JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
61, 3, pp. 465-480, Warsaw 2023
https://doi.org/10.15632/jtam-pl/166276

INSTABILITY MECHANISM AND ANCHORING CONTROL TECHNOLOGY OF EXPANSIVE WEAKLY CEMENTED SOFT ROCK ROADWAY

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A long-term discontinuous development of the plastic zone and broken zone of weakly cemented surrounding rock is the main reason for instability of the surrounding rock of a roadway. The load-bearing support concept of "allowable deformation + releasable pressure + limited deformation" for a weakly cemented soft rock roadway is proposed, and an "allow-release-limit" support structure mechanical model with U-shaped steel as the main body is established. Anchoring control measures of "U-shaped steel + flexible material wall backfill + key parts strengthening" can solve problems of large deformation and long deformation duration of weakly cemented roadways.

Keywords: weakly cemented soft rock, roadway support, deformation control, expansion, support concept

1. Introduction

Hongqingliang mine is a modern large-scale mine at the background of China's in-depth implementation of the western development strategy and acceleration of construction of key mining areas and coal power as well as coal chemical bases in the Inner Mongolia Autonomous Region (Zhao *et al.*, 2020; Zhang *et al.*, 2022a, 2023). The coal-bearing strata of Hongqingliang coal mine are widely distributed in a special kind of soft rock, namely weakly cemented soft rock. Fang *et al.* (2019) found through triaxial testing that the ultimate strength of wet rock blocks is 60%-85% of the ultimate strength of dry rock blocks. Theocharis *et al.* (2020) determined that the softening coefficient of weakly cemented sandstone ranges from 0.22 to 0.92. Sharma *et al.* (2010) confirmed that the failure mode of weakly cemented sandstone during water softening is mainly due to detachment of cementitious materials. Weakly cemented soft rock has properties of low strength, poor cementation, and easy mudding in contact with water (Wang *et al.*, 2020; Zhang *et al.*, 2022b; Li *et al.*, 2018). The RQD (Rock Quality Designation) and uniaxial compressive strength of weakly cemented soft rock are smaller than the common soft rock indicators in the eastern mines in the past (Zhang *et al.*, 2022c). According to the past domestic and engineering experience, weakly cemented soft rock roadways have characteristics of short self-stabilization time and large deformation, which often leads to traditional construction and support methods that cannot effectively maintain long-term stability of the roadway, which seriously threatens safety of mine production (Mineo and Pappalardo, 2019; Aguilera *et al.*, 2019; Showkati *et al.*, 2015).

In the recent years, many scholars have studied the engineering support method of soft rock roadways from different aspects, among which the most representative theories are the Fenner and Kastner formula, new Austrian method and energy support theory. Yang *et al.* (2019) proposed a support method that used a rigid truss with sufficient strength to limit deformation of soft rock. Luo *et al.* (2018) proposed a comprehensive reinforcement support method using high prestressed and high-strength anchor rods. Kang *et al.* (2015) proposed a design concept of the step-by-step joint support. Bhuiyan *et al.* (2018) proposed a strong anchoring and grouting support technology. The research on the instability mechanism of expansive cemented soft rock roadways is not thorough, and there are few ideas for roadway supports, and a set of research techniques suitable for weakly cemented soft rock roadways that are prone to disintegration has not been formed. In the present application process, the support structure and roadway deformation are often not coupled, or the support structure is wasted, or the support structure cannot reach the strength. Therefore, studying deformation characteristics and stress patterns of weakly cemented soft rock to solve the problems encountered in support design and construction can provide experience and reference for similar research.

During the excavation process of Hongqingliang mine, there are notable features such as poor roadway formation, large deformation of surrounding rock and long duration of a large deformation rate. Yang and Jing (2011) found that the surface of the roadway is broken, and the roadway tray is plunged into the anchor net by using the anchor net spray. Tu *et al.* (2022) found that the anchor net became a pocket under the action of broken surrounding rock, the roof and floor were seriously deformed. Zhang *et al.* (2020) found that the maximum value exceeds 800 mm, and the volume of the bottom drum reached more than 600 mm, which seriously affected formation and safety of the roadway. Therefore, it is necessary to carry out research on the instability mechanism and control technology of expansive weakly cemented soft rock roadways to provide a guarantee for safe production of coal mines.

While the intensity of coal resource extraction has significantly increased, in order to meet the requirements of coal mine intelligence and intensification, more large cross-section chambers need to be arranged underground. The cavern group is generally characterized by a large cross section, dense layout, long service life, etc., and the surrounding roadways are complex. Affected by unpredictable geological conditions such as high ground stress, faults, folds, etc., it is difficult to maintain the cavern group, the surrounding rock deformation is serious, and the surrounding rock instability is easily induced, which is a major problem to be solved in the geotechnical engineering field. At present, research on large cross-section chambers in high stress concentration areas near the intersection of complex rock strata is relatively rare, and the design and support methods are not yet mature. The research results have important significance in improving the current situation of mine safety production, maintaining stable and sustainable development of mining areas, and improving enterprise economic benefits. They have important practical significance and certain reference value for achieving safe and efficient mining in mines with such geological conditions. At the same time, they can further enrich the relevant theories of weak cemented soft rock roadway surrounding rock control.

2. Analysis of instability mechanism and influencing factors of roadways

2.1. Instability form of a soft rock roadway

The coal-measure stratum in Hongqingliang mine is a weakly cemented soft rock, and the surrounding rock of the roadway has characteristics of easy expansion, low strength, weak cementation, developed fissures, softening in contact with water, easy disintegration and rheological properties.

