Study on Optimum Design of Support Technology for Large Section Belt conveying Roadway

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Abstract: Aiming at the problems of slow excavation speed, large support workload, large number of assistants, high excavation and support cost in belt conveying roadway in a mine at present, the finite difference software FLAC3D is used to establish the numerical simulation model based on the production geological conditions. Through numerical calculation, reasonable supporting parameters such as bolt diameter, length, spacing between rows, number of anchor wire and spacing between the two are determined to support a belt conveying roadway, that realized the optimization of roadway support, improves the driving speed and guarantees the normal continuity of production.

1. Introduction
With the improvement of production capacity and speed of fully mechanized mining face, there is a tension of mining replacement in many mines. Rapid excavation and support of mining roadways have become one of the key technologies for high-yield, high-efficiency and safe production in mines[1-2]. Xiaojiawa Coal Mine is a large modern mine with an annual output of tens of millions of tons, the cross-section area of belt conveying roadway of No. 110802 face in No. 8 coal seam is large, and influenced by many factors, the driving speed is relatively slow at present, and scattered production, large auxiliary workload, large number of auxiliary personnel, occupying more equipment, high cost of tunneling occur, affecting the normal replacement of the working face and economic benefits of coal mines. Therefore, the reasonable optimization of roadway support parameters by means of computer numerical simulation research can not only improve the roadway excavation speed, realize the matching of excavation and anchor, solve the problem of mining replacement tension, but also reduce the roadway support cost and improve the economic and social benefits of the mine.

2. General situation of engineering geology in 1110802 working face
The Coal seam No. 8 in Xiaojiawa Coal Mine is shallow, with an average depth of 286 m, an average thickness of 3.68 m and an average dip angle of 12 degrees. It is a gently inclined coal seam. Mining roadways are arranged by double roadways, and coal pillars with a width of 20 m are set up. The belt conveying roadway of no.110802 working face in11 mining area is arranged in the southeast wing of the mine, it is adjacent to 110801 working face in the east and 8 coal seam in the west. The length of working face is 250 m, and the length of continuous propulsion is 3179 M.
The situation of coal seam roof and floor is as table 1:

| Name          | thickness /m | Rock classification     | Lithologic characteristics                                                                 |
|---------------|--------------|--------------------------|-------------------------------------------------------------------------------------------|
| Roof          |              |                          |                                                                                           |
| main roof     | 6.8          | Medium grain sandstone   | The main ingredient is quartz with medium-thick texture.                                    |
| immediate roof| 2.1          | sandy mudstone           | Blocky Sandy and unevenly distributed, with more plant fossils, thin seam coal, and developed lower cracks |
| false roof    | 2.9          | Grey-light grey mudstone | Occurrence of unstable, thin-layered structures                                             |
| Floor         |              |                          |                                                                                           |
| immediate floor| 7.3         | post stone               | Quartz is predominant, calcareous cementation and fissure development                       |
| Main floor    | 9.6          | sandy mudstone           | Massive flat fracture with a small amount of plant fossils                                  |

3. Optimum design and parameter determination of roadway support

3.1 Establishment of numerical model

In order to minimize the influence of boundary effect on Simulation results, the left and right boundaries of the model are determined according to the law of strata movement angle caused by strata mining. That is to say, the left and right boundaries of the model should be taken out of the influence area of the full mining angle formed by the mining face, and the upper boundaries of the model should be taken out of the key strata of the overlying strata. The boundary conditions of horizontal direction and bottom boundary of the model are fixed boundary, and the top boundary of the model is stress boundary. According to the relationship between actual production geological conditions and roadway layout, a three-dimensional numerical simulation model is established. The size of the numerical simulation model is as follows: The X direction is 180m, Y direction is 10m, Z direction is 61.6m. The numerical model is shown in Figure 1. The rock mechanics parameters of numerical simulation are determined according to borehole histogram and relevant rock mechanics data. The vertical stress at the upper boundary of the model is 7.0 MPa in depth of 280 m and bulk density of 25 kN/m$^3$. Mohr-Coulomb yield criterion is used in numerical simulation.

![Figure 1 The numerical model](image)

3.2 Determination of Support Parameters of Roadway

Using FLAC3D to set up numerical model and carry out numerical calculation on the basis of field production geological conditions. Firstly, under the condition that the bolt and anchorage length remain unchanged, analyzed the influence of different bolt spacing and row spacing on the surface displacement of roadway, and determined the reasonable row spacing. Secondly, the influence of different bolt lengths on the surface displacement of roadway is analyzed under the condition of constant bolt spacing and row spacing, and then the appropriate bolt length is determined. Finally, the
support parameters are determined according to the simulation results and actual construction conditions.

