma_2 + \sigma_3)}{3} \tag{10}$$

The deviatoric stress controlled the plastic deformation in the dam body. The higher the deviatoric stress level, the lower the stability of the coal dam body. As can be seen from the deviatoric stress curve in Figure 9, with the width of the coal pillar dam decreasing from 60 m to 20 m, the deviatoric stress level in the coal pillar dam continued to rise and the minimum value of the deviatoric stress increased from 1.53 MPa to 6.59 MPa, accelerating with the increase in the width of the dam. The peak value of the deviatoric stress on the roadway side also increased from 3.92 MPa to 8.78 MPa. It can be seen from the deviatoric stress curve that when the width of the coal pillar dam body was greater than 35 m, the decreasing speed of the deviatoric stress in the dam body was relatively reduced. The analysis of the supporting stress curve in the coal pillar dam showed that with the increase in the width of the coal pillar dam, the level of supporting stress in the coal pillar dam gradually decreased and the concentration coefficient of the supporting stress at the roadway side showed a decreasing trend. When the width of the dam was greater than 35 m, the concentration coefficient of the bearing stress dropped below 2.0.

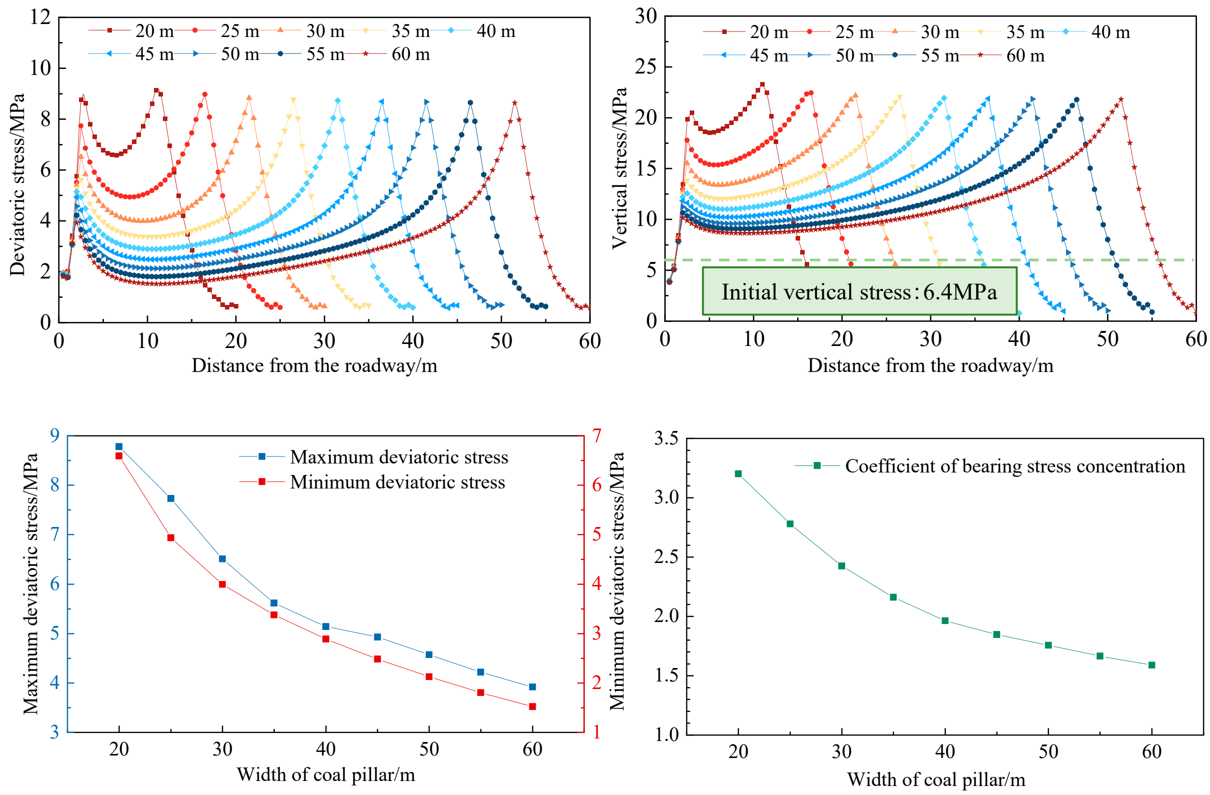


Figure 9. Curves of the vertical stress and deviatoric stress in the dam.

