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# Design of the Appropriate Width of the Filling Body for Gob-side Entry Retaining in Hard and Thick Top Coal with Gangue Concrete

**Jianye Feng[1, *], Kang Wang[2], Jiasen Chen[2], Yikun Liu[2], Xiaodong Zheng[3], Kun Niu[4]**

[1]*School of Mining Engineering and Geology, Xinjiang Institute of Engineering, Urumqi, 830023, China*
[2]*Key Laboratory of Xinjiang Coal Resources Green Mining, Ministry of Education, Xinjiang Institute of Engineering, Urumqi, 830023, China*
[3]*Xinjiang Key Laboratory of Coal-bearing Resources Exploration and Exploitation, Xinjiang Institute of Engineering, Urumqi, 830023, China*
[4]*Xinjiang Engineering Research Center of Green Intelligent Coal Mining, Xinjiang Institute of Engineering, Urumqi, 830023, China*
**Corresponding author*

***Abstract:*** *The roadway support and goaf treatment under the condition of hard and thick roof are key challenges in the coal mining process. The gob-side entry retaining technology provides a new solution. This paper takes the 15311-working face of the 1890 Coal Mine of Xinjiang Jiao Coal Group as the engineering background to conduct research on the design of the reasonable width of the coal-gangue concrete filling body for gob-side entry retaining. By establishing a mechanical action model of gob-side entry retaining, the support resistance of the coal-gangue concrete is calculated to be 14266.96kN, and the bearing capacity of the 1.2-m-wide filling body is theoretically checked. The outcomes demonstrate that it complies with the support requirements. By means of FLAC3D software, numerical models featuring different widths were constructed for analysis. It is thus concluded that the entry-retaining with a 1.2-m-wide filling body exhibits high overall stability and low deformation. Field practice shows that during the entry-retaining period, the overall deformation of the roadway is small, the integrity of the surrounding rock is good, and the entry-retaining effect is satisfactory. Finally, the reasonable width of the coal-gangue concrete filling body in the 15311-working face is determined to be 1.2m. The research findings can serve as a reference for designing the filling body width under analogous geological conditions.*

***Keywords:*** *Hard Roof; Coal Gangue Concrete; Gob-side Entry Retaining; Filling Body Width; Numerical Simulation*

## 1. Introduction

In the context of China's modern industrial system, coal resources assume a position of utmost significance, being both pivotal and irreplaceable[1]. The continuous rise in both mining depth and intensity has caused the underground coal-mining environment to be-come increasingly intricate and demanding. Among the various challenges faced, road-way support and goaf treatment under the condition of hard and thick roofs have emerged as the key bottleneck factors that severely impede the safe and highly-efficient exploitation of the coal industry[2-4].

During the mining process, due to the unique geological features and mechanical properties inherent in hard and thick roofs, their natural caving is extremely difficult to occur. This situation leads to a large-scale suspension of the roof above the goaf, which is highly likely to trigger powerful dynamic-pressure disasters. These disasters not only pose a serious threat to the lives and health of underground workers and the normal operation of mining equipment but also, in severe cases, can cause a series of ecological and environmental disasters such as ground subsidence[5, 6]. Therefore, how to effectively control the stability of the surrounding rock under the hard-thick-roof condition and scientifically and rationally handle the goaf has become a major technical problem that urgently needs to be solved in the coal-mining industry[7, 8].

As an innovative green-mining technology in the coal-mining domain, gob-side entry retaining offers

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a novel technical approach for preventing and controlling the pressure-induced disasters caused by hard and thick roofs[9]. As shown in Figure 1, gob-side entry retaining in-volves constructing a filling body on one side of the goaf. After the mining work is completed, the roadway can be retained and repurposed as the return-air or transportation passage for the next working face. This approach not only substantially cuts down the workload of roadway excavation but also efficiently boosts the stability of the roadway's surrounding rock, and consequently reduces the adverse impact of mine pressure on the roadway and the working face. [10-12, 22].

Coal-gangue concrete, a new-generation filling material specifically designed for gob-side entry retaining, mainly uses waste gangue generated during coal mining as its filling aggregate. Through the processing and crushing of the waste gangue for the preparation of coal-gangue concrete in gob-side entry retaining, we can not only achieve the efficient utilization of the coal gangue as a resource, transforming the waste into valuable substances and minimizing environmental pollution, but also make full use of the out-standing mechanical properties of the coal-gangue concrete, including its high strength and high toughness. These properties endow the filling body with enhanced bearing capacity and deformation-resistance, effectively resolving the stability issues of the filling body[13, 14].