3.2.1 Determination of bolt diameter
In order to control the deformation and separation of surrounding rock effectively, the bolt must provide reliable support resistance. When the bolt material is fixed, the support resistance is proportional to the square of the radius of the bolt. That is to say, the bigger the diameter, the bigger the support resistance and the stiffness of the bolt support system, the better the support. On the other hand, the reasonable matching between bolt diameter and borehole diameter should be considered. The diameter difference between anchor hole and bolt is 6-8 mm, and the anchoring effect is the best, and the anchorage effect can only be guaranteed with difference 4-10 mm\(^3\text{-}^5\). The diameter of bolt hole commonly used in coal mines in China is 28 mm, and the suitable diameter of bolt is 18-24 mm. By comparing and analyzing the safety of numerical calculation and taking into account the economic factors such as cost and construction tools on site, Fiberglass bolts with 18 mm diameter are used in the mining side of belt conveying roadway in 110802 working face, and 20 mm diameter left-handed screw bolts are used in roof and non-mining side. Which can meet the requirements of high anchoring force, material saving and construction convenience.

3.2.2 Determination of bolt spacing
The spacing of bolts is one of the important parameters of bolt support, which affects the strength of surrounding rock bolts directly. It is difficult to form anchorage in surrounding rock of roadway with too large bolt spacing, and it is easy to waste if the bolt spacing is too small\(^6\). In numerical simulation, the influence of different bolt spacing on surrounding rock deformation is studied and analyzed by changing the size of bolt spacing. In the belt conveying roadway of 110802 working face, the cross-section width * height is 5600 mm * 3600 mm (hardening of bottom plate 200 mm). Four kinds of anchor spacing schemes are proposed for numerical simulation. See table 2.

| scheme | Bolt number | bolt spacing /mm |
|--------|-------------|-----------------|
| 1      | Six roofs and four sides | Roof bolt 1000, the side 850 |
| 2      | Six roofs and four sides | Roof bolt 1000, the side 900 |
| 3      | Seven roofs and four sides | Roof bolt 850, the side 850 |
| 4      | Seven roofs and four sides | Roof bolt 850, the side 900 |

The cumulative deformation of surrounding rock of roadway under four different schemes is numerically simulated. The results are shown in table 3.

| scheme | Roof Deformation /mm | floor Deformation /mm | non-mining side Deformation /mm | mining side Deformation /mm |
|--------|----------------------|-----------------------|---------------------------------|---------------------------|
| 1      | 158                  | 208                   | 114                            | 182                       |
| 2      | 140                  | 194                   | 102                            | 153                       |
| 3      | 101                  | 184                   | 89                             | 140                       |
| 4      | 92                   | 179                   | 80                             | 132                       |
Under four different schemes, the cumulative deformation of surrounding rock of roadway varies greatly. In the first and second schemes, the roof subsidence is much larger than that in the third and fourth schemes, and the cumulative deformation of the surrounding rock of the roadway is relatively large, so the first and second schemes are excluded. The number of Roadway Bolts Used in scheme 3 and scheme 4 is the same, and the deformation of roadway surrounding rock in scheme 4 is smaller. Therefore, the optimal scheme is scheme 4, that is, there are seven bolts on the roof of the roadway, with a distance of 850 mm and four bolts on each side of the roadway, with a distance of 900 mm.

3.2.3 Determination of Row Spacing of Bolts

Whether the anchor row spacing is reasonable or not directly affects the support cost and effect. Excessive bolt row spacing is not conducive to the formation of surrounding rock anchorage, which easily leads to excessive deformation of local surrounding rock, thus the overall deformation of roadway and making surrounding rock anchorage instability. And too small bolt row spacing will affects construction speed and support cost [7-9]. The relationship between bolt row spacing and accumulated deformation of roadway surrounding rock is shown in table 4.

| bolt row spacing /mm | Roof Deformation /mm | floor Deformation /mm | non-mining side Deformation /mm | mining side Deformation /mm |
|----------------------|----------------------|-----------------------|-------------------------------|-----------------------------|
| 800                  | 83                   | 201                   | 76                            | 124                         |
| 850                  | 89                   | 205                   | 81                            | 135                         |
| 900                  | 98                   | 206                   | 90                            | 143                         |
| 1000                 | 136                  | 208                   | 110                           | 176                         |
| 1100                 | 158                  | 211                   | 134                           | 189                         |