At present, deformation and failure forms of the surrounding rock of the anchor-net-spray--cable support structure adopted in Hongqingliang mine are manifested in the following aspects:

- The surrounding rock on the roof is broken, and there are pockets, tearing of the mesh and damage to the overlap of the mesh.
- The anchor rod and anchor cable are pulled or sheared, resulting in a reduction in the support strength,

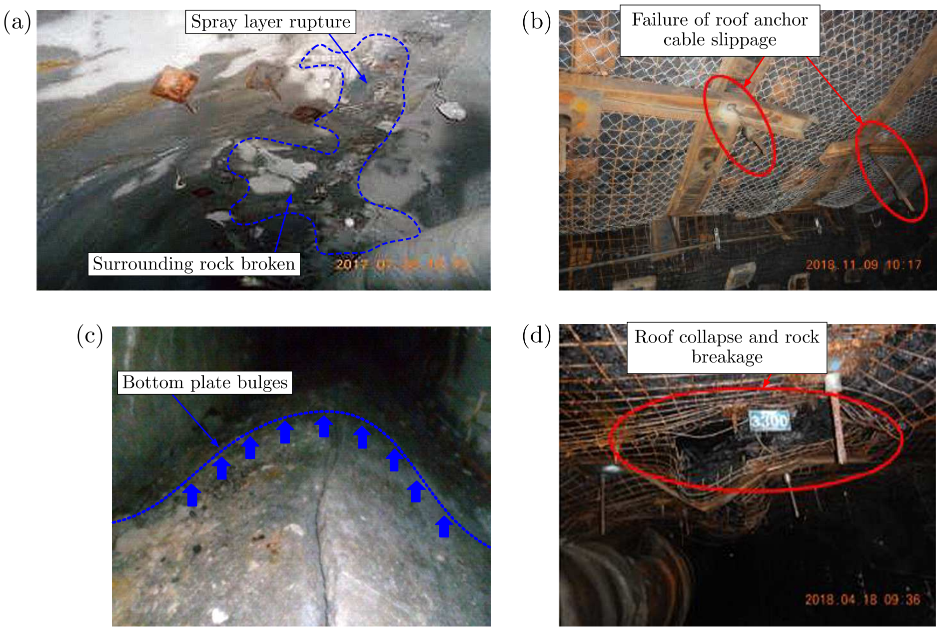

Fig. 1. The failure mode of a weakly cemented soft rock roadway: (a) spray layer rupture, (b) roof anchor cable slippage, (c) deformation of the bottom plate, (d) failure of the roof

- The lap joint of the mesh is cracked, the surface spray layer is cracked, and the spray layer falls off.
- The rock around the pallet is crushed and sheared, and the bolt pallet falls into the anchor net.

The anchor net becomes pocket-shaped under the action of broken surrounding rock, and the support resistance is reduced.

2.2. Deformation characteristics of the weakly cemented soft rock roadway

The deformation characteristics of the surrounding rock in weakly cemented soft rock roadways are mainly manifested in a short self-stabilization time, large initial deformation rate, long deformation duration, easy to be disturbed, and easy to become muddy when encountering water. The deformation of the weakly cemented soft rock roadway is obvious after excavation, which is embodied in:

- The self-stabilization time is short and the stress release is obvious. Within a few hours of excavation or excavation of the roadway, the surface surrounding rock of the roof and the two sides begins to break or even peel off.
- The initial deformation rate is fast and the deformation lasts for a long time. The maximum deformation rate of the roadway after one-time support is 50 mm/d, the average deformation rate of the roadway is 8-15 mm/d, and the deformation rate of the roadway gradually slows down into a stable state at about 60 d and keeps deforming at a low rate.
- The surrounding rock of the roadway is easily disturbed. Due to development of cracks, low strength and disintegration in water, the stability of the roadway can easily be changed and leads to deformation and damage when the stress of the rock mass changes under the influence of dynamic pressure.

2.3. Analysis of the instability mechanism of the weakly cemented soft rock roadway

The excavation of the roadway destroys the original stress balance state of the surrounding rock, resulting in redistribution of the surrounding rock stress and occurrence of stress concentration in the surrounding rock of the roadway. The surrounding rock mass of the roadway changes from the original three-way stress state to a two-way or even one-way stress state, and the bearing capacity of the surrounding rock is greatly reduced, resulting in deformation or even rupture of the surrounding rock, and a certain range of damage areas is formed. The factors affecting roadway stability of Hongqingliang mine are divided into two categories: mining condition factors and construction quality factors.

- The mining condition factors are mainly affected by inherent characteristics of the coal strata and coal-forming environment, which are embodied in:
  - The roof and floor rocks are weakly cemented, soft and broken, easily disturbed, and have low integrity.
  - The rock strength is low. The average uniaxial compressive strength of mudstone is 3-7 MPa, and the average uniaxial compressive strength of fine sandstone is 5-11 MPa, and the uniaxial compressive strength of coal generally does not exceed 6 MPa.
  - The initial in-situ stress field has a great influence. The maximum principal stress of Hongqingliang mine is mainly horizontal stress, and it is easy to cause large deformation of the bottom drum and the two sides.
- Construction quality factors are mainly determined by the level of design and construction management, which are embodied in:
  - The size and shape of the roadway section. There is a close relationship between the size of the roadway section and the deformation of the surrounding rock.
  - Design support strength is not reached. The flexibility or stiffness of the support body is not up to the standard, and some surrounding rock is not coupled with the deformation of the support structure, resulting in deformation and damage of the roadway, or even instability.

3. Thinking and principle of the soft rock roadway support

3.1. Supporting ideas for the weakly cemented soft rock roadway

The key measures for the roadway support should be placed on making a full use of and exerting the self-supporting capacity of the surrounding rock, so that the surrounding rock pressure can be fully released while supporting in time. Combined with the present situation of Hongqingliang mine, the support idea of "timely closure, combination of long and short supports, secondary control, reinforcement of key parts, and long-term monitoring" and the load-bearing support concept of "allowable deformation + releasable pressure + limited deformation" for weakly cemented soft rock roadway are proposed as shown in Fig. 2.