A reasonable width of the gob-side entry retaining filling body is a fundamental pre-requisite for ensuring the long-term stability of the roadway's surrounding rock under the control of gob-side entry retaining. Although scholars at home and abroad have achieved certain research results in the field of gob-side entry retaining filling bodies, the research on the design of a reasonable width for coal-gangue concrete under the hard-thick-roof condition remains relatively scarce. Most of the existing research focuses on aspects such as the material properties of the filling body and the filling process. A deficiency in in-depth and systematic research on key issues, namely the interaction mechanism be-tween the width of the filling body and the surrounding rock of the hard and thick roof and the method for determining the optimal width, has been identified. Therefore, con-ducting research on the design of a reasonable width for the coal-gangue-concrete filling body in gob-side entry retaining under the hard-thick-roof condition is of great theoretical significance and practical application value[15-17].

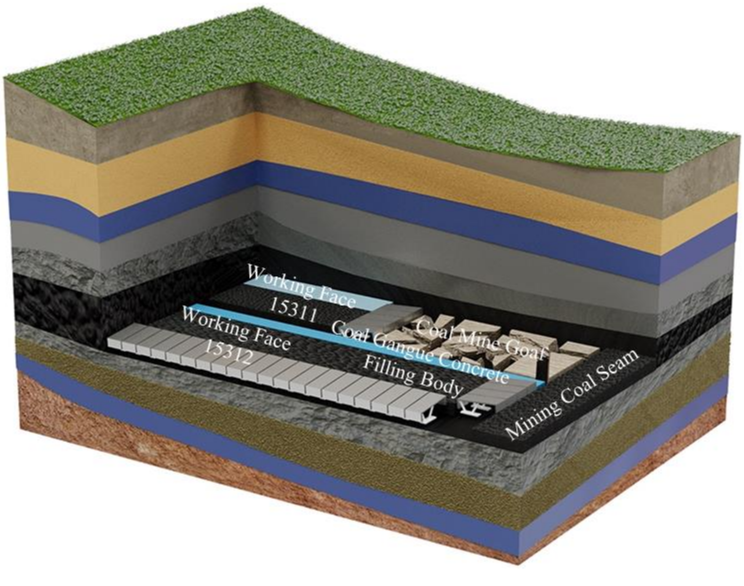


*Figure 1 Gob-side Entry Retaining Technological System of Coal Gangue Concrete*

The transportation roadway of the 15311-working face in the 1890 Coal Mine serves as the research object in this study. By means of theoretical calculations and numerical simulations, the stress distribution laws and the deformation-failure characteristics of the surrounding rock of flexible-mold concrete filling bodies with different widths during the mining of thick coal seams are analyzed. The interaction mechanism between the filling body and the surrounding rock of the hard and thick roof is elucidated, and a methodology for ascertaining the rational width of the filling body is developed. What's more, the re-liability of the coal-gangue-concrete-reinforcement support technology during the mining period is verified through mine pressure monitoring. The research results of this study can provide significant references and practical suggestions for the design of filling bodies in other similar geological settings[18-20].

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## 2. Materials and Methods

### *2.1 Mine Overview*

This study selects the transportation roadway of the 15311-working face in the 1890 Coal Mine of the Xinjiang Coking Coal Group as the research subject. As shown in Figure 2, the 15311-working face is situated in the third mining area of the first level. It has a burial depth of 141 meters and a strike length of 988 meters. The dip length extends from the outcrop line of the No. 5 coal seam in the east to the 15312-working face in the west and to the protective coal pillar of the southern mine-field boundary in the south. The average thickness of the coal seam is 3.6 meters, and the average dip angle is 3°, categorizing it as a nearly horizontal coal seam. The geological parameters of the 15311-working face are presented in Table 1. The floor is mainly composed of medium-grained sandstone with an average thickness of 22.6 meters. The roadway section is rectangular. At present, coal-gangue-concrete gob-side entry retaining is being implemented in the transportation gateway of the 15311-working face, and after the retaining process, it will serve as the return-air roadway for the 15312-working face, with a retaining length of 840 meters.

*Table 1 The geological conditions of the surrounding rock in the 15311-working face*

| Roof and Floor | Roof and Floor | Average Thickness / m | Lithology Characteristics |
|---|---|---|---|
| *Main Roof* | *Siltstone* | 13.85 | Light gray, argillaceous cementation, wavy bedding |
| *Immediate Roof* | *Medium-grained Sandstone* | 3.88 | Gray-brown, wavy bedding |
| *False Roof* | *Coarse-grained Sandstone* | 10.3 | Gray, argillaceous cementation, horizontal bedding |
| *No. 5 Coal* | *Coal* | 3.6 | Mainly coking coal and gas-fat coal |
| *Immediate Floor* | *Medium-grained Sandstone* | 22.6 | Gray-white, siliceous cementation, horizontal bedding |

The transportation roadway of the 15311 southern working face undergoes gob-side entry retaining mining construction, and the length of the retaining section is 840 m. The schematic diagram of the construction location is shown in Figure 2[18].