The analysis shows that the cumulative deformation of surrounding rock of roadway increases with the increase of bolt row spacing, but the increase is different. When the bolt row spacing increases from 800 mm to 900 mm, the cumulative deformation of roof and non-mining side increases slowly, while the cumulative deformation of floor surrounding rock remains basically unchanged. When the bolt row spacing increases from 900mm to 1100mm, the cumulative deformation of roof and mining side rock increases significantly. Considering the stability of surrounding rock and the overall deformation of roadway, the bolt row spacing should be less than or equal to 900mm. Considering the economic factors, the design of roof and two sides bolt row spacing are 900mm.

3.2.4 Determination of Bolt Length

After the row spacing between bolts is determined, the length of bolt becomes one of the important parameters of bolt support, which should ensure the formation of a stable bearing structure in the anchorage area, with sufficient bearing capacity. The length of bolt is too short and the range of anchorage zone is too small, which is not conducive to the stability of roadway surrounding rock. On the contrary, if the length of the anchor increases to a certain value, the additional lengthening of bolt has no obvious effect on the bearing capacity of the anchor. Therefore, the length of bolt has a reasonable range [9].

(1) Determination of the length of glass fiber reinforced plastics bolt

By changing the length of FRP bolt in numerical simulation, the influence of different length of FRP bolt on surrounding rock deformation is studied and analyzed. The results are shown in table 5.

| Bolt Length /m | Roof Deformation /mm | floor Deformation /mm | non-mining side Deformation /mm | mining side Deformation /mm |
|----------------|----------------------|-----------------------|-------------------------------|-----------------------------|
| 1.6            | 90                   | 135                   | 86                            | 108                         |
| 1.8            | 87                   | 132                   | 83                            | 104                         |
| 2.0            | 85                   | 130                   | 79                            | 103                         |
The analysis shows that with the increase of bolt length, the cumulative deformation of surrounding rock shows a decreasing trend. When the length of bolt increases from 1.6 m to 2.4 m, the deformation of the mining side decreases from 108 mm to 98 mm, and the cumulative deformation of the surrounding rock changes little. Therefore, considering the economic factors, the length of FRP bolt is 1.6m.

(2) Determination of left-handed screw steel bolt length

In the numerical simulation, the influence of different left-handed screw steel bolt lengths on the deformation of surrounding rock is studied and analyzed. The results are shown in Table 6.

| Bolt Length /m | Roof Deformation /mm | floor Deformation /mm | non-mining side Deformation /mm | mining side Deformation /mm |
|---------------|----------------------|-----------------------|--------------------------------|-----------------------------|
| 2.0           | 89                   | 150                   | 108                            | 135                         |
| 2.2           | 61                   | 142                   | 83                             | 109                         |
| 2.4           | 57                   | 138                   | 79                             | 103                         |
| 2.6           | 54                   | 127                   | 71                             | 102                         |
| 2.8           | 51                   | 124                   | 68                             | 98                          |

The analysis shows that with the increase of bolt length, the cumulative deformation of surrounding rock shows a decreasing trend. When the length of bolt increases from 2.0 m to 2.2 m, the cumulative deformation of roadway surrounding rock is more significant, especially the roof deformation. When the length of bolt increases from 2.2m to 2.8m, the variation range will decrease obviously. Because when the length of bolt is 2.2m, the cumulative deformation of surrounding rock is small, and when the length of bolt continues to increase, the cumulative deformation of surrounding rock is not obvious. Considering the economic and technical factors, the length of bolt is 2.2m.

3.2.5 Determination of Anchor Standard

The specifications of anchor cables directly affect its strength. The early stage excavation in 110802 belt-conveyed roadway is in solid coal, but in the later stage, it will experience the influence of dynamic pressure of the first mining face. According to the actual situation of the site, the steel strand anchor cable with diameter of 21.6 mm and length of 6500 mm is selected.