3.1.1. Timely closure

The surrounding rock on the roadway surface of Hongqingliang mine is generally broken after excavation. If it is not closed in time, the surrounding rock will be easily broken and extended to depth under the condition of one-way or two-way force and weathering, resulting in formation of fins or roofs rock falls. Therefore, after excavation, the surrounding rock should be sealed by the initial injection in time, and a support should be carried out immediately after the initial injection to ensure integrity of the surrounding rock on the roadway surface.

3.1.2. Combination of long and short supports

Because the plastic loosening area formed by the soft rock is generally large, the supporting pressure is also relatively large, and the bearing ring formed by the anchor net spraying to

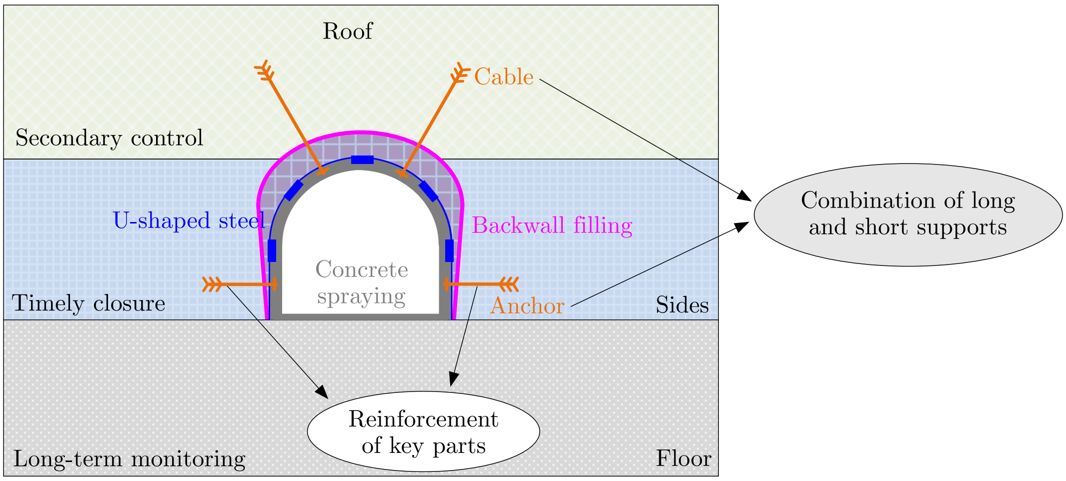

Fig. 2. Support concept of the weak cementation roadway

stabilize the shallow surrounding rock often cannot achieve an effective supporting effect. It is necessary to use an anchor cable to mobilize strength of deep surrounding rock and realize combination of long and short structures, so that the entire support body and the surrounding rock within the largest range can achieve the best supporting mechanical state.

3.1.3. Secondary control

In order to ensure that the deformation of the surrounding rock is controlled within a reasonable range and realize safety and normal use of the roadway, the "allowable deformation" should be fully considered when restoring the support, and the support body should leave a certain deformation space for the surrounding rock of the roadway. The "releasable pressure" allows the surrounding rock to release a certain amount of pressure. The "limited deformation" keeps the surrounding rock deformation within a controllable range to ensure the shape of the roadway section.

3.1.4. Reinforcement of key parts

The key point of the reinforcement is to determine the key parts, which can be judged according to stress field distribution characteristics in numerical simulation results. The U-shaped steel bracket has a certain shrinkability, which can realize full-section support of the roadway, evenly bear the surrounding rock stress, and fully guarantee the cross-sectional shape of the roadway. The concept of restoration and support requires a U-shaped steel shed as the main support method. On the basis of the support of the retractable U-shaped steel bracket, the cobblestone wall is backfilled, which has functions of flexible energy release and deformation and conforms to the support and bearing concept of "allowable deformation" and releasable pressure.

3.1.5. Long-term monitoring

The deformation of the surrounding rock is the most direct manifestation of the mechanical shape change of the surrounding rock. By performing on-site deformation measurements, the active state and time effect of surrounding rock deformation can be grasped, and the supporting structure and parameters can be determined. The deformation of weakly cemented strata has characteristics of a long time effect, so insisting on long-term monitoring is of great significance for timely understanding the stability information of the surrounding rock and taking the corresponding reinforcement measures.

3.2. Principles for maintaining residual strength of surrounding rock

The strength of weakly cemented soft rock will generally decrease after being affected by water or weathering. Therefore, after excavation of the roadway, concrete should be shot in time to seal the rock surface to prevent weathering and deliquescence of the surrounding rock, reduce the loss of surrounding rock strength, and help maintain the surrounding rock strength. There are four technical ways to improve the residual strength of the surrounding rock.

