Numerical Simulation on Support of Roadway with Compound Roof and Large Cross Section

YUE Zhong-wen, YANG Ren-shu, YAN Zhen-dong, WANG Guo-dong, WU Bao-yang
School of Mechanics & Civil Engineering
China University of Mining & Technology(Beijing)
Beijing, China
Zwyue75@163.com

Abstract: In order to study the stability of coal roadway surrounding rock with large cross-section and compound roof, three dimensional numerical simulation of optimization of support on big section roadway with FLAC^{3D} was studied under the engineering background of Zhaozhuang Mine of Jincheng Mining Group. Stress distribution and deformation of surrounding rock, stress state of rock-bolt and anchor cable were obtained under different supporting schemes. The affection of the spacing of anchor, the length and spacing of anchor cable to the support in mining roadways were obtained and the optimization of supporting parameters were brought out, which is suitable for joint support of anchor arm and anchor cable of the compels roof on big section roadway.

Keywords: compound roof; large section roadway; support technology; parameter optimization

1. Introduction

In recent years, coal minning technology of digging overall height floor coal at one time under the condition of thick seam adopted fully has been spread across nation. Meanwhile some problems about excavation and support of the large-cross-sectional roadway were put on the agenda[1]. Two reasons lead to the roof ascend calamity. Firstly, weakness of the roof structure caused by long-span drift and roof increases the probability of roof falling in roadway. Secondly, the research on support theory in big section roadway and equipment investment is weak[2]. Under large cross-section coal roadway with anchor nets supporting, coal seam roof and floor are belong to sedimentary layers and deformation and failure of surrounding rock are produced by excavation. Mechanism of force and deformation about bolt is very complicated in roadway. Under the condition of supporting of bolt + anchor + steel joist + metal mesh. And reasonable supporting parameter will guarantee the good effect of support of surrounding rock[3-7]. In this paper, based on an example of Zhaozhuang Mine of Jincheng Mining Group, FLAC^{3D} numerical simulation combined with field test is used to study different supporting effect of bolt anchors net distance among the rows, cable length, cable location and other parameters in large section of the coal, which may serve as an important reference for the support parameters.

2. Project background

Zhaozhuang Mine of Jincheng Mining Group is a new modern production mine which designing productivity is 6Mt/a. Main mining average thickness of 3# coal seam is 4.5m, the coal bed is thick and stable. The following one is a stable layer of shale or carbonaceous mudstone partings, medium faults in the region is less developed, small faults and collapse columns are more developed. Driving along the full height roof and floor is used, and the section of roadway excavation is 5.5m×4.5m. In the underground construction process, as the special geological structure of soft coal, low strength and seam strength of

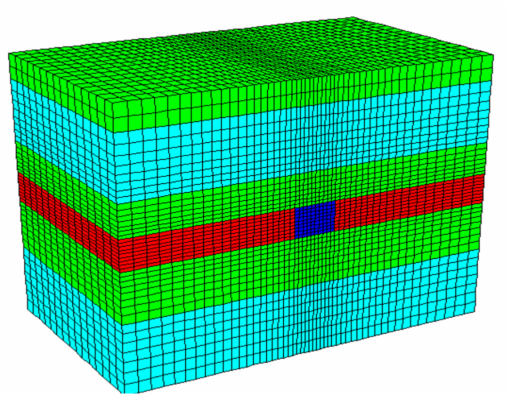

Figure 1. The numerical model

different levels, development of coal fracture, after digging the coal fracture is growth and coal expands under the side compression. Meanwhile, high stress, serious well-bedded and many micro crevasse roof are easy to make the crag surface decency to be broken, and eventually lead to roof falling, sides damaging, floor heaving and other forms.

Supported by the Special Fund from the Central Collegiate Basic Scientific Research Bursary.

