Force analysis and design of backfill retaining wall in large complex Goaf

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Abstract: The design of backfill retaining wall and construction technology are important factors that affect the cost, quality and safety of backfill. In order to reduce the cost, improve the quality and prevent the collapse of the Goaf, it calculates the total pressure and the maximum bending moment of the retaining wall with different filling height. Then it determines the filling height and the thickness of the retaining wall. Finally it studies the technical measures of dewatering, drainage and slurry running of backfill. The research shows that it should control the filling height within 1.5 m, the maximum thickness of backfill retaining wall should not be less than 3.8 m, it should connect the suspended dewatering pipe with the steel pipe embedded in the bottom of the retaining wall, and set up a drainage body to realize rapid dewatering and drainage, to reduce the pressure on the retaining wall.

1. Introduction
To make full use of resources, protect the environment and reduce costs, tailings produced by the concentrator and flocculant mixture are increasingly used in mines [1-2] to fill the goaf, but goaf airtightness is an important preparatory work in filling. The goaf airtightness degree directly relates to the filling effect and filling production safety. If the goaf is not well-sealed, the filling slurry will overflow and run everywhere, and there will even be serious accidents in which the filling slurry floods the roadway and equipment. At present, filling retaining walls are often used to seal the goaf, and the filling quality and filling production safety of the goaf are also inseparable from the setting of the filling retaining wall [3-4], especially for large-scale goafs. Therefore, it is necessary to determine the reasonable form and structure of the filling retaining wall according to actual engineering research, avoid monotony [5], and adopt safe and reliable technical measures to rapidly increase the filling body strength, increase the filling efficiency, and guarantee stability of the filling body and the retaining wall.

2. Current status of mine production
Huili Mine is a glutenite copper deposit. Mainly found in purple-gray alternating rocks, the ore body has six ore-bearing layers from bottom to top, with inclination angle of 5° ~ 30° and thickness of 0.21 ~ 9.98 m. As the gently inclined thin-medium-thick ore body, it is present mainly at an elevation
of 1350 m ~ 1800 m, with a distance of 50 ~ 440 m from the surface. The roof and floor rocks of the ore body are conglomerate and sandstone with medium to hard firmness. The cracks are not developed, mostly small and weak types, with good rock stability. Mine development is to develop inclined shafts, and the primary mining methods are full-scale and room-pillar methods. After years of mining, the mine has now formed ten major goafs with a total volume of 2.57 million m$^3$, and the goafs are interconnected to each other. If it is not filled in time, intensified ground pressure activities will greatly impact underground production and surface safety. In addition, the mine tailings pond has limited storage capacity, and the tailings stacking elevation has reached as high as 1880 m. To comprehensively solve the problems of underground goaf and tailings stacking, after comprehensive consideration, this paper fully mixed the whole tailings produced by the concentrator and flocculant, let it quickly settle and concentrated to make high-concentration tailings, which were then mixed with cement and added with an appropriate amount of water to configure filling slurry that meet the quality and concentration requirements for goaf filling. In the early stage, retaining wall was built by mine technicians based on experience, which is not only costly, but also has many potential safety hazards. To reduce the masonry cost of the filling retaining wall and ensure filling construction safety, this project discussed the relationship between the total pressure of the filling retaining wall, the maximum bending moment and the one-time filling height in view of the production situation of the Huili Mine, and reasonably determines the one-time filling height of the mining area. Also, thickness of the filling retaining wall was designed more scientifically, and the construction technology was studied.

3. Design of filling retaining wall

3.1. Position and specifications of the filling retaining wall

The design scope of the filling retaining wall is the 1~11# retaining wall pre-filled in the middle second, third, fourth and fifth sections of the mine. The retaining wall has a minimum height of +1660 m, the goafs are interconnected, featuring a big area and high height, and the largest section size is 11 m × 9 m. See Table 1 for details.

| Retaining wall number | 1# | 2# and 9# | 3# | 4# | 5# | 6# | 7# | 8# | 10# and 11# |
|-----------------------|----|-----------|----|----|----|----|----|----|-------------|
| b×h/m×m              | 3.9×4 | 2.5×3 | 4×4 | 5×5 | 3×4 | 6×7 | 10×6 | 11×9 | 4.5×5       |

3.2. Selection of retaining wall types

Under normal circumstances, there are many forms of retaining walls, such as brick retaining walls, wooden retaining walls, reinforced flexible retaining walls, concrete retaining walls, etc. Since the Huili Mine has a big goaf with high height, and most of the filling retaining walls are large in size, concrete retaining wall is selected based on comprehensive consideration.

