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Research and practice of rapid excavation technology for the large section and compound roof coal roadway

Targeting at slow tunnelling advance rate problem of the coal roadway with large section and compound roof in Zhaozhuang mine, on the basis of site investigation and statistical analysis, revealed that the engineering geological conditions, support parameters and construction technology are the main factors affecting tunnelling efficiency, and then through the numerical simulation to optimize the roadway support parameters, the theoretical calculation of a reasonable cycle step, the EJM270/4-2 header with bolting machine with higher tunnelling efficiency and tunnelling and bolt integration was selected, the improved excavation construction programme compared to the original construction programme, increased the cycle pace, shortening the cutting of coal, support and other major processes of working time. Field practice results show: not only ensured the safety of tunnelling construction and the stability of surrounding rock, but also increased the monthly footage from 210 m/month to 262 m/month, tunnelling speed increased by 24.7%, at the same time, the roadway molding was better, the labour intensity of workers was reduced, and good benefits have been achieved.

Keywords: *Large section, compound roof, cycle step, bolting machine, rapid excavation*

1. Introduction

The roadway in coal mining is responsible for coal transport, material transport, equipment transport, personnel access, mine ventilation and drainage and other tasks, with the vigorous development of China's coal resources, roadway tunnelling project is very large, according to incomplete statistics, China's key coal mines each year more than 12000km roadway, of which coal roadway and half coal seam roadway accounted for more than 80% [1]. However, the unbalanced development of the technical level of fully mechanized mining and fully mechanized excavation has led to the unbalanced mining proportion in the coal production process, seriously affecting the improvement of coal mining efficiency [2-5]. Compound roof is one of the typical structures of roadway roof, which has the characteristics of low strength, small thickness of stratification and the development of geologic weakness such as joint fissures. After the tunnel digging, the exposed roof is easy to separate from the ground and fall, which will inevitably affect the tunnelling [6-7]. In addition, with the gradual increase of large-scale mines and reconstruction and expansion of mines, in order to meet the requirements of mine ventilation and heavy equipment transportation, major changes have taken place in the specifications of roadways, large section tunnelling not only increased the amount of excavation, but also affects the stability of surrounding rock seriously affected, and then restrict the tunnel driving speed improvement [8]. Therefore, it is of great significance to improve the tunnelling speed of large section compound roof coal roadway to realize high productivity and high efficiency in mine.

For a long time, scholars at home and abroad have carried out a great deal of researches on coal road tunnelling [9-11], MA Changle [12] on the basis of influencing factors of large-section coal tunnelling in Yuwu Coal company, it improved the single-entry level of coal tunnelling by changing temporary support and optimizing excavation construction technology. ZHU Xianlei [13] and other parameters through the optimization of roadway support, reducing support time to achieve rapid excavation. Song Zuowen [14] raised the level of equipment to achieve the purpose of rapid driving. Fan Mingjian [15] put forward a reasonable unsupported roof distance, speeding up the tunnelling speed. After all, coal tunnelling is a comprehensive construction technology affected by many factors, there is still much room for exploration in speeding up coal tunnelling. In this paper, according to the existing conditions of the coal roof with large section and compound roof in Zhaozhuang mine and the influencing factors of excavation speed, the tunnelling

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equipment, circulation step, support parameters and so on are optimized and determined, and achieved good results.

2. Project overview

The main seam of Zhaozhuang mine is 3# coal seam, coal seam thickness of 4.6 m ~ 5.0 m, the average thickness of 4.8m, the average coal seam angle is 6 degrees, the roof of coal seam is dominated by mudstone, fine sandstone and sandy mudstone, thickness of stratification is small and joints and fissures develop, it belongs to the typical composite roof structure. The #53152 roadway is conveyance road of the 5315# fully-mechanized face, roadway design length of 1806m, the roadway using rectangular section and along the roof of 3# coal seam for tunnelling, the roadway tunnelling width and driving height are 5m and 4.5m, the sectional area of 22.5 m^2. The roadway is joint supported with anchor mesh and beam-rope.

Heading face of Zhaozhuang mine used fully mechanized excavation, the EMZ20 boom-type roadheader to complete breaking coal and coal charging, supporting the use of EZQ-300 transfer machine and DTL-1m belt conveyor for coal transportation, the CMM2-18 hydraulic drill carriage to complete the anchor (bolt) drilling and bolt-grouting work. The tunnelling process mainly includes the main processes of reaming coal, advancing and retreating into the machine, knocking to help ask the top, temporary support, permanent support, cleaning up the floating coal, extending the belt and coupling fan drum, adopt “dig two anchor two”, the cycle step during excavation is 2.4 m. Through on-site investigation and statistics, each tunnelling operation cycle, cutting coal accounted for about 18%, supporting time accounted for about 60%, other influences time including advancing and retreating into the machine, knocking to help ask the top, cleaning up the floating coal accounting for 22%, the maximum footage in a month is 226 m, the average footage length per month is 210 m. In order to ensure the normal tunnelling of the heading face, the number of heading faces will increase, the manpower and material resources will be greatly increased, which will make it more difficult to affect safety in production and management.

3. Analysis of influencing factors of driving speed

In heading face, tunnelling, support, transport and other major processes are mutually configured which will directly affect the speed of driving, and tunnelling, support, transportation and other processes are subject to the combined effects of many factors, determine the specific factors and take corresponding measures to improve the efficiency of driving the key. By excavation process and its time-consuming comprehensive analysis in the Zhaozhuang mine heading face, Zhaozhuang mine slow tunnelling mainly affected by the following factors:

3.1 Engineering geological conditions

Although the tunnelling in the loose and fractured coal is good for breaking coal; it is more difficult to support and extend the supporting time. At the same time, the compound roof roadway excavation, due to the difference of lithology and the physical and mechanical properties of each rock mass, the roof rock mass rapidly changes after the stress state changes, such as slippage and tension failure. It is easy to happen from the layer and fall, which not only affects the support parameters but also limits the