3. Model establishment

FLAC^{3D} software is used to analyse the coal seam. The model size is long ×wide × high =50m×30m×40m. The roadway, which section is a rectangle and size is wide×high=5.5m×4.5m which is located in the central model. Fig.1 shows three-dimensional model of 30750 units and 34272 nodes generated by FLAC^{3D} software. In order to inspect the tunnel adjacent formation distortion and the stress situation accurately, the cell near the roadway is closer, while it is sparse away from the roadway department.

Table 1. Rock Parameters

Parameter Terrance	Description of Petro Physical Property	Poisson Ratio	Elastic Modulus (GPa)	Density kg/m3	Cohesive Strength (MPa)	Angle of Internal Friction	Tensile Strength (MPa)
Main Roof	Sandy and Argillaceous Rocks	0.23	23.5	2540	1.5	30	4.06
Main Roof	Fine-median Grained Sandstone	0.23	26.8	2650	1.6	35.5	8.60
Immediate Bottom Roof	Sandy and Argillaceous Rocks	0.24	23.5	2400	1.8	25	1.20
Coal		0.30	14.7	1500	1.2	25	2.0
Immediate	Sandy and Argillaceous Rocks	0.29	18.9	2570	1.5	30	4.62
Main Bottom	Fine-median Grained Sandstone	0.21	25.9	2650	1.6	35.5	8.60

Table 2. Calculation Parameters of Supporting Structure

Materials for Support	Elastic Modulus(GPa)	Elastic Limit(MPa)	Tensile Strength(MPa)	Length(m)	Diameter（mm）
Anchor of Roof	210	425	590	2.0	22
Anchor Cable of Roof	195	\	1730	8.4	22
Coal Side Anchor	210	425	590	2.0	22
Coal Side Anchor Cable	195	\	1730	5.3	17.8
Joist of Roof	200	265	405	5.1	16
Joist of Coal Side	200	265	405	4.5	16

After the model has been built, the boundary conditions are set and initial stress is given on the model, the model is balanced in the elastic condition and forms the initial stress field. Mohr - Coulomb elastic-plastic constitutive is given to rock formation. Then roadway excavation and support are implemented. Table 1 shows various rock layers mechanics parameter, while table 2 gives the mechanical parameters of support.

Because of the main original rock stress of horizontal stress and absolute advantage of tectonic stress, Zhaozhuang Mine belongs to the typical tectonic stress field. The direction of maximum principal stress is consistent with the roadway excavation in the model. The vertical stress is in the size of 12.5MPa and 13.5MPa, while horizontal stress is between 7.77MPa and 8.47MPa.

4. Support parameters simulation results and analysis

4.1. Inter-row spacing of anchor

In support design, under the premise of ensuring safety, reasonable bolt distance between the rows should reduce material consumption and labor quantity, improve driving speeds. However, this is always counter-balance relationship between several factors. Therefore, many programs need to be selected in the optimal solution to play a good supporting effect.

1) Simulation programs

Through orthogonal experimental method the simulation is carried out in three different parameters of row and spacing of supporting.

According to the actual site support design, row spacing changes, meanwhile, anchor row spacing has also been adjusted accordingly. The parameters of the support programs are showed in Table 3. In this nine support programs, bolt, top cable and help cable length are respectively 2400mm, 8400mm and 5300mm. The anchors lay out symmetrically along the roadway, with the side anchor cable spacing 1500mm and anchor cable spacing 2000mm.

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Table 3. Scheme of Bolt Distance And Simulation Results

Program	The row spacing of anchor (mm)	Spacing between the anchor(mm)	Anchor Cable Row spacing (mm)	Sink measurement (mm)	Bulge measurement (mm)	Roof-to-floor convergence (mm)	Left side displacement (mm)	Right side displacement (mm)	Two sides displacement (mm)
1	800	800	1600	42.27	26.79	69.06	55.14	55.18	110.32
2	800	950	1600	42.63	26.91	69.54	56.54	56.63	113.17
3	800	1050	1600	43.16	27.08	70.24	57.60	57.62	115.22
4	900	800	1800	42.66	26.93	69.59	56.59	56.38	112.97
5	900	950	1800	43.04	27.04	70.08	57.71	57.71	115.42
6	900	1050	1800	43.53	27.17	70.70	58.80	58.76	117.56
7	1000	800	2000	43.10	27.05	70.15	57.52	57.48	115.00
8	1000	950	2000	43.39	27.12	70.51	58.69	58.81	117.69
9	1000	1050	2000	43.85	27.24	71.09	59.55	59.58	119.13