3.2.6 Determination of Anchor Cable Spacing

The deformation characteristics of surrounding rock under different numbers of anchor cables are simulated. The results are shown in table 7.

| number of anchor cables | Roof Deformation /mm | floor Deformation /mm | non-mining side Deformation /mm | mining side Deformation /mm |
|-------------------------|----------------------|-----------------------|--------------------------------|-----------------------------|
| 0                       | 130                  | 216                   | 114                            | 178                         |
| 1                       | 118                  | 214                   | 105                            | 176                         |
| 2                       | 107                  | 209                   | 94                             | 158                         |
| 3                       | 89                   | 205                   | 78                             | 142                         |
| 4                       | 83                   | 200                   | 76                             | 134                         |

The analysis shows that the number of anchor cables has a significant effect on the cumulative deformation of surrounding rock. When the anchor rope increases from 0 to 4, the cumulative deformation of roof surrounding rock decreases from 130 mm to 83 mm, the surrounding rock of both sides decreases approximately in a straight line, and the floor surrounding rock hardly changes. When the number of anchor cables is 3 and 4, the overall deformation of roadway is small. Considering the effect of controlling the deformation of roof and surrounding rock of both sides, combined with economic factors, three anchor cables are selected to support roof, and the corresponding spacing is 1400 mm.

3.2.7 Determination of Anchor Cable Row Distance

Reasonable anchor cable spacing can significantly increase the strength and deformation resistance of the anchor. The deformation relationship between anchor cable spacing and surrounding rock can be
analyzed by numerical calculation, and the result as shown in table 8.

| anchor cable row distance /mm | Roof Deformation /mm | floor Deformation /mm | non-mining side Deformation /mm | mining side Deformation /mm |
|------------------------------|----------------------|-----------------------|-------------------------------|-----------------------------|
| 900                          | 85                   | 201                   | 123                           | 132                         |
| 1800                         | 92                   | 205                   | 135                           | 141                         |
| 2700                         | 104                  | 209                   | 148                           | 154                         |

The analysis shows that the influence of anchor cable row distance on the cumulative deformation of surrounding rock of floor is not obvious, but on the coal roof and surrounding rock of both sides is relatively obvious. When the anchor cable row spacing increases from 900mm to 2700mm, the cumulative deformation of roof and two sides increases gradually. Considering the effect of surrounding rock deformation control and economic benefits, the anchor cable spacing is chosen to be 2700mm.

3.2.8 Support Material and Parameter Determination

1. Determination of supporting materials

Bolt: The roof and non-mining side of roadway used left-handed threaded steel bolt with diameter of 20mm, length of L2200mm, ultimate tensile strength of the bolt body not less than 500 MPa and elongation not less than 16%, the tail threads of bolt body must be processed by rolling process with length of 100 + 5mm. The mining side of roadway used glass fiber reinforced plastics bolt with diameter of 18mm, length of L1600mm, and the exposed length of the bolt is not more than 40mm. The spacing and row spacing between roof bolts is 850 mm x 900 mm, and between two sides is 850 mm x 900 mm.

Bolt tray: Left-screw steel bolt tray is made of 150 *150 *10 mm Q235 arch steel plate and FRP bolt tray is made of plastic tray with diameter of 125 mm.

Anchorage: Each bolt is anchored with a CK2360 resin anchorage, the designed anchorage force is not less than 50 kN.

Metal mesh: The solid coal body side used steel bars with diameter of 6.5mm (mesh hole 100 *100mm), overlap length is not less than 100mm, and tied with double 18# iron wire, Coal mining side adopts plastic mesh with size of 3.2 *100m.

W-steel strip: BHM270-2.75 W-steel strip for mining is selected. The length of the strip is 5400 mm, fixed by threaded steel bolts, and the row spacing is 900 mm.

Anchor cable: Anchor cable is machined by 21.6 *6500mm strand with a distance of 1400 *2700mm, and three in each row.

4. Conclusion

The finite difference software FLAC3D is used to establish the model based on the geological conditions of field production, and the reasonable supporting parameters such as bolt diameter, length and row spacing of 110802 belt conveying roadway are determined by numerical calculation.

(1) When the length of bolt and anchorage is unchanged, the influence of different bolt spacing and row spacing on the surface displacement of roadway is analyzed, and the suitable row spacing between bolts is determined as follows: roof bolt spacing is 850 mm *900 mm, and the spacing between two sides bolts is 850 mm *900 mm.

(2) The influence of different bolt lengths on the surface displacement of roadway is analyzed when the distance between bolts and rows is constant, thus, the diameter of the left-handed threaded steel bolt is 20mm and the length is 2200mm, the diameter of FRP bolt is 18mm and the length is 1600mm.

(3) Simulated the deformation characteristics of surrounding rock under different numbers of anchor cables and row spacing between the two, and determined according to the actual construction conditions that the anchor cables are machined with 21.6 *6500mm steel strands, with spacing of 1400 *2700mm, three in each row.
After the support improvement according to the above scheme, the driving speed is greatly improved and the normal production continuity is guaranteed.

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