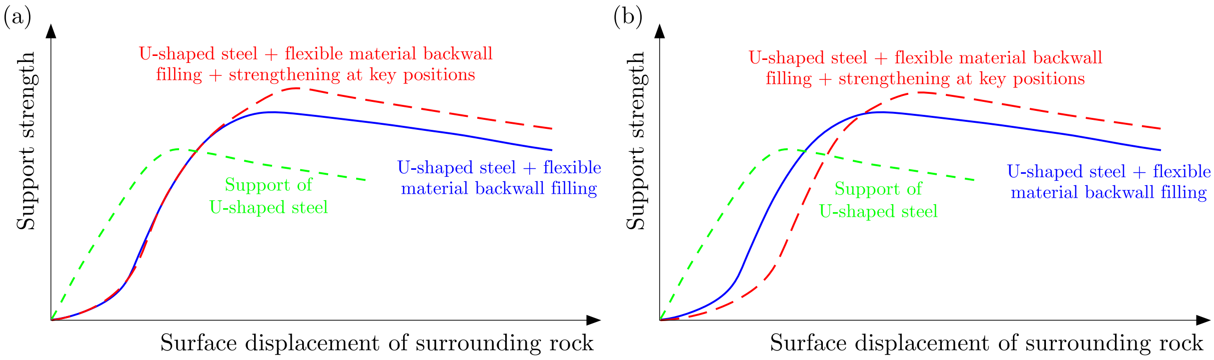

Fig. 3. Support concept of the weak cementation roadway: (a) effect of roadway roof repair, (b) effect of roadway sides repair

- Enhance support resistance and improve surrounding rock stress state. After the roadway is excavated, the support should be carried out as soon as possible to make the surrounding rock change from a one-way or two-way stress state to a three-way stress state, so as to improve the residual strength of the surrounding rock. The support body must not only have a certain support strength, but also a considerable amount of deformation, and the deformation of the support body should always occur under a higher support resistance.
- Give full play to the bearing capacity of the surrounding rock. Considering factors such as the existence of voids and the broken surrounding rock after U-shaped steel repairs the support wall, problems such as a poor contact state between the support and surrounding rock and uneven stress on the support are caused. The surrounding rock is easy to damage the U-shaped steel support to different degrees under the action of a concentrated load, or even lose its function, resulting in a poor overall support effect and unnecessary economic losses. Therefore, on the basis of the support of the retractable U-shaped steel bracket, the backfilling of the cobblestone (flexible material) wall is performed. At the same time, the shed anchors are added to the shed legs at the key parts of the surrounding rock support, and the steel mesh + concrete is laid on the bottom plate.
- Focus on the secondary support. It is generally difficult to use a rigid support with a strong resistance in soft rock roadways, because it is not suitable for characteristics of large initial deformation and fast deformation speed of soft rock roadways. In order to adapt to the deformation characteristics of soft rock, the method of the secondary support and repair should be adopted. The primary support is mainly to strengthen the surrounding rock and improve its residual strength. Under the condition of no excessive expansion and shear deformation, the active support is used to control deformation of the surrounding rock and relieve the pressure. The secondary repair and support should be completed in a timely manner after the surrounding rock is deformed and stabilized, so as to provide the final support strength and stiffness to the surrounding rock of the roadway and maintain stability and safety reserves of the roadway for a long time.

4. Engineering practice of soft rock roadway control

The auxiliary transportation roadway of Hongqingliang mine is arranged in 2 coal seams. The lithology of the roof and floor is mainly muddy and sandy rocks, the uniaxial compressive strength is 3-11 MPa, and the cohesion is 1.8-3.4 MPa. The surrounding rock is determined to be expansive soft rock by physical component analysis, and its mineral composition is made of quartz, albite, illite and chlorite, which belongs to the category of geological soft rock. During construction of an auxiliary transportation roadway, the following problems occurred: after the roadway was excavated, the roof of the newly excavated roadway sinked, and the shotcrete layer was cracked and damaged. Secondly, the bottom plate bulged and the concrete floor was damaged. Finally, the gangway was damaged. Roadway damage was mainly due to roof sinking and bottom bulging. In view of the failure of the auxiliary transportation inclined roadway, the supplementary anchor cable is used for support, but the effect is limited, and the roadway deformation continues to increase. Finally, the support method of U-shaped steel + flexible material wall backfill + reinforcement of key parts was used.

4.1. Engineering practice of the U-shaped steel support and backfilling

Combined with the original section size of the roadway, the parameters of the U-shaped steel restoration support section are designed, and the spacing between the U-shaped steel restoration and support sheds is determined by numerical simulation.

4.1.1. Determination of section size

As shown in Fig. 4, the section size of the roadway failure zone is 5.3 (5.0) m×4.35 (4.1) m in width and height. The arch radius of the net section is 2.3 m and the height of the right--angle side is 1.8 m. In order to maintain the original shape of the roadway section and consider installation of U-shaped steel into the roadway, the arch radius of the U-shaped steel support section is 2.4 m, and the installation space of the roof and the two gangs is 0.1 m.

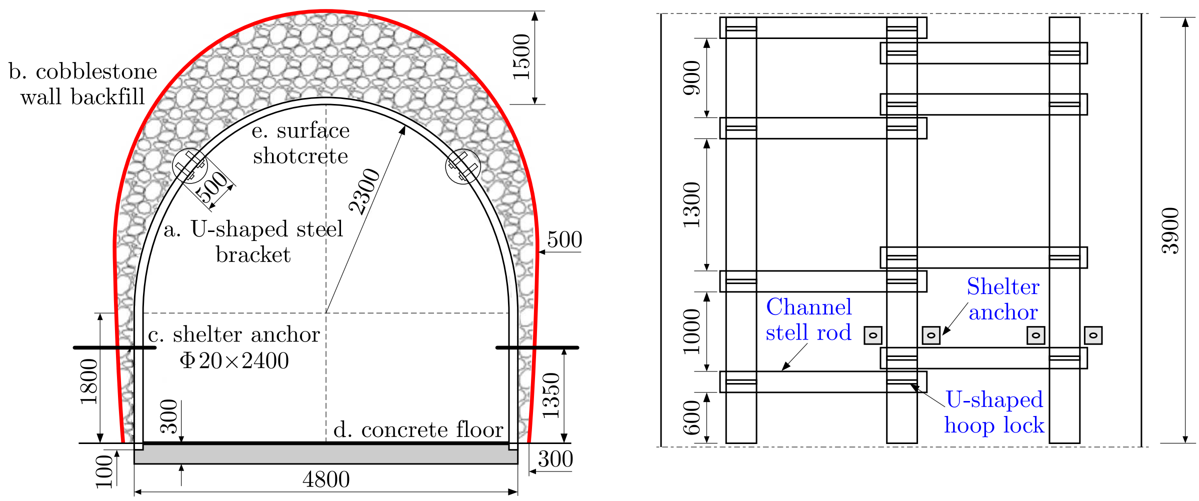

Fig. 4. Schematic diagram of the support section (unit: mm)