2) Results analysis

From the Table 3, we can see that in nine support programs as bolt inter-row spacing changes from 800mm×800mm to 1050mm×1000mm, top floor and two sides convergence respectively increase only 2.03mm and 8.81mm. Therefore, roadway deformation is small.

The two support forms of program 5 and on-site 5102 lane are same, shown in Fig.2. From Fig.2, simulation distortion and measured rules of two groups in tunnel are consistent basically. In the first two weeks the deformation rate was greater, and then it decreased after two weeks. Roadway deformation almost ceases and entries into the stable stage after 40 days. The difference is that deformation of simulation is smaller than the measured one. The actual distortion speed has two inflexions, while the deformation rate of simulated is smooth. This is because that, in the actual project, the effect factors of blasting seismic along with penetration of crossheading and construction, while simulation of tunnel deformation is done under quasi-static. Overall, the simulation results and actual values are in agreement.

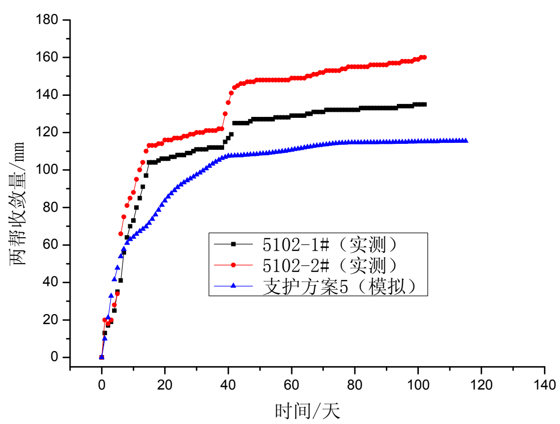
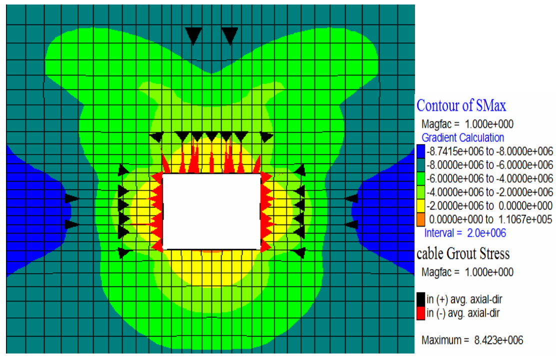
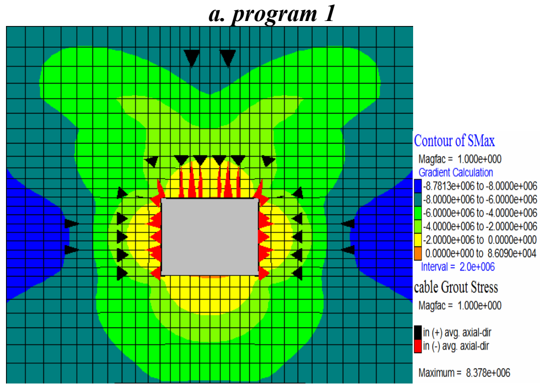


