Bolt-grouting Repair and Reinforcement Technology for Damaged Soft-rock Roadway in Deep Mine

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ABSTRACT

Facts have proved that it is of important significance to study repair and reinforcement technology for damaged soft-rock roadway in deep mine. With field survey and borehole TV detection of large soft-rock roadway in south wing of Yangcheng Coal Mine, failure characteristics of surrounding rocks in the roadway were discussed. Based on the principle of bolt-grouting support, the repair and reinforcement plan of full-face high-strength pre-stressed bolt support to reinforce surrounding rocks actively + full face grouting lines and long grouting reinforcement with anchor cable + floor overbreak and bolting-backfill for floor heaving control was proposed. Moreover, reasonable support parameters and process were designed. Numerical simulation and field application test confirmed that the proposed plan can control deformation failure of surrounding rock effectively and safeguards the long-term roadway stability. The proposed plan can be popularized to similar roadway repairs.

KEYWORDS: deep mine, damaged soft-rock roadway, repair and reinforcement, bolt-grouting, numerical simulation

INTRODUCTION

Complicated high geostress conditions and soft rocks bring great quick persistent nonlinear flowing deformation of surrounding rocks in excavated soft-rock roadway of deep mine, making it very difficult to control surrounding rock stability in roadway[1]. Without reasonable support and support parameters, adequate considerations to practical conditions and scientific construction design, many soft-rock roadways in deep mines suffer serious deformation failure which affects safe and normal production of coal mines. Therefore, it is necessary to repair and reinforce roadways. Key attention shall be paid to roadway repair and reinforcement technology, because blind entry expansion without consideration to roadway situations is easy to cause secondary failure after repaired. As the roadway is repaired over and over again, surrounding rocks will become too broken to bear their dead load and will suffer serious deformation failure soon. This will delay the best time for roadway repair and reinforcement, and form the vicious circle of “excavation-repair-failure”. As a result, it is of important significance to study repair and reinforcement technology for damaged soft-rock roadway in deep mine[2-3].

The large roadway in -650 south wing of Yangcheng Coal Mine is a typical soft-rock roadway. With surrounding rocks of fine sandstone-mudstone interbed and developed joint
fissures, it suffers serious deformation failure after excavation, which couldn’t be repaired and reinforced well by conventional means. Based on the analyzed failure characteristics of surrounding rocks, this paper put forward the bolt-grouting repair and reinforcement technology. Later, support parameters were optimized according to the numerical simulation using FLAC3D. The field test confirmed that the proposed bolt-grouting repair and reinforcement technology not only avoids negative effects of repeated repairs, but also ensures safe and high-efficient production of the coal mine.

**BRIEF INTRODUCTION TO THE PROJECT**

Locating in Wenshang County, Jining City, Shandong Province, Yangcheng Coal Mine covers a mining area of 46km² with 153 million tons recoverable reserves. It was constructed and put into production in 2007, with an estimated production capacity of 2.4 million t/a and 42.2 years of service. It is exploited by the combination of vertical shaft and subinclined shaft. The main mining level is -650m and the primary mineable coal bed is 3-coal. The mean thickness of 3-coal is 7.78m and mean dip angle is 25°. It is supported by fine sandstone-siltstone interbed with joint fissures on top and block mudstone with sliding surface at bottom. Faults are developed in the mine field. During tunneling, the -650 horizontal large roadway passes through 3-coal as well as its roof and floor strata. Surrounding rocks in the roadway has poor integrity and are easy to be weathered and deliquesced. The roadway section is designed as semicircle arch (2.4m high) with vertical wall (1.8m high). The roadway is 4.8m wide. It takes conventional combined support with bolt wire cable and shotcrete as the permanent support. Serious deformation failure (e.g. large-scale wall caving and heaving floor) occurs at the end of roadway construction, showing as great persistent nonlinear flow deformation. The roadway section shrinks more than 80% 3 months later (Fig.1). Considering these roadway failure conditions, several roadway repairs and reinforcements were organized. Without reasonable selection and scientific design of repair and reinforcement technology, only brushing, dinting and reinforcement using bolt wire cable and U-shaped steel shed were implemented according to previous experiences, which achieved unsatisfying effect. Repaired roadway suffered serious failure soon.