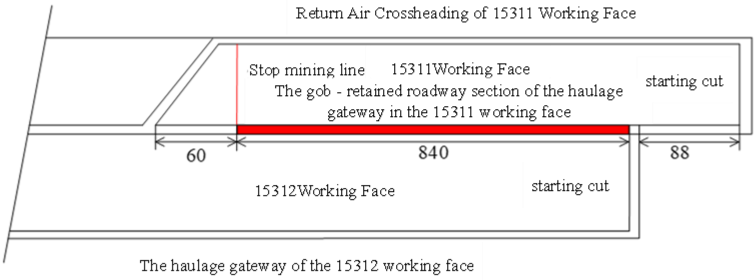


*Figure 2 Construction Layout of Gob-side Entry Retaining with Coal Gangue Concrete in the 15311-Working Face*

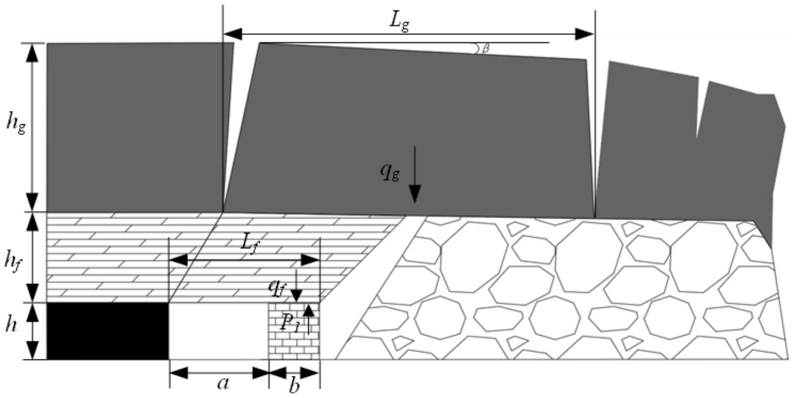


*Figure 3 Mechanical Action Model of Gob-side Entry Retaining*

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### *2.2. Design of the Reasonable Width of the Coal-gangue Concrete Filling Wall*

#### *2.2.1. Calculation of the Support Load of the Coal-gangue Concrete Filling Wall*

Taking into account the impact of the supporting role of the coal wall and the fragmented rocks in the goaf on the movement of the overlying strata, we assume that the main roof is positioned above the roadway roof, and the immediate roof, once fractured, directly fills the goaf. A mechanical action model of gob-side entry retaining, as shown in Figure 3, is established[16].

Considering the actual situation of the 15311-working face in the 1890 Coal Mine of Xinjiang Coking Coal Group, when taking into account the combined influence of the immediate roof load and the main roof load on the support resistance, the basic mechanical conditions to be satisfied are as follows:

$$P_1 + P_2 = \mathrm{q_f} + q_g = \gamma_\mathrm{f}\mathrm{h_f}L_\mathrm{f} + \gamma_\mathrm{g}\mathrm{h_g}L_\mathrm{g} \tag{1}$$

Where:

$P_1$ is the support resistance of the coal-gangue-concrete filling body, in kN;

$P_2$ is the supporting force of the goaf waste rocks, in kN;

$q_f$ is the self-weight of the immediate roof strata, in kN;

$q_g$ is the self-weight of the main roof strata, in kN;

$h_f$ is the thickness of the immediate roof, taking 5 m;

$h_g$ is the thickness of the main roof, taking 20 m;

$q_g$ is the action of the self-weight of the immediate roof, in kN;

$\gamma_f$ is the unit weight of the immediate roof, taking 25.6 kN/m³;

$\gamma_g$ is the unit weight of the main roof, taking 28.73 kN/m³;

$L_g$ is the width of the main roof, less than or equal to the periodic weighting step distance of the main roof, taking 21 m;

$L_f$ is the roadway support scope, in m, which is the sum of the roadway width and the width of the coal-gangue-concrete support area.

Since the support resistance of the coal-gangue-concrete gob-side filling body is much greater than the roadway support resistance, the roadway support resistance can be neglected[16].

According to the elastic foundation beam theory, the support reaction force of the goaf coal-gangue is:

$$P_2 = 1/2\left[\gamma_\mathrm{g}\mathrm{h_g}\ \ L_\mathrm{g} - L_\mathrm{f} - \mathrm{h_f}\cot\beta\ \right] \tag{2}$$

β is the rotational fracture angle of the immediate roof strata, which is equal to the subsidence angle of the main roof, in (°).