The maximum axial force of U-shaped steel is located at the spandrel position, where depth of the brush and cobblestone filling needs to be increased. Considering the arch radius of the U-shaped steel section with a radius of 2.4 m and height of the right-angle edge of the U-shaped steel of 1.9 m, the filling thickness of the cobblestone is 0.5 m. At the height of 3/4 of the straight leg of the scaffolding (1.35 m above the scaffolding foot), the bending moment is the largest, where it is easy to bend and deform, and the scaffolding anchor rod of ∅20 mm×2400 mm is added to restrain the scaffolding deformation. The axial force at the lap joint of the roof and shed is close to the maximum axial force of the U-shaped steel, which is easily subjected to concentrated stress. By installing the U-shaped hoop, U-shaped steel expansion and relative slippage are prevented. The foot of the U-shaped steel frame has a large force, and it needs to be reinforced by shotcrete. The bottom plate reserves a shotcrete thickness of 0.3 m to prevent the bottom plate from extruding and deforming the U-shaped steel.

4.1.2. Determination of the U-shaped steel spacing

In order to fully compare the influence of U-shaped steel support parameters on the control effect of roadway surrounding rock, three support schemes with U-shaped steel spacing of 0.8 m, 1 m and 1.2 m were studied by numerical simulation. The numerical calculation model was established by FLAC3D. The size of the model is 50 m×50 m×30 m, 50 m in the x direction, 50 m in the y direction, and 30 m in the z direction, as shown in Fig. 5. The Mohr-Coulomb model is selected for the constitutive relationship, and the beam unit is used for U-shaped steel. The top, left and right boundaries of the model are stress boundaries. The uniformly distributed forces of 10 MPa and 25 MPa are applied to represent the ground stress, and the front, back and bottom boundaries are displacement boundaries. The mechanical parameters of the rock stratum are listed in Table 1. The U-shaped steel spacing is set to 0.8 m, 1.0 m and 1.2 m, and the stress and plastic zone corresponding to the three shed spacing schemes are calculated respectively.

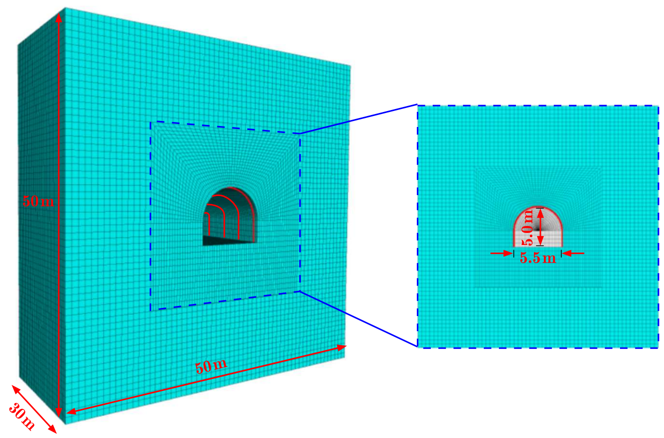

Fig. 5. Schematic diagram of the support section

Table 1. Rock layer physical and mechanical parameters

Name of rock stratum	Density [kg/m^3]	Bulk modulus [GPa]	Shear modulus [GPa]	Tensile strength [MPa]	Cohesion [MPa]	Internal friction angle [°]
Siltstone	2450	0.70	0.49	0.96	4.84	40
Coal	1300	0.41	0.23	0.20	0.34	29
Mudstone	2620	0.39	0.24	0.25	2.42	40

According to Fig. 6, under the condition of different spacing support schemes, the vertical and horizontal stress distribution are similar, and stress concentration occurs at the top and bottom of the roadway. The difference is that the stress distribution range increases with an increase of spacing. Compared with 1 m and 1.2 m spacing, the vertical stress distribution range is reduced by 15% and 60%, and the horizontal stress distribution range is reduced by 20%