The width of the plastic zone of the goaf side and roadway side under different coal pillar dam widths was extracted, and the curve was drawn as shown in Figure 10.

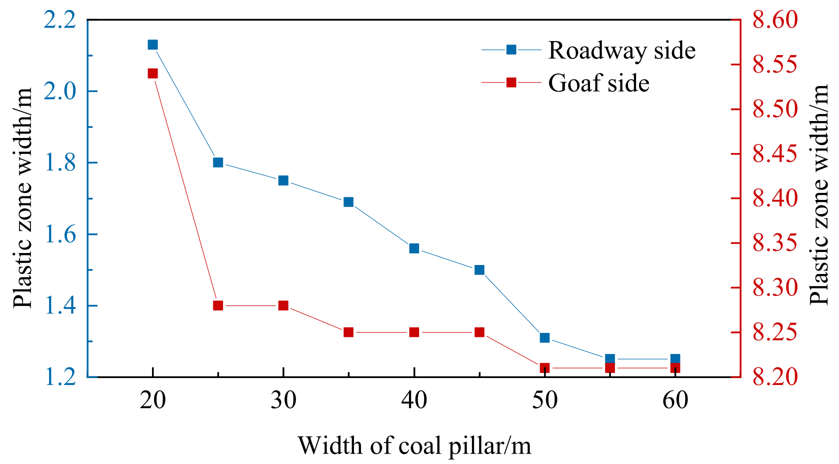


Figure 10. Curves of the plastic zone width.

As can be seen from Figure 10, with the decrease in the width of the coal pillar dam body, the width of the plastic zone at both the roadway side and the goaf side increased. When the width of the coal pillar dam was less than 25 m, the plastic zone of the goaf side and the roadway side increased rapidly, which indicated that the plastic zone scope in the coal pillar dam with a width of less than 25 m can more easily expand. When the width of the coal pillar dam was between 25 m and 50 m, the plastic zone increased slowly with the decrease in the dam width. When the width of the coal pillar dam body was greater than 50 m, the width of the plastic zone at the goaf side and roadway side tended to be stable and did not decrease.

The following can be seen from the above analysis. First, with the increase in the width of the coal pillar dam body, the deviatoric stress and supporting stress in the dam body gradually decreased, while the width of the plastic zone at the goaf side and the roadway side also gradually decreased. Second, with the decrease of the width of the coal pillar dam, the width of the plastic zone, the level of deviatoric stress, and the level of supporting stress of the dam showed an accelerating trend. When the width of the coal pillar dam was larger than 50 m, the level of deviatoric stress in the dam was low and the plastic zone in the dam no longer expanded.

According to the above calculations, considering the softening effect of the mine water on the coal body, the reasonable width for the coal pillar dam body, as calculated theoretically, was 32.65 m. It can be seen from the numerical simulation results that when the width of the coal pillar dam was less than 30 m, with the decrease in the width of the coal pillar dam, the expansion speed of the plastic zone at the side of the goaf and the side of the roadway increased, while the level of deviatoric stress and supporting stress in the dam also accelerated. Therefore, the theoretical calculation of the width of the coal pillar dam may play a guiding role in the development of the coal pillar dam. The width of the coal pillar dam should be greater than the minimum width calculated theoretically. Considering the influence of the service life of the mine reservoir and the mine dynamic events on the stability of the coal pillar dam, the width of the coal pillar dam should be increased.

6. Discussion

This paper provides a theoretical method for calculating the reasonable width of a coal pillar dam. The research results will play an important role in the construction of coal pillar dams and the improvement of the coal recovery rate. The influence of different factors on the width of the plastic zone of the dam body in this paper was consistent with previous research results [18], while the influence of the mining height and coal depth on the width of the plastic zone under different mine conditions was also the same. By extracting the data from reference [18] and comparing it with the research data in this paper, the plastic zone change curve was able to be drawn, as shown in Figure 11.