Then the support resistance of the coal-gangue-concrete is:

$$P_1 = 1/2\left[\gamma_\mathrm{g}\mathrm{h_g}\ \ L_\mathrm{g} + L_\mathrm{f} + \mathrm{h_f}\cot\beta\ + \gamma_\mathrm{f}\mathrm{h_f}L_\mathrm{f}\right] \tag{3}$$

Then, by substituting the above-mentioned values into the formula, the calculated result is:

$$P_1 = 14266.96\mathrm{KN} \tag{4}$$

#### *2.2.2. Calculation of the Bearing Capacity of the Coal-gangue Concrete Filling Wall*

Based on the practical experience of gob-side entry retaining in the mine, the width of the coal-gangue-concrete filling body for gob-side entry retaining is confirmed to be 1.2 m. Currently, a theoretical verification of the bearing capacity of the filling body with a 1.2-m-wide entry-retaining is carried out. The bearing capacity of the filling-body wall is related to its internal structural materials. The tension-resistant anchor bolts, serving as the skeleton structure of the filling wall, bear the lateral resistance received by the filling wall[19].

The calculation formula for the bearing capacity of the coal-gangue-concrete filling body is:

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$$F = \alpha \ \ f_c + 4N_1 \ \ A_c \tag{5}$$

The calculation formula for the restraining force of the tie-anchor bolts is:

$$N_1 = \frac{\sigma_r \pi d^2}{4 a_1 a_2} \tag{6}$$

Where:

$F$ is the bearing capacity of the coal-gangue-concrete filling body, in kN;

$\alpha$ is the bearing-capacity coefficient, taking 0.96;

$N_1$ is the restraining force of the tie-anchor bolts, in MPa;

$A_c$ is the cross-sectional area of the coal-gangue-concrete filling body, in m$^2$; taking 1.2 m$^2$;

$f_c$ is the compressive strength of the coal-gangue-concrete, in MPa, with a strength value of 14.2 MPa;

$d$ is the diameter of the tie-anchor bolts, taking 200 mm;

$\sigma_r$ is the tensile strength of the steel-bar structure, in MPa, taking 300 (HRB335);

$a_1$, $a_2$ are the row-and-column spacing of the tie-anchor bolt layout, taking 800×800 mm.

The effective restraining force of the anchor bolts is:

$$N_1\text{=0.15MPa} \tag{7}$$

After calculation, the bearing capacity of the coal-gangue-concrete filling body is:

$$F\text{=17036.6KN} \tag{8}$$

After calculation, it can be obtained that the bearing capacity of the coal-gangue-concrete filling body is greater than the support resistance required for the stability of the roadway's surrounding rock. Therefore, when the width of the coal-gangue-concrete entry-retaining is 1.2 m, the support strength meets the requirements of on-site safe production[22].

$$F\text{=17036.6KN} > P_1\text{=14266.96KN} \tag{9}$$

To comprehensively verify the rationality of the width of the coal-gangue-concrete entry-retaining, it is necessary to simulate the distribution characteristics of the stress field and displacement field of the roadway's surrounding rock under different width conditions through numerical calculations. By comparing and analyzing the stress distributions of coal-gangue-concrete with different widths, the reasonable width of the flexible-mold concrete gob-side entry retaining in the 15311-working face of the 1890 Coal Mine can be further determined[17, 20].

### *2.3. Numerical model establishment of coal gangue concrete gob side entry retaining*

As can be known from the above-mentioned theoretical and technical analysis, when the width of the coal-gangue-concrete entry-retaining is 1.2 m, the bearing capacity of the wall can meet the requirements of on-site safe production. Based on the above analysis, three numerical models with filling-body widths of 0.8 m, 1.2 m, and 1.6 m were respectively established through the FLAC3D numerical software to verify the results of the theoretical analysis[17, 20].

Based on the conditions of the roof and floor strata and the mining technologies of the 15311-working face in the 1890 Coal Mine of Xinjiang Coking Coal Group, numerical calculation models with widths of 0.8 m, 1.2 m, and 1.6 m were established respectively. The meshing in the entry-retaining area and around the roadway was intensified for more accurate simulations. To simplify the calculation process, the dip angle of the model was set to 0°. The model had a length of 204.8 m, a width of 200 m, and a height of 59.6 m. The model boundaries were fixed, and the deformation value was set to 0. The burial depth of the 15311-working face is 320 m. During the calculation, an equivalent load of 6 MPa needed to be applied to the upper boundary of the model to replace the self-weight of the overlying strata, with a lateral pressure coefficient of 1.2. After the ground stress of the model was balanced, the roadway was excavated, and then the support was applied. After the coal seam was excavated, the stress and deformation characteristics of the coal-gangue-concrete filling body with different entry-retaining widths under the influence of mining were studied. The numerical calculation model adopted the Mohr-Coulomb criterion, and the rock mechanical parameters of the model are presented as shown in Table 2.