(a) Physical section area reduction
FAILURE CHARACTERISTIC ANALYSIS OF THE ROADWAY

Distribution of Detection Probes

Test points for borehole TV camera are set at the head of repairing roadway to detect potential crack zones at different depths surrounding the roadway and determine broken-rock zone scope surrounding the roadway and failure characteristics of surrounding rocks. They detect roof and side surrounding rocks of the roadway. Boreholes are 32mm wide in diameter and 10m deep. For automatic water outflow from boreholes at two roadway sides and convenient borehole TV detection, detecting boreholes shall be drilled from elevation (≤5°). YTJ20 rock detector (borehole TV made by Zhongkuang Huatai) is used (Fig.2).

Detection result analysis

Detection results of boreholes at roadway roof and sides are shown in Fig.3 and Fig.4.
Deformation characteristics of repairing roadway are:

(1) Serious discontinuous large-scale deformation of surrounding rock is observed. The diameter of broken-rock zone exceeds 3m and even reaches 5m in some places.

(2) More cracks are developed within 2m of roof surrounding rocks. Crack is observed at about 4m and there are more fractures and fracture zones within the range of 7m~10m.

(3) Abundant fracture zones exist on the surrounding rocks within 4.0m of right side. Boreholes present poor integrity. A large fracture zone is observed at 4.7m. Different degrees of failures, mainly fractures, are detected on the surrounding rocks within 7m~10m to the boreholes.

(4) Roadway sides suffer more serious failure compared to the roof.

To sum up, superficial surrounding rocks have significantly low integrity and self-supporting capacity. Moreover, fractures and fracture zones alternate with each other on surrounding rocks beyond the deep anchoring range. As a result, combined support with bolt wire cable couldn’t restore the stability of surrounding rocks. It is impossible for original support plan and parameters
BOLT-GROUTING REPAIR AND REINFORCEMENT TECHNOLOGY AND PARAMETERS

Principle of Bolt-grouting Support

Bolt-grouting support, the combination of anchoring and grouting reinforcement, reinforces broken surrounding rocks in roadway actively by taking the full advantage of self-supporting capacity of bolting surrounding rocks. It implements anchoring and grouting simultaneously by using hollow anchor rod or cable. Bolt-grouting support is one of the most effective measures to control serious failure of soft-rock roadway\(^4\)\(^-\)\(^8\). The anchor rod restricts broken surrounding rocks with the anchoring force to form an extruding reinforcing belt. The anchor cable hangs the superficial reinforcing belt of surrounding rocks on deep solid surrounding rocks and expands the reinforcing scope. Grouting glues broken rocks into high-strength induration again, which improves physical and mechanics properties of broken rocks, especially cohesion (c) and internal friction angle (\(\phi\)). On one hand, the bolt-grouting support can increase strength and overall bearing capacity of surrounding rocks effectively. On the other hand, grouting can seal cracks on deep surrounding rocks and eliminate stress concentration at crack tip, thus stopping crack growth. This contributes to long-term stability of surrounding rocks of roadway.

Repair Plan and Parameters

(1) Repair plan

Borehole TV probes at repairing roadway in south wing of Yangcheng Coal Mine detect a large broken-rock zone (3~5m), poor integrity of superficial surrounding rocks, fracture and fracture zone in 7m~10m deep surrounding rocks and big heaving floor. Therefore, the repair plan includes full-face high-strength pre-stressed bolt support to reinforce surrounding rocks actively + full-face grouting lines and long grouting reinforcement with anchor cable to rebuild broken surrounding rocks and inhibit crack growth in deep surrounding rocks and deformation + floor overbreak and bolting-backfill for heaving floor control.