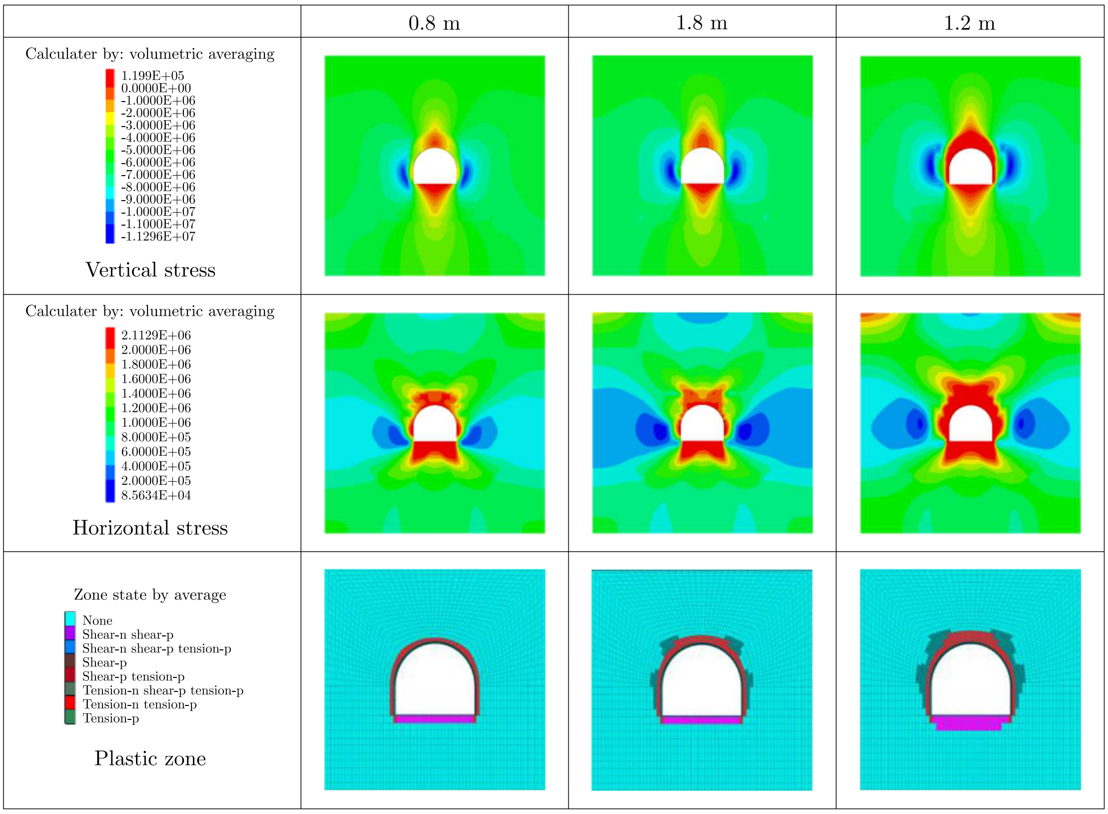

Fig. 6. Calculation results of the stress and plastic zone

and 90% respectively when the spacing is 0.8 m. It shows that shortening the spacing can fully improve the bearing capacity of U-shaped steel, and the difference between 0.8 m and 1 m in reducing the stress range is within 20%.

After the U-shaped steel support is adopted, the overall distribution range of the plastic zone in the failure zone of the roadway is reduced. When the U-shaped steel spacing is 0.8 m, the plastic deformation is concentrated on the edge of the U-shaped steel. When the spacing is 1 m, the plastic zone is concentrated on the roof of the roadway, and the range of the plastic zone is 0.2 m. When the spacing is 1.2 m, the plastic zone expands more obviously on the roof and floor of the roadway, and the scope of the plastic zone is increased to 0.5 m, which is significantly larger than that of the 0.8 m and 1 m spacing. It shows that shortening the spacing can reduce the area of the plastic zone around the U-shaped steel, and the spacing of 0.8 m and 1 m is similar in reducing the area of the plastic zone.

According to the deformation amount, the stress value and plastic zone distribution of the surrounding rock, it is comprehensively analyzed that the spacing of 0.8 m can effectively control the deformation of the surrounding rock of the roadway compared with the spacing of 1 m and 1.2 m. The gap between the support effect of 0.8 m and 1 m spacing is small, but the 1 m spacing can save large economic cost compared with the 0.8 m spacing.

4.2. Application practice of the support parameter optimization

The construction process of the U-shaped steel support on the roadway site mainly includes: brush the roof and sides, brush the floor, reinforce the mesh on the floor, install I-beams and shed legs, install the ceiling, backfill, lay the floor, repair shed anchor and shotcrete.

4.2.1. Brush the roof and sides

As shown in Fig. 7, the brushing is performed by a rock drill. In the case of uneven rock, it is necessary to use the air pick to further complete the brushing to ensure that the two bottoms are brushed out on average 300 mm each, and the waist is brushed out on average 500 mm.

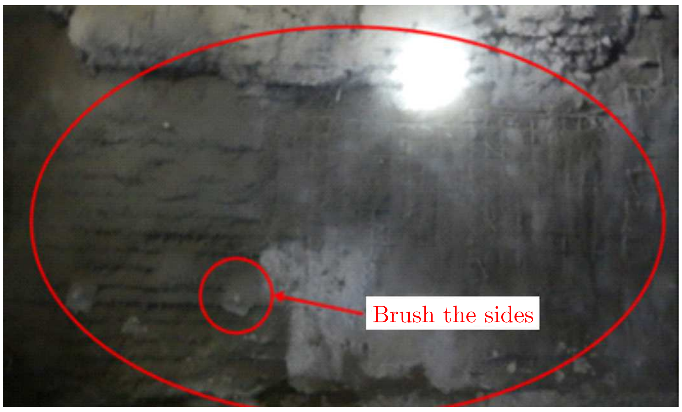

Fig. 7. Clear the roadway anchor

4.2.2. Brush the floor

After the top of the roadway is supplemented with anchor cables and the nets are laid on the side to supplement the bolts, the fully mechanized excavator is used to sweep the bottom, and then the forklift is used for leveling. Finally, manual leveling is performed to ensure that depth of the roadway is about 300 mm. The scope of sweeping the bottom is within 10 m in front of the U-shaped steel, and the gangue generated by the supplementary anchor cable, brushing and bottom pulling is transported out through the belt.

4.2.3. Reinforcing mesh on the floor

After sweeping the floor of the roadway, use the explosion-proof vehicle to transport the steel mesh to the floor of the roadway where the mesh is laid, and start laying the steel mesh at the floor as shown in Fig. 8. The size of the steel mesh is ∅6.5 mm, the mesh size is 100×100 mm, and the size of the steel mesh is 1200×2000 mm. The roadway floor is completely covered by the steel mesh, and the two steel meshes are tightened with steel wires.

Fig. 8. Laying reinforced mesh

4.2.4. Install I-beams and shed legs

As shown in Fig. 9, after the net laying is over, the explosion-proof truck transports the 12# I-beam to the net laying place, and manually arranges the I-beam at a spacing of 1 m.