Figure 2. Convergence of two sides



a. program 1



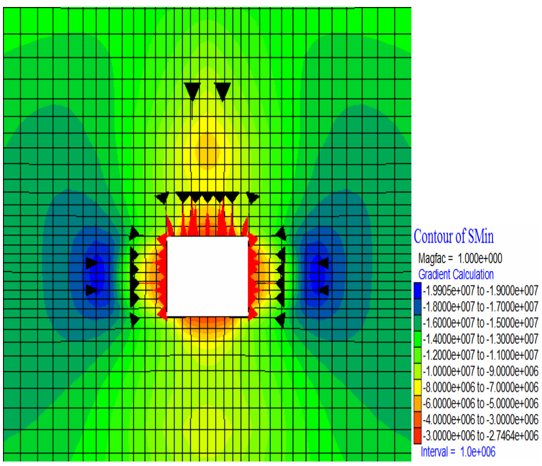
b. program 9

Figure 3. Comparison of Min-stress distribution

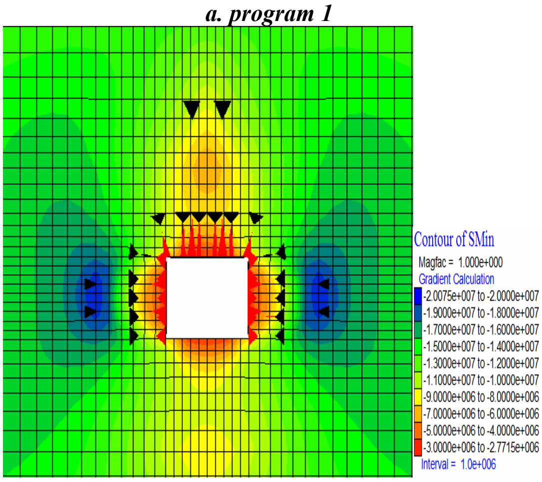
Fig.3 shows the minimum principal stress distribution of surrounding rock of program 1 and program 9, respectively. As can be seen from Fig.3, the small tensile stress exists in the shallow rock middle of bottom, besides that, the minimum principal stress is compressive stress. The maximum value of the two minimum principal stresses respectively is 8.74MPa and 8.78MPa and is equivalent to the level of the original rock stress. In anchoring areas the minimum principal stress is basically same. But the stress between the 2MPa and 4MPa in the area of the outside of roof bolting of program 1 is bigger than that of program 9. Therefore, increasing density of roof bolting is conducive to the protection of the integrity of the roof.

Fig. 4 shows the distribution of maximum principal stress of program 1 and program 9, respectively. The higher stress areas of the two programs are focused on the two sides of deep surrounding-rock, which peak value of maximum principal stress reaches 20MPa. The measured maximum strength of coal is only 20MPa, so rock will be destructed under the peak stress. The destroy range of the coal sides will easily develop to the deep without effective limit of the two sides' deformation of shallow surrounding rock. Therefore, there should be enough bolt consistency of the two sides.

Fig.5 shows the comparison of horizontal displacement distribution. Which can be inferred from the diagram, the horizontal displacement mainly occurs on the two sides and the max displacement occurs in the middle part. The two sides show curved surface after deformation. The extending range and depth of two sides of rock range in program 9 is more than that of program 1. Therefore, the restriction of the maximum displacement of high-density supporting is more significant than controlling the whole surrounding rock deformation.