3.3. Force analysis of retaining wall

When the filling slurry just enters the goaf, because it is not dewatered and not hardened, it exerts a great force on the filling retaining wall. After filling for a period of time, the filling slurry undergoes dewatering, sedimentation, coagulation and hardening to form a filling body, and its force on the filling retaining wall will gradually weaken. Therefore, in force analysis of the filling retaining wall, it is only needed to consider the condition when the filling slurry just enters the goaf. According to the filling slurry surface height, the force analysis of the filling retaining wall can be analyzed based on two conditions: (1) the filling slurry surface height is lower than or equal to the filling retaining wall height; (2) the filling slurry surface height is higher than the filling retaining wall height.

According to the theory of soil mechanics, the force on the filling retaining wall is greater when the filling height is higher. The filling height $h$ is the biggest factor affecting safety of the filling retaining
wall. If the filling height is greater than the filling retaining wall height, the retaining wall will be more stressed, which is adverse to stability of the retaining wall. Therefore, when filling retaining wall is set up, the location height of the filling retaining wall should be fully considered, the filling height should be clarified, so that filling retaining wall can be constructed based on comprehensive consideration. When the retaining wall is filled for the first time, the filling height should not exceed the retaining wall height. Force analysis of the filling retaining wall is shown in Figure 1.

![Figure 1 Force analysis of filling retaining wall in the stope](image)

It can be seen from the size of the enclosed retaining wall in the goaf that the retaining wall has a minimum height of 3 m and a minimum width of 2.5 m. When the height of the filling slurry surface is lower than or equal to the filling retaining wall height, the force analysis of the filling retaining wall [7-8] is as follows:

\[
q = \begin{cases} 
0 & 0 \leq Z_0 \leq H - h \\
\gamma_L \times (Z-H + h) & H - h < Z_0 \leq H 
\end{cases}
\]  
Equation (1)

Total pressure

\[
P = \frac{1}{2} \gamma_L \times h^2 \times W
\]  
Equation (2)

The bending moment of the filling retaining wall is:

\[
M = \begin{cases} 
\frac{\gamma_L}{6H} \times h^3 \times Z_0 & 0 \leq Z_0 \leq H-h \\
\frac{\gamma_L}{6H} \times h^3 \times \left[ Z_0 \times \frac{(Z-H+h)^3}{h^3} \right] & H-h \leq Z_0 \leq H 
\end{cases}
\]  
Equation (3)

The maximum bending moment is:

\[
M_{max} = \frac{\gamma_L}{H} \times h^3 \times \left( H-h + \frac{2h}{3} \times \sqrt{\frac{h}{3H}} \right)
\]  
Equation (4)

Where: \(q\) refers to the filling pressure; \(H\) refers to the height of the filling retaining wall; \(W\) width refers to the filling retaining wall; \(\gamma_L\) refers to the bulk density of the filling slurry; \(h\) refers to the filling slurry surface height, which is calculated from the bottom of the filling retaining wall; \(Z_0\) refers to the action point of maximum bending moment.
According to the calculation formula of the total pressure and the maximum bending moment of the filling retaining wall, the filling height is progressively increased by 0.5 m respectively. The relationship between the filling height and the total pressure and the relationship between the filling height and the maximum bending moment of the retaining wall are plotted, as shown in Figure 2 and Figure 3.

![Figure 2](image1.png)

Figure 2 The relationship between the total pressure $P$ of the retaining wall and the filling height $h$

![Figure 3](image2.png)

Figure 3 The relationship between the maximum bending moment $M$ of the retaining wall and the filling height $h$

It can be seen from Figure 2 and Figure 3 that the total filling pressure and maximum bending moment are closely related to filling height. Under low filling height, the total filling pressure and the maximum bending moment are also low. With the increase of the filling height, the total filling pressure and the maximum bending moment first increase slowly, and then undergo accelerated growth when a certain height is reached, which is not conducive to the stability of the retaining wall. It can be seen from the figure that when the filling height reaches 2.5 m, 8# retaining wall suffers from the biggest total pressure of 68.234 t, with the maximum bending moment of 24.148 t/m. When the filling height is 1.5 m, the maximum pressure on the retaining wall is 24.564 t and the maximum bending moment is 5.758 t/m. When the filling height is 1.5 m, the force on the retaining wall is about 1/3 of the force when the filling height is 2.5 m. The retaining wall is less stressed, and under this stress state, the retaining wall is safer. Therefore, the first filling height is recommended to be 1.5 m.
3.4. Calculation of retaining wall thickness