Fig. 9. Field installation of U-shaped steel shed legs

The laying length of the I-beam is within 10 m in front of the U-shaped steel. The U-shaped steel shed legs are erected from the side of the lane, and the base of the shed legs is placed on the I-beam. There are four sets of screw holes on the base of the shed leg, and 2 U-shaped steels are inserted into the screw holes from the bottom of the I-beam, and the screws are tightened with a pneumatic wrench. At this time, it is necessary to prevent the shed leg from being sideways.

4.2.5. Install the ceiling

After the two sets of U-shaped steel are erected, the ceiling is erected from the initial erection legs firstly, and the second channel steel tie rod of the lane is erected. The ceiling is lifted by a forklift, and the ceiling is pulled by ropes and hung on the top of the roadway finally. Then a 40 mm U-shaped steel is installed in the groove with the upper end of the U-shaped steel scaffolding down 500 mm as a limit device to prevent the upper beam from sliding down and expanding. Two 40 mm U-shaped hoops are installed on both sides of the overlapping section between the ceiling and the shed legs, as shown in Fig. 10.

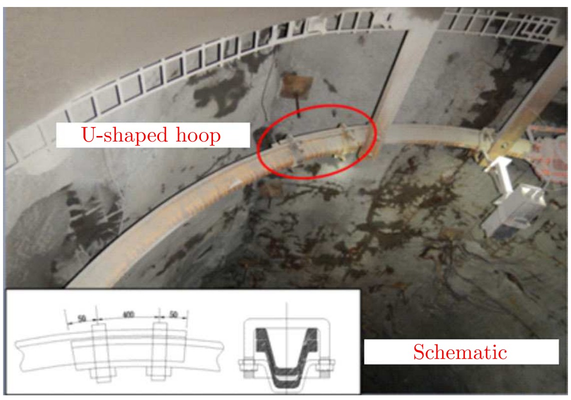

Fig. 10. Erecting the ceiling in the roadway

4.2.6. Backfill

As shown in Fig. 11, the order of filling behind the wall is to fill the gap between the roadway and the U-shaped shed firstly. Then the cobblestone is lifted with a forklift, and the worker stands above the bare netting shed and fills the gap between the top and the U-shaped shed. The cobblestone filling of the roof and lanes is gradually advanced at a speed of 1 m.

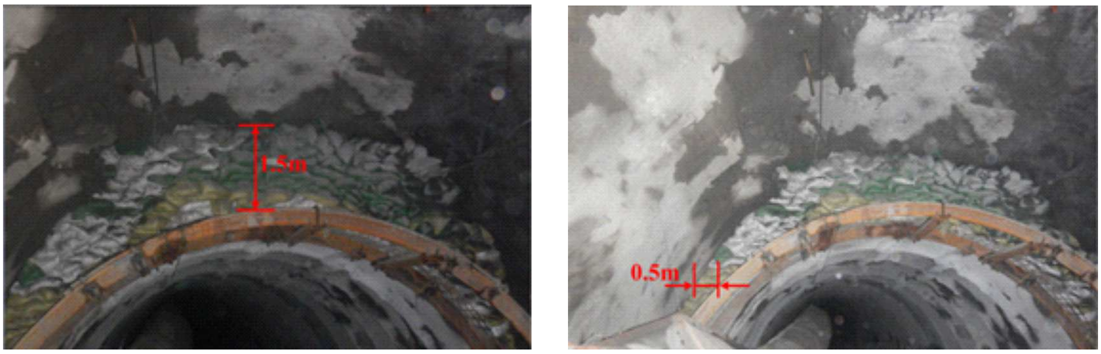

Fig. 11. Backfill with pebbles

4.2.7. Laying the floor

After the roof and sides of the roadway are filled with cobblestones, the floor will be laid. The thickness of concrete laid on the floor is about 300 mm, and the concrete burial depth of the base of scaffolding is about 100 mm (the floor is laid as shown in Fig. 12). The laying length of the floor is within 10 m in front of the shed, and the uneven area needs to be leveled manually.

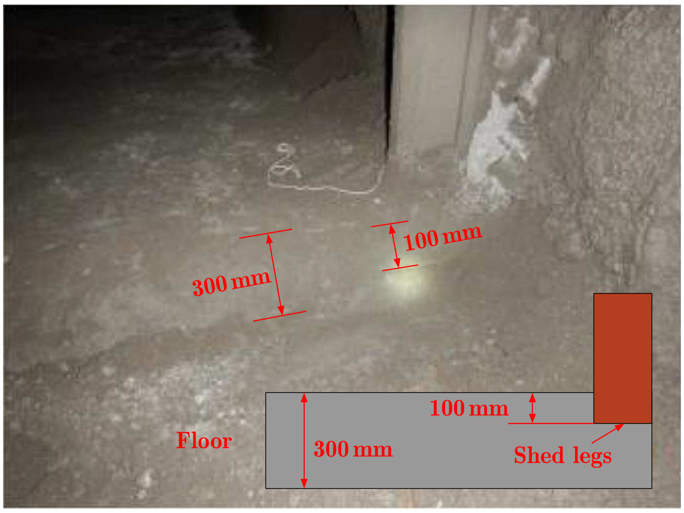

Fig. 12. Laying concrete in the roadway floor

4.2.8. Repair shed anchor

After the roadway floor is laid with concrete, two shed anchors are installed at each of the shed legs. The specification of the anchors is ∅20×2400 mm. The specific arrangement is shown in Fig. 13.