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*Table 2 Rock Mechanical Parameters of the Strata in the 15311-Working Face*

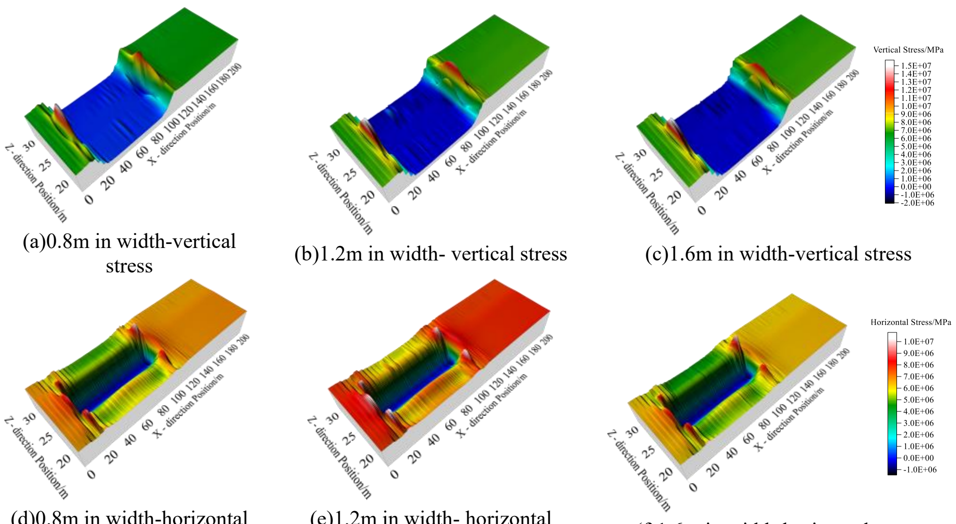
| Strata | Layer Thickness | Elastic Modulus / GPa | Cohesion / MPa | Internal Friction Angle / ° | Tensile Strength / MPa | Density / ($kg\cdot m^{-3}$) |
|---|---|---|---|---|---|---|
| *Siltstone* | 20 | 1.95E+10 | 2.75E+06 | 38 | 1.8 | 2460 |
| *Medium-grained Sandstone* | 4 | 5.99E+09 | 2.75E+06 | 32 | 1.2 | 2580 |
| *Coarse-grained Sandstone* | 10 | 7.00E+09 | 5.00E+06 | 30 | 0.8 | 2560 |
| *No. 5 Coal* | 3.6 | 5.30E+09 | 1.25E+06 | 28 | 0.6 | 1380 |
| *Medium-grained Sandstone* | 22 | 5.99E+09 | 2.75E+06 | 31 | 1.3 | 2580 |

## 3. Results

### *3.1. Numerical Simulation Analysis*

#### *3.1.1. Stress Distribution Characteristics of the Surrounding Rock of Filling Bodies with Different Widths*

As depicted in Figure 4 and Figure 5, the vertical stress of the coal-gangue-concrete filling body exhibits a diagonal distribution pattern from the goaf side to the roadway. Vertical stress concentration is observed at the floor position on the goaf side and the roof position of the roadway. As the width of the filling body increases, the range of vertical stress concentration expands, and the stress gradually transfers to the filling wall. When the width of the filling body is 1.2 m, the range of stress concentration it undergoes is the largest. The difference in the asymmetric stress borne by the filling body and the solid coal of the 15312-working face exerts an influence on the stability of the roadway. As shown in Figure 4, when the width of the filling body is 1.2 m, the difference in asymmetric stress is the smallest, and the overall stability of the roadway is higher at this moment[21]. The horizontal stress has a significant influence on the stability of the roadway roof. As the width increases, the stress transfers from the roof of the 15311-working face transportation roadway to the 15312-working face. It can be observed that as the width of the filling body increases, the concentration of mining-induced stress around the wall and the roadway becomes more prominent, and the requirements for maintaining the overall stability of the filling body and the roadway are higher[20].




(a)0.8m in width-vertical stress

(b)1.2m in width- vertical stress

(c)1.6m in width-vertical stress

(d)0.8m in width-horizontal stress

(e)1.2m in width- horizontal stress

(f)1.6m in width-horizontal stress

*Figure 4 Stress Distribution of Surrounding Rock of Filling Bodies with Different Widths*