(2) Support parameters and process

The roadway support design is shown in Fig.5.
(1) Anchor rod + metal mesh + primary grouting: Φ 22×2500mm high-strength pre-stressed left-handed anchor rods without longitudinal reinforcement thread are used in the full face. Anchor rods are applied on roof and sides at an interval of 700mm×700mm. The floor is excavated for additional 800mm and then reinforced by anchor rods. A piece of anchor rod is placed at the middle. The interval between anchor rod rows is 900mm×900mm. 2000×1000mm metal meshes made of Φ 6mm steel bars (grid: 100×100mm) are applied before anchor rod reinforcement. After finished such bolt-mesh-cable support, 30mm thick grouting will be applied as primary grouting. MSK2550 and MSCK2535 anchoring agents are used in each borehole. The square 150×150×8mm pallets are pressed from 8mm thick steel plates.

(2) Grouting lines + grouting-anchor cable + secondary grouting: Grouting lines (Φ 26×2500mm) and grouting-anchor cable (Φ 22×8000mm) are constructed after finished bolting-wire mesh-shotcreting support. Grouting lines are used in full roadway (roof, sides and floor) at the interval of 1800×1800mm. One grouting line is installed at the middle roof. Grouting-anchor cables are placed at the interval of 1400mm×1400mm and one at the middle roof. Tunneling is implemented immediately after finishing the pavement of grouting-anchor cables. Additional two grouting-anchor cables (Φ 22×6000mm) are paved at floor (angle between left/right footing and floor=45°) at the interval of 1400mm. Later, spray 100mm thick grouting.

(3) Grouting: Due to broken superficial surrounding rocks and fracture development in deep surrounding rocks, coupling grouting is implemented to the whole roadway as soon as finished the secondary grouting. The grout is Po42.5 single liquid prepared from ordinary Portland cement at the water/cement ratio of 1:2. The final grouting pressure of grouting-anchor cable is 7~8MPa and the final grouting pressure of grouting lines is 3~4MPa.

(4) Floor backfill: Backfill the overbreak floor with C40 concrete.
NUMERICAL SIMULATION ANALYSIS

Model Establishment

To analyze feasibility and effectiveness of the proposed bolt-grouting repair and reinforcement technology, the numerical simulation model is established by using FLAC3D (Fig.6). It is a Coulomb-Moore model. Boundary conditions are: zone above z direction in the model is free face where is applied with vertical load to simulate dead load of overlying rock stratum; zone below z direction in the model restricts vertical displacement, while x and y directions restrict horizontal displacement. Since the buried depth of the roadway is about 700m, 17.5MPa stress is applied to the upper boundary of the model. The acceleration of gravity is 10m/s².

![Figure 6: Numerical simulation model](image)

Since the testing roadway runs through complicated soft rock strata, it is deformed greatly during construction. The section area of some sections reduces by more than 80%. Therefore, we assume that after section area reduction, wall is 0.5m high; arch is 1m high; and the roadway is 2m wide. They return to 2.7m (including overbreak height), 2.4m and 4.8m respectively after repair. According to properties of surrounding rocks and comprehensive column chart of rock strata, mechanics parameters of rock strata in the model are presented in Table 1.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>h (m)</th>
<th>ρ (kg/m³)</th>
<th>E (GPa)</th>
<th>G (GPa)</th>
<th>φ (°)</th>
<th>C (MPa)</th>
<th>σt (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium sandstone</td>
<td>5</td>
<td>2500</td>
<td>21</td>
<td>12</td>
<td>40</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Mudstone</td>
<td>5</td>
<td>2470</td>
<td>2.3</td>
<td>1.7</td>
<td>36</td>
<td>2.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Fine sandstone</td>
<td>10</td>
<td>2400</td>
<td>8.75</td>
<td>6.0</td>
<td>29</td>
<td>2.4</td>
<td>0.8</td>
</tr>
<tr>
<td>3 Coal seam</td>
<td>8</td>
<td>1480</td>
<td>2.59</td>
<td>1.65</td>
<td>28</td>
<td>3.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Fine sandstone</td>
<td>2</td>
<td>2400</td>
<td>8.75</td>
<td>6.0</td>
<td>29</td>
<td>2.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Firstly, excavate a 2m wide roadway with 0.5m high wall and 1m high arch by using null unit. Weak parameters of rock within certain scope and operate to balance. Then, simulate broken surrounding rocks after section area reduction. Secondly, excavate the roadway to original designed section size and clear displacement. After finished all bolt-grouting repair and reinforcement, operate to balance and then simulate stress displacement of surrounding rocks. The simulation results are analyzed, which can disclose effectiveness of the proposed bolt-grouting repair and reinforcement technology.