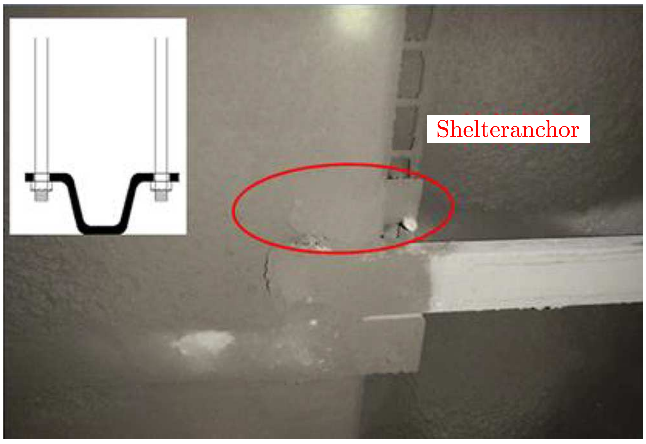

Fig. 13. Repair shed anchor

4.2.9. Shotcrete

After the shed guard bolts of the two gangs of the roadway are finished, the shotcrete work will be carried out. According to the construction requirements, the thickness of the shotcrete layer is not less than 70 mm, and the actual thickness of the shotcrete layer is about 100 mm. The on-site effect of the U-shaped steel shed is shown in Fig 14.

Fig. 14. Application diagram of the U-shaped steel support

4.3. On-site monitoring

After the roadway damage area is supported by the U-shaped steel, in order to detect the support effect, two groups of monitoring stations 1# and 2# are arranged in the roadway. The displacement of the roadway surface is observed by the cross point method, and the bolt force is monitored by a bolt dynamometer. As shown in Fig. 15, the surface displacement of the roadway 1# and 2# measurement points are both 0 during the monitoring time. The minimum value of the force monitoring of the 1# bolt is 19 kN, the maximum value is 23 kN, and the overall force value fluctuates around 21 kN. The minimum value of the force monitoring of the 2# bolt is 19 kN, the maximum value is 24 kN, and the overall force value fluctuates around 22 kN. The monitoring data of the bolt stress gauge fluctuates around a certain value and is relatively stable, indicating that the U-shaped steel-rod support plays an important role in the support of the surrounding rock of the roadway. After the roadway in the damaged area is supported by the U-shaped steel, the section is complete and the deformation of the surrounding rock is effectively controlled.

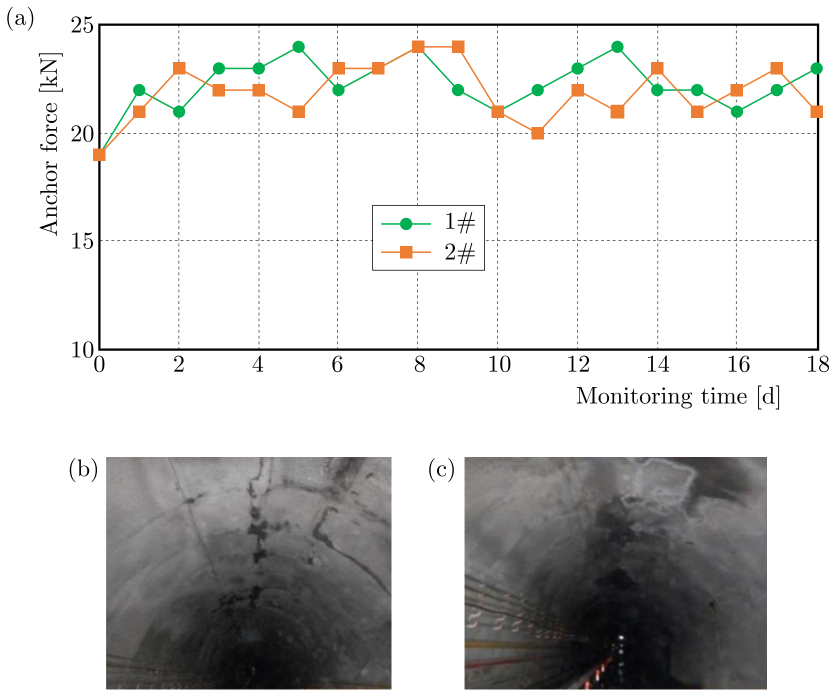

Fig. 15. Supporting effect monitoring method and equipment: (a) anchor dynamometer, (b) deformation of 1#, (c) deformation of 2#

5. Conclusion

- The main reasons for deformation and failure of weakly cemented caverns and surrounding tunnels are the large cross-section of the cavern, complex geological and mechanical conditions of the surrounding rock, low strength of the surrounding rock, and abundant easily expandable clay minerals. The roof and floor of the tunnel are the key points for reinforcement and support.
- The support idea of "timely closure, combination of long and short supports, secondary control, reinforcement of key parts, and long-term monitoring" and the load-bearing support concept of "allowable deformation + releasable pressure + limited deformation" for weakly cemented soft rock roadways are proposed, which effectively solves the problem of excessive excavation deformation of the roadways and plays a key role in maintaining the integrity of surrounding rock of the roadways.
- The location of adjacent weakly cemented chambers should be conducive to stability of the surrounding rock, efficient production, convenient transportation and construction safety while avoiding mutual interference between the chambers and other tunnels in the mine. On this basis, a mechanical model of the cave group under complex geological conditions is constructed to explore the mechanism of rock failure and instability in the cave group. This can provide a theoretical basis for the layout design of large cross-section cave groups and control of rock stability.

Acknowledgements

The authors would like to thank the editors and anonymous referees for detailed and valuable suggestions that helped to improve the original manuscript to its present form.

Funding

The research described in this paper was financially supported by Natural Science Foundation of Shandong Province (No. ZR2022ME060 and ZR2022ME165), National Natural Science Foundation of China (No. 52204093) and Scientific Research Fund of Liaocheng University (318052263).

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Manuscript received October 22, 2022; accepted for print April 27, 2023