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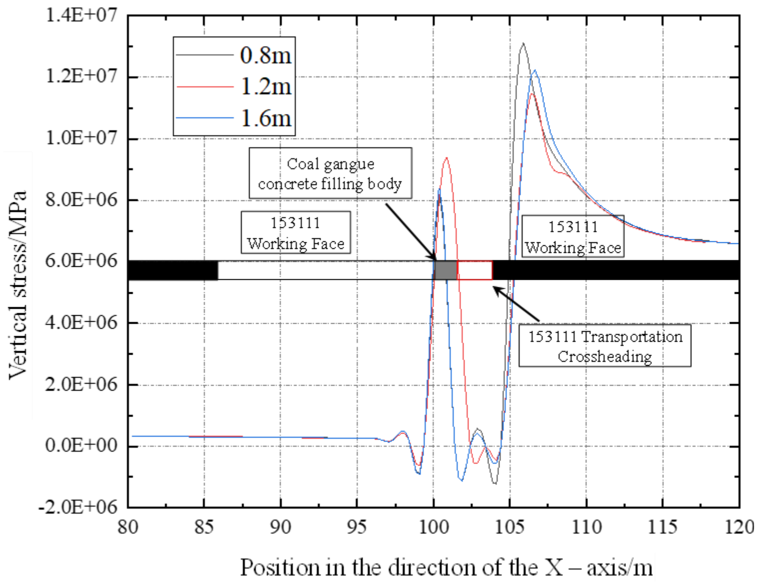
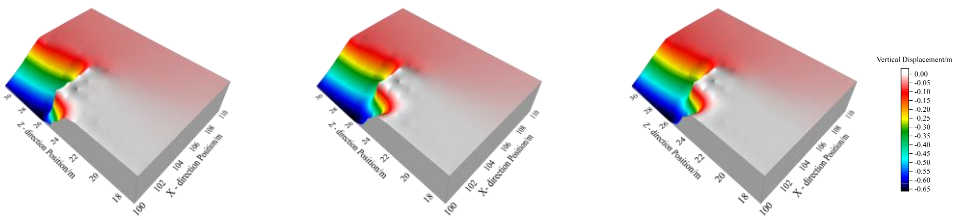



*Figure 5 Vertical stress distribution of the surrounding rock of filling bodies with different widths*

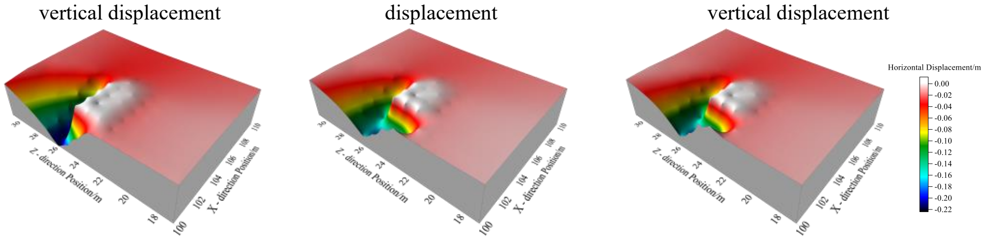
### *3.1.2. Deformation Characteristics of the Surrounding Rock of Filling Bodies with Different Widths*

As shown in Figure 6, the maximum roof subsidence of the coal-gangue-concrete filling body with widths of 0.8 m, 1.2 m, and 1.6 m is 600 mm, 240 mm, and 330 mm respectively. For the filling body, the position with severe deformation gradually transfers from the top to the middle as the width increases. The maximum deformations of the two sides of the coal-gangue-concrete with widths of 0.8 m, 1.2 m, and 1.6 m are 300 mm, 200 mm, and 600 mm respectively. It is obvious that the horizontal deformation of the 1.6-m-wide filling body is the most serious, followed by the 0.8-m-wide one, and the 1.2-m-wide one has the lowest horizontal deformation. Through the analysis of the stress distribution laws and surrounding-rock deformation characteristics of the coal-gangue-concrete filling bodies with three widths (0.8 m, 1.2 m, and 1.6 m), it can be known that when the width is 1.2 m, the overall stability of the entry-retaining is high, and the roadway deformation is low, which can fully exert the coordinated effect between the "support body" and the "surrounding rock".

In conclusion, combining the results of theoretical calculations and numerical simulation analyses, it can be known that the optimal width of the coal-gangue-concrete for gob-side entry retaining in the 15311-working face of the 1890 Coal Mine is 1.2 m.



(a)0.8m in width- vertical displacement (b)1.2m in width- vertical displacement (c)1.6m in width- vertical displacement



(d)0.8m in width- horizontal displacement (e)1.2m in width- horizontal displacement (f)1.6m in width- horizontal displacement

*Figure 6 Displacement Changes of Surrounding Rock of Filling Bodies with Different Widths*

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### *3.2. Field Monitoring Data*

A set of measuring stations is arranged every 40 m from the starting cut-off of the 15311-working face. Each set of measuring stations encompasses the observation of roadway surface displacement and the development of roof-surrounding-rock fractures. The following takes the measuring station I adjacent to the starting cut-off as an example for analysis[18].