Based on the previous theoretical analysis and calculation, design the thickness of the filling retaining wall in accordance with a wall height of 1.5 m. Refer to the waterproof gate design \[9\] in "Shafting and Drifting Engineering Volume" in the "Mining Design Manual" for calculation. The required thickness of the retaining wall is calculated by using calculation formulas for compressive strength, shear strength, and permeability resistance conditions. The calculation formula is as follows:

(1) Calculated according to compressive strength

\[
B = \left\{ \left( \frac{(b + h)^2 + 4Fbh}{(c/c_f)} \right)^{\frac{1}{2}} - (b + h) \right\} / (4 \tan \alpha)
\]

Equation (5)

Where: \( B \) refers to the thickness of the filling retaining wall; \( b \) refers to the clear width of the roadway where the filling retaining wall is located; \( h \) refers to the net height of the roadway where the filling retaining wall is located; \( F \) refers to the hydrostatic pressure on the filling retaining wall; \( \varepsilon \) refers to the concrete safety factor; \( c_f \) refers to the axial compressive strength design value of the filling retaining wall; \( \alpha \) refers to the induced angle between the bearing surface of the retaining wall and the roadway.

(2) Calculated according to shear strength

\[
B = \frac{Fbh}{2(b + h) f_v}
\]

Equation (6)

Where: \( f_v \) refers to the shear strength of the filling retaining wall material, which can be calculated as (0.1-0.15) times of \( f_c \); the other symbols have the same meaning as above.

(3) Calculated according to permeability resistance

\[
B \geq 48KH\beta h
\]

Equation (7)

Where: \( K \) refers to the permeability resistance coefficient of concrete; \( H \) refers to the designed height to withstand the hydrostatic head, that is, the goaf height. The value is 35 m here, and the other symbols have the same meaning as above.

The retaining wall thickness calculated by compressive strength, shear strength and permeability resistance is summarized in the table, as shown in Table 2.

| Retaining wall number | 1# | 2# and 9# | 3# | 4# | 5# | 6# | 7# | 8# | 10# and 11# |
|-----------------------|----|-----------|----|----|----|----|----|----|-------------|
| Thickness calculated based on compressive strength /m | 0.05 | 0.02 | 0.05 | 0.08 | 0.03 | 0.12 | 0.22 | 0.32 | 0.06 |
| Thickness calculated based on shear strength /m | 0.21 | 0.09 | 0.22 | 0.34 | 0.14 | 0.53 | 1.02 | 1.49 | 0.29 |
| Thickness calculated based on permeability resistance /m | 0.58 | 0.28 | 0.59 | 0.92 | 0.44 | 1.55 | 2.22 | 3.66 | 0.83 |
| Recommended value /m | 0.70 | 0.40 | 0.70 | 1.10 | 0.60 | 1.70 | 2.40 | 3.80 | 1.00 |

To ensure safety and reliability of the filling retaining wall, the filling retaining wall thickness must meet the three conditions of compression resistance, shear resistance and permeability resistance at the same time. It can be seen from the calculation results that the thickness of the filling retaining wall calculated according to permeability conditions is the largest. Hence, the result based on
impermeability calculation shall prevail. In addition, for the sake of certain safety reserve, the thickness of the filling retaining wall needs to be appropriately increased on the basis of the impermeability calculation results. The results are shown in the recommended values in Table 2.

3.5. Design scheme of filling retaining wall structure

The internal structure of the filling retaining wall and the problem handling of its relation with the surrounding rock are factors affecting stability of the retaining wall. To prevent large displacement of the retaining wall relative to the surrounding rock and prevent leakage of the filling slurry\[10\], several anchor rods are installed in the surrounding rock on both sides of the retaining wall, and the top of the anchor rod is anchored with an anchoring agent. Also, the exposed part of the anchor rod is reinforced with steel bars, so that the retaining wall is integrated with the surrounding rock, thereby increasing the bearing capacity of the filling retaining wall and avoiding side leakage of the slurry.

The concrete follows C20 standard, with its mix ratio: 0.47:1:1.342:3.129 (water: cement: sand: stone), sand ratio: 30%; water-cement ratio: 0.47; maximum particle size of coarse aggregate 20mm, retaining wall reinforcement: φ10 and spacing: 150 mm.

After the concrete retaining wall is finished, perform guniting or use cement scrolls to seal the surroundings and prevent slurry running from the surrounding.

4. Filling construction technology

4.1. Filling scheme and sequence

Adopt whole tailings cement filling process, using cement and new binding material as cementing materials. The slurry pump is used to pump it to each goaf in the pit, and the blowing pipeline is shuttled in the goaf. Two safe high points in the goaf are selected as the blowing points for alternate blowing, and the slurry is filled into the goaf by gravity flow and stockpiled in interrupted stope rooms.