Result Analysis

(1) Surrounding rock failure after section area reduction
It can be seen from Fig.8 that after the south roadway suffers heavy shrinkage distortion induced by deep high geostress, large-scale failure of surrounding rocks takes place. The plastic deformation zone on roof expands to 9m. The plastic deformation zone on floor and sides reaches 6m at most.

![Figure 7: Plastic deformation zone after section area reduction](image)

(2) Surrounding rock failure and displacement after bolt-grouting repair and reinforcement
The plastic deformation zone and displacement distribution of surrounding rocks after bolt-grouting repair and reinforcement are shown in Fig.9 and Fig.10. The bolt-grouting repair and reinforcement enhances integrity of surrounding rocks and controls plastic deformation zone effectively. Surrounding rocks mainly present shear failure. In Fig.9, shear plastic deformation zone is only formed on roof, floor and about 1m within the surrounding rocks of two roadway sides. Displacement of surrounding rocks reduces significantly. The maximum vertical displacement of roof reaches 12.5cm and the maximum floor heaving is 7cm. The horizontal displacements of two roadway sides are relative smaller (4cm to the most). This indicates that the proposed bolt-grouting support can control failure expansion and deformation of surrounding rocks effectively.
FIELD TEST

To test field application effect of the proposed bolt-grouting repair and reinforcement technology, an industrial field test is conducted to the repair roadway in south wing. Test points for measuring surface displacement of the roadway are set. Test results are exhibited in Fig.10.
Fig. 10 shows that the left-to-right convergence is 45mm. The roof settlement is 42mm and the floor heaving is 93mm, indicating the roof-to-floor convergence is 135mm, close to numerical simulation results. The roadway deformation begins to converge about 30d after the bolt-grouting repair and reinforcement, confirming the effectiveness of bolt-grouting repair and reinforcement in controlling soft-rock roadway deformation.

CONCLUSIONS

(1) Due to the significantly lower integrity and self-support capacity of surrounding rocks in soft-rock roadway in south wing of Yangcheng Coal Mine, blind repair and passive support couldn’t stop crack growth and deformation of surrounding rocks, but can only make it more difficult to control roadway failure. Bolt-grouting support is the one of the most scientific repair technologies from the perspective of increasing strength and bearing capacity of surrounding rocks.

(2) Based on the principle of bolt-grouting support, a repair and reinforcement plan including full-face high-strength pre-stressed bolt support to reinforce surrounding rocks actively + full-face grouting lines and long grouting reinforcement with anchor cable to rebuild broken surrounding rocks and inhibit crack growth in deep surrounding rocks and deformation + floor overbreak and bolting-backfill for heaving floor control is proposed. Reasonable support parameters and process are designed.

(3) The numerical simulation and field test confirm the effectiveness of the bolt-grouting repair and reinforcement technology in controlling failure zone expansion and deformation development on surrounding rocks as well as converging and slowing down surrounding rock deformation significantly. It safeguards long-term stability of the roadway and provides important references for similar roadway projects.

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