#### *3.2.1. Roadway and Rib Convergence*

As depicted in Figure 7, the "cross-observation method" is employed to observe the roadway surface displacement during the lagging stage of entry-retaining in the course of the working-face advancement. The roof-floor displacement and rib-to-rib convergence gradually increase during the 30-m advancement of the working face. When the advancement reaches 40 m, the deformation generally tends to stabilize. During this process, the maximum roof subsidence is 202 mm, and the maximum floor heave is 161 mm. The maximum rib-to-rib convergence is 192 mm, and the deformation of the coal rib is notably greater than that of the filling wall. This is because the strength of the concrete filling body is significantly higher than that of the supporting coal body on the other side[21]. The fragile coal body is more prone to deformation under the influence of mining-induced stress. Overall, the overall deformation of the 15311 transportation roadway during the entry-retaining period is relatively small, ensuring safe and highly-efficient production[18, 19].

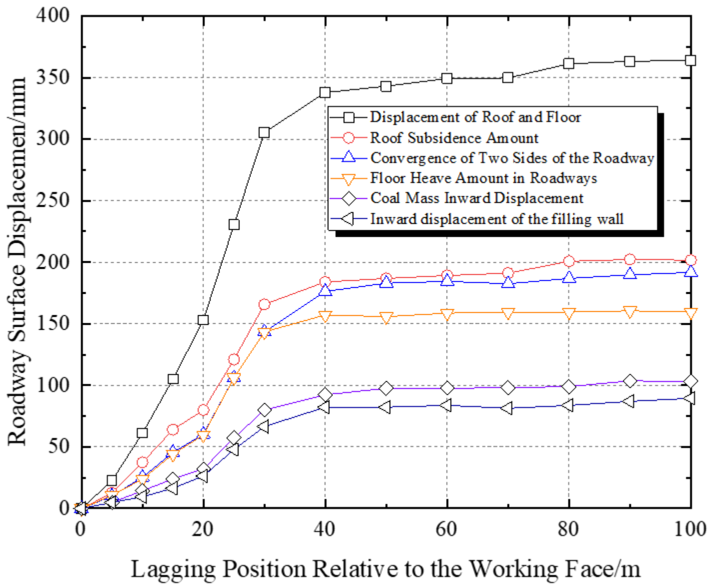


*Figure 7 Surface Displacement of the Roadway during the Gob-side Entry Retaining Stage*

#### *3.2.2. Borehole Observation*

Lagging 30 m behind the 15311-working face, a borehole is drilled vertically into the roof at the center of the entry-retaining, with a borehole depth of 10 m. As shown in Figure 8, from 0 to 4 m of the roof-surrounding rock, the overall surrounding rock is relatively intact, with only one transverse fracture at 0.45 m and 1.55 m respectively, and obvious fragmentation occurs at 4.02 m. From 4 to 10 m, the surrounding rock is relatively intact, and basically no fractures and fragmented surrounding rock emerge. It can be seen that the integrity of the surrounding rock in the gob-side entry-retaining during the mining stage is favorable[19, 22].

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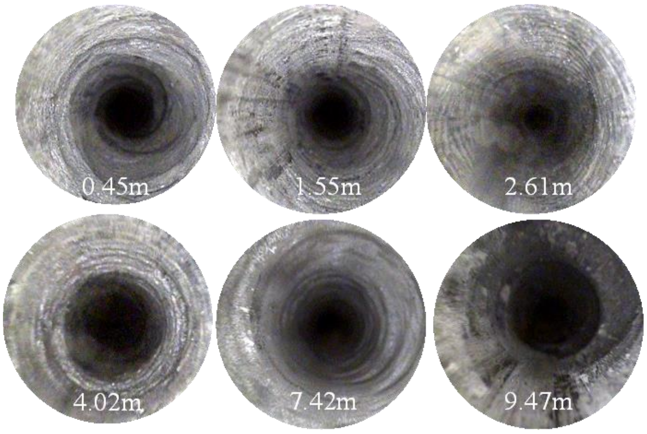


*Figure8 Characteristics of Fracture Development in the Surrounding Rock of Gob-side Entry Retaining*

**4. Discussion**

This research undertakes a thorough exploration into the determination of the appropriate width for the coal gangue concrete filling body in gob - side entry retaining within the context of hard and thick top - coal conditions, presenting findings that carry substantial significance for the coal - mining industry. However, several aspects emerging from this study prompt further in - depth discussion.