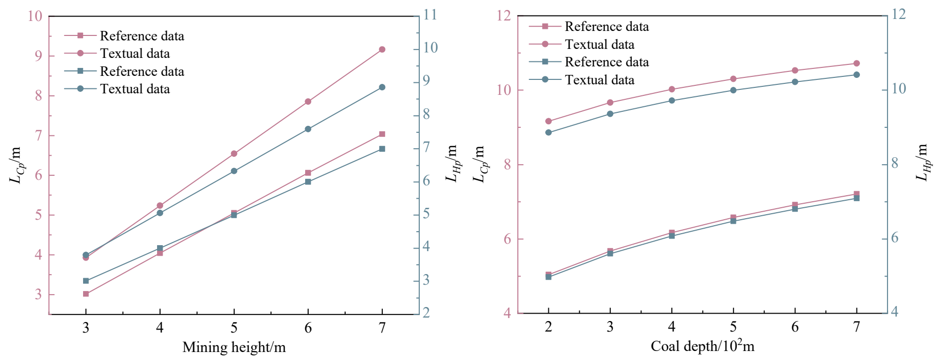


Figure 11. Plastic zone under the influence of the mining height and coal depth.

As can be seen from Figure 11, under different mine conditions, with the increase in the mining height and coal depth, the width of the plastic zone on the reservoir side and the roadway side showed an upward trend, while the width of the plastic zone on the reservoir side was always greater than that on the roadway side, which was consistent with engineering practice.

One difference between this paper and previous studies is that the calculation method used for the elastic region width was different. In previous research results, the width of the elastic zone was always calculated with K times the mining height, without considering the properties of the coal body and water pressure [18], while the elastic zone calculation formula adopted in this paper took into account the combined action of the water pressure, mining height, and the tensile strength of coal [19]. In order to reflect the changing trend in the elastic zone width under the influence of different factors, the elastic zone width calculated by K times the mining height and the elastic zone widths under the influence of different influencing factors were drawn, as shown in Figure 12.

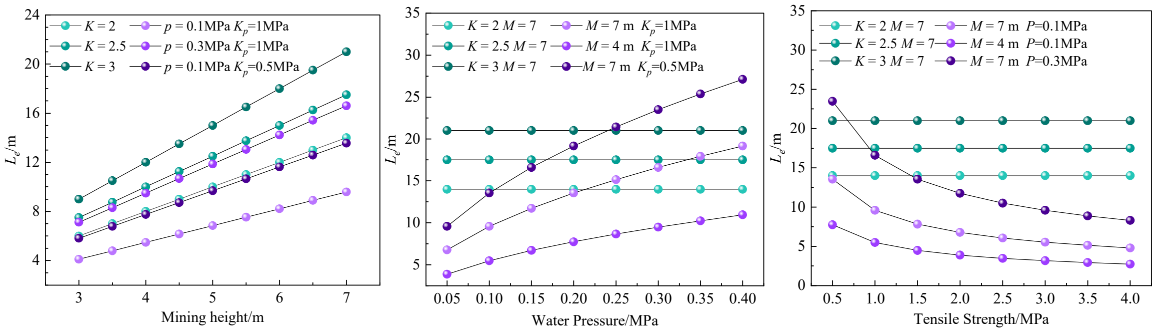


Figure 12. Elastic zone under different influencing factors.

As can be seen from Figure 12, with the increase in the mining height, the width of the plastic zone under the two calculation methods presented a linear upward trend, although the increase in the water pressure and the decrease in the tensile strength caused the increase in the growth slope of the elastic zone. With the increase in the water pressure, when the mining height was 7 m, the elastic zone width of the multiple mining height method was a fixed value, although the elastic zone width calculated in this paper showed an increasing trend. With the increase in the tensile strength of coal, the elastic zone width of the multiple mining height method was also fixed, but the elastic zone width calculated in this paper showed a decreasing trend. Different mining heights, water pressures, and coal tensile strengths will affect the growth rate of the elastic zone width but not the overall trend.

7. Conclusions

(1) The theoretical formula for a reservoir dam was given in this study. The coal pillar width of a reservoir is very sensitive to the change in the mining height and coal body parameters, and the increase in the mining height and coal body parameters will cause a sharp increase in the coal pillar width.

(2) The influence of the mine drainage on the coal pillar in the reservoir is mainly reflected in the strength weakening of the coal body in the plastic zone and the water pressure. The strength weakening of the coal body will lead to the enlargement of the plastic zone of the dam body, while the increase in the water pressure will greatly increase the width of the elastic core to maintain the stability of the coal pillar.

(3) When the width of the coal pillar is smaller than the width of the dam body, which is calculated theoretically, the deviatoric stress and supporting stress in the dam body will increase greatly, while the plastic zone will expand obviously. The actual width of the dam should be further increased according to the service life and the actual situation of the mine.

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