As the goafs are interconnected to each other, if the local filling height is too high, some retaining walls will be excessively stressed and unstable, which will affect the construction of the entire filling project. When the goaf is filled, it is necessary to coordinate the goaf for simultaneous filling and strictly control one-time filling height. Fill the goaf until 1.5 m first, then stop the filling and dewater the slurry. After the filling body is condensed, perform the next goaf filling (the filling height is controlled within 1.5 m each time), followed by cycle operations in turn. Excessive filling can only be carried out after the goaf is filled above the height of the highest filling retaining wall, and the lower filling body has reached the final setting state to produce strength.

4.2. Filling and dewatering measures

When the tailings are filled via pipeline transportation, the filling concentration is generally between 65~75%. When the goaf is filled with 1m³ filling slurry, there will be 0.5 m³~0.6 m³ water. Such water needs to be removed from the goaf filling body in time to form a dense filling body. The quality of filling and dewatering in the filling process affects the filling speed, the strength of the filling body and the pressure on the filling retaining wall. If the filling and dewatering measures are ineffective, there will be greater pressure on the filling retaining wall, which will endanger the safety of the retaining wall and pollute the underground environment. The underground goaf of the mine is large. When tailings are used for filling, it is difficult to set dewatering structures in the goaf. Therefore, new requirements are put forward for dewatering technology, and design of a variety of efficient and practical dewatering facilities is a major technical problem that the project must solve. According to the characteristics of the mine goaf, suspended dewatering pipes are used for filling and dewatering of the goaf based on comprehensive consideration. The dewatering pipe is lowered from the goaf top to the filling retaining wall at the goaf bottom. The dewatering pipe is connected with the steel pipe pre-buried in the retaining wall, and the excess water during the filling process is discharged to the outside of the wall through the dewatering pipe and the steel pipe. According to the goaf size, 9
full-section flexible dewatering pipes with a diameter of DN100 are arranged in the goaf. Where, 5 dewatering pipes are arranged vertically and 4 are placed horizontally. The dewatering pipes are connected with steel pipes pre-buried in the retaining wall to form three-dimensional dewatering system.

In addition, a drainage pipe is installed in the middle and lower part of the retaining wall, and a drainage body is equipped on the drainage pipe which is 3~6 m away from the end face of the retaining wall (the drainage body is composed of drilled iron pipe, geotextile, brown leather, and gravel). The saturated water within the slurry and the clear water on the slurry surface enter the drainage pipeline through the drainage body and then enter the underground water pump station, which is then sent to the ground pool for production use in the concentrator.

4.3. Preventive measures for slurry running
To prevent slurry running during the filling process, before filling, it is necessary to carefully check whether each retaining wall in contact with the surrounding rock is sprayed or sealed with cement scrolls. If the seal is not tight, re-seal to ensure that there is no slurry running from the side seam of the retaining wall. In addition, to prevent slurry running due to rupture of the dewatering pipe, a knife gate valve is installed on the steel pipe outside the filling retaining wall. In an emergency, the knife gate valve is closed to prevent the tailing paste from leaking. During normal filling and dewatering, open the knife gate valve of each pipeline to strengthen drainage.

5. Conclusion
The goafs of Huili Mine are interconnected with each other, with large area and high height. If it is not filled in time, intensified ground pressure activity will greatly impact underground production and surface safety. This paper studied the impact of filling height on the total pressure and maximum bending moment of filling retaining wall in this project, finally determined the control range of each filling height, i.e. 1.5m, and then decided thickness of each retaining wall in view of compression, shear, and permeability resistance when the height was 1.5 m. 1# and 3# retaining wall thickness was 0.7 m, 2# and 9# retaining wall thickness was 0.4 m, 4# retaining wall thickness was 1.1m, 5# retaining wall thickness was 0.6m, 6# retaining wall thickness was 1.7 m, 7# retaining wall thickness was 2.4 m, 8# retaining wall thickness was 3.8 m, 10# and 11# retaining wall thickness was 1.0 m. Drainage body was set in the goaf, and suspended dewatering pipe was used for connection with the steel pipe pre-buried at the retaining wall bottom, so that rapid dewatering and drainage was possible and the pressure on the filling retaining wall would be lower. Before filling, it was necessary to carefully check whether each retaining wall in contact with the surrounding rock was tightly sealed to ensure that there was no leakage of slurry. After each filling was completed, the next filling can be carried out after the filling body reached the final setting state.

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