The theoretical calculation approach adopted in this research represents a fundamental cornerstone. Through the establishment of a mechanical action model that accounts for the impact of the coal wall and fragmented rocks in the goaf on the movement of overlying strata, a specific value for the support resistance of the coal gangue concrete filling body was calculated. This calculation provides a crucial quantitative basis for the initial design phase. Nevertheless, it is important to recognize that the model simplifies the intricate geological conditions. In actual mining scenarios, the mechanical properties of rocks can vary significantly over short distances. Lithological changes, the presence of joints and fractures, and the influence of groundwater all play crucial roles in altering the stress distribution and stability of the surrounding rock and filling body. For example, a fracture in the roof rock can act as a stress - concentration point, potentially changing the load - bearing mechanism of the filling body. In future research, it would be beneficial to incorporate more detailed geological data into the theoretical model. By accurately mapping the distribution of weak planes, fracture networks, and the influence of water - bearing strata, the model can be refined to better represent the actual stress state within the gob - side entry retaining system. This would lead to more accurate calculations of the support resistance and a more precise prediction of the filling body's performance.

The numerical simulations conducted using FLAC3D software offer valuable insights into the stress distribution and deformation characteristics of the surrounding rock under different filling - body widths. The results clearly indicate that a 1.2 - m - wide filling body exhibits favorable stability and low deformation levels. Despite these useful findings, numerical models have their limitations. The constitutive models employed in FLAC3D may not fully capture the complex behavior of coal gangue concrete and the surrounding rock. Coal gangue concrete, for instance, may experience unique mechanical responses under cyclic loading, which is a common occurrence during mining operations. The continuous movement of the mining face and the associated stress changes can subject the filling body to cyclic loading, potentially leading to fatigue - like behavior and long - term deformation. Additionally, the interaction between the filling body and the surrounding rock is a dynamic process involving phenomena such as creep and stress relaxation. Creep can cause the filling body to gradually deform over time, while stress relaxation can lead to a redistribution of stresses within the system. Future numerical studies should explore the use of more advanced constitutive models that can better represent these complex behaviors. Incorporating time - dependent factors and dynamic interactions into the numerical simulations would provide a more realistic portrayal of the gob - side entry retaining process.

The field practice results from the 15311-working face are promising, demonstrating that the 1.2 - m - wide filling body can effectively control roadway deformation and maintain the integrity of the surrounding rock. However, it is essential to note that the conditions in the 15311-working face are specific to that location. Applying these results to other mines requires careful consideration. Different mines may have distinct geological structures, coal seam thicknesses, and mining methods. For example, a mine with a steeper coal seam dip angle may experience different stress distributions and rock - movement patterns compared to the 15311-working face. When implementing gob - side entry retaining technology in other mines, a comprehensive geological survey must be conducted. This survey should include detailed information about the rock formations, stress fields, and groundwater conditions. Numerical simulations tailored to the local conditions should also be carried out to determine the most suitable filling - body width and support system. By taking these steps, the safety and stability requirements of the roadway can be met, ensuring the successful implementation of gob - side entry retaining technology in diverse mining environments.

In summary, while this study has made significant progress in determining the appropriate width of the coal gangue concrete filling body for gob - side entry retaining, there is still room for improvement. Future research should focus on refining the theoretical models, enhancing the accuracy of numerical simulations, and validating the results in a broader range of field conditions. By addressing these aspects, more efficient and reliable gob - side entry retaining technologies can be developed, contributing to the sustainable and safe development of the coal - mining industry.

## 5. Conclusions

1) With the gob-side entry retaining of the 15311-working face in the 1890 Coal Mine as the engineering foundation, a roadway reinforcement and support scheme for the transportation roadway of the 15311-working face was proposed, and the surrounding rock stability control concept of "coal-gangue concrete" + "reinforcement support" tailored for the mining of thick coal seams was established. This concept is of great significance for ensuring the safety and efficiency of coal mining.

2) Drawing on the practical experience of gob-side entry retaining in the 15310 working face and the geological characteristics of the surrounding rock of the 15311-working face, the bearing effect of the 1.2-meter-wide flexible form concrete wall was meticulously analyzed through theoretical calculations. Subsequently, a gob-side entry retaining model was established based on the numerical simulation method. By comparing and analyzing the stress evolution and deformation characteristics of the surrounding rock of the flexible form concrete filling body under three different widths, the reasonable width of the coal-gangue-concrete filling body was accurately determined to be 1.2 m[17, 18, 20]. This determination provides a crucial reference for the design and implementation of gob-side entry retaining projects.

3) The technical scheme of "coal-gangue-concrete filling body + reinforcement support" has effectively exploited the coordinated control effect between the surrounding rock and the support body. During the entry retaining process, the maximum roof displacement is limited to 202 mm and the maximum rib-to-rib convergence is 192 mm, respectively. The operating conditions of the bolts (cables) and the filling body anchor bolts are excellent, ensuring the stability of the support system. Moreover, no obvious fracture development is observed in the roof borehole observation, indicating good integrity. Thus, under this technical scheme, the gob-side entry retaining of the transportation roadway of the 15311 working face can meet the strict safety production requirements of the hard and thick roof coal seam[18, 19], providing a reliable guarantee for the continuous and stable operation of the mine.

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