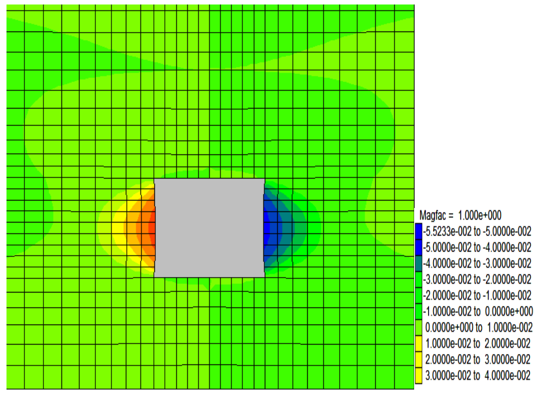


a. program 1

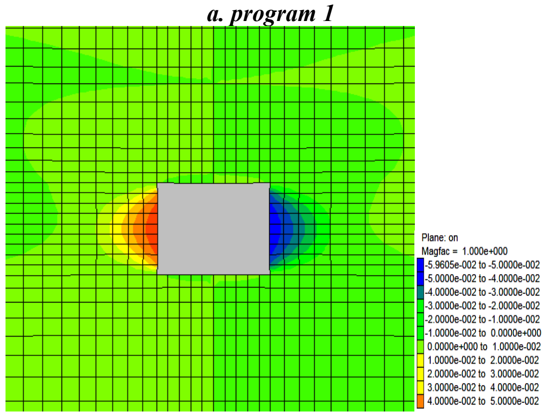


b. program 9

Figure 4. Comparison of Max-stress distribution

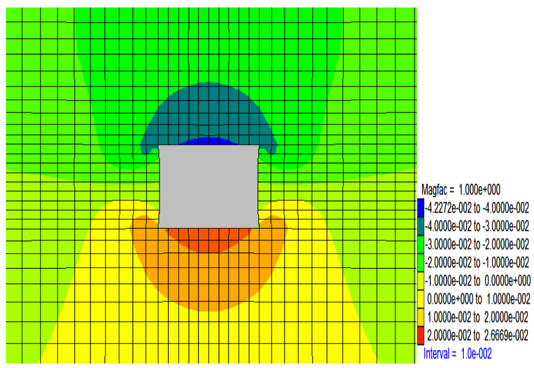


a. program 1

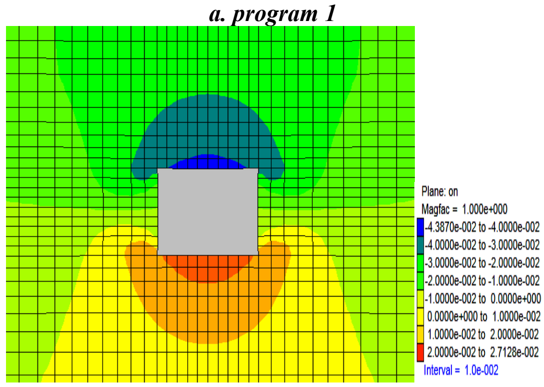


b. program 9

Figure 5. Comparison of horizontal displacement distribution



a. program 1



b. program 9

Figure 6. Comparison of vertical displacement distribution

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Fig.6 shows the comparison of vertical displacement distribution. It can be inferred from the figure 6 that the vertical displacement mainly occurs on the two sides and the maximum displacement occurs in the middle part. The two sides also show curved surfaces after deformation. The area of roof subsidence above 30mm in program 9 is larger than that in program 1, especially the range of roof subsidence above 40mm. So the deformation of low-density supporting is more than high-density supporting.

In a certain range increasing supporting density can not change stress distribution of surrounding rock and limit the maximum displacement, but can limit failure mode and damage degree of shallow surrounding rock. In the numerical simulation, the rock of model tunnel is isotropic and elastoplasticity, and the unit can not be separated. In fact, there are a lot of joints and cracks in the surrounding rock. So after the destruction of surrounding roadway surface will be stripped, which led to the development of continued damage to the deep, especially this situation will be even more intense after being affected by mining. The increase in the support density can reduce the number of surrounding rock surface damage. In practice, it can reduce the peel and fall off. The simulation results show that in a certain extent the supporting density of the bolt (cable) has little effect on maximum deformation of roadway, but obvious effect on the controlling deformation of surrounding rock. Therefore, in practical engineering, the inter-row spacing can not be designed long.

4.2. Length analysis of roof anchor cable

The roof anchor cable plays an important role in supporting reinforcement by suspending a whole anchorage body formed by bolts to deep stable rock mass. So it is very important of safety and efficiency by designing a reasonable length of roof anchor cable.

According to the analysis of distance between rows of program 9, the length of anchor cable is changed and other parameters are the same which is showed in Table 4. The simulation process monitors the convergence between roof and floor and convergence between two sides as the supporting effect standard. And the monitoring points are located in the middle of bottom-top and two sides.

Table 4. Scheme of roof bolt length and results of simulation

Plan	Length of Roof Anchor cable(mm)	Roof Convergence（mm）	Floor Heave（mm）	Roof to Floor Convergence（mm）	Left Side Displacement（mm）	Right Side Displacement（mm）	Two Sides Displacement（mm）
A	4400	43.90	27.24	71.14	59.56	59.63	119.19
B	5400	43.87	27.25	71.12	59.60	59.63	119.23
C	6400	43.91	27.24	71.15	59.59	59.61	119.20
D	7400	43.88	27.25	71.13	59.59	59.63	119.22
E	8400	43.85	27.24	71.09	59.55	59.58	119.13
F	9400	43.87	27.24	71.21	59.59	59.63	119.22

As showed from Table 4, roof to floor convergence and two sides displacement almost do not change if the length of roof anchor cable is between 4400mm and 9400mm. So increasing the length of anchor cable has little influence if there is a complete roof.

The results show that a certain length of roof anchor cable is conducive to the stability of deep roof rock and achieve the purpose of coupling support. But there is no need to design a too long length because anchorage sections should anchor in stable strata. Based on the analysis results and actual geological conditions of mining, the immediate roof is sandy mudstone with an average thickness of 4.8m and the main roof is middle-fine sandstone with an average thickness of 9.2m. Cable length designed 7.5m is reasonable.

4.3 Layout optimization of anchor cable

Based on the analysis of program 9, it is to investigate the deformation of the tunnel affected by anchor cable position which changes the cable position. Roof and each side lay out two cables for each row with a total of 6. Each row and two cables lay out in symmetrical arrangements according to the middle and height of tunnel. Simulation is carried out for five supporting programs in Table5 by changing the spacing of cables. Among them, program III is the same to spacing of bolts in program 9. The simulation process monitors the convergence between roof and floor and convergence between two sides as the supporting effect standard. And the monitoring points are located in the middle of bottom-top and two sides. The results are shown in table 5.

Showed by table 5, the maximum surface displacement has a reduction to some extent with the narrow space between cables. Analysis showed that it can reduce the overall displacement of surrounding rock, especially the two sides. It is not obvious of roof convergence by reducing roof anchor spacing. The approximately 2m cable spacing is reasonable from the perspective of maintaining the integrity of the roof. It is obvious of two sides displacement by reducing anchor spacing of two sides. Considering the actual construction, the length designed for 1m or so of anchor cable is reasonable.

Table 5. Scheme of bolt arrangement and simulation results

Program	Spacing of Side Anchor Cable（m）	Spacing of Roof Anchor Cable（m）	Roof Con-verGence（mm）	Floor Heave（mm）	Roof to Floor Convergence（mm）	Left Side Displace-ment（mm）	Right Side Displacement（mm）	Two Sides Displacement（mm）
I	2.5	3.5	43.95	27.24	71.19	60.48	60.55	121.03
II	2	2.5	43.88	27.25	71.13	59.98	60.11	120.09
III	1.5	2	43.85	27.24	71.09	59.55	59.58	119.13
IV	1	1.5	43.80	27.25	71.05	58.88	58.88	117.76
V	0.5	1	43.74	27.24	70.98	58.22	58.25	116.47

5. Conclusions

1) It is not obvious that changing spacing range of bolt row between 800mm × 800mm and 1050mm × 1000mm for maximum deformation of the tunnel. And the relatively short spacing can control the extent of the shallow rock damage. The length designed for 950mm × 900mm of anchor cable is reasonable.

2) Based on the practical geological conditions, the length optimal design of anchor cable for 7.5m is reasonable.

3) It is not obvious of reducing spacing of anchor cable for reducing roof convergence than that of controlling deformation of two sides. The length designed for 2m of spacing of roof anchor cables and 1m of spacing of sides anchor cables is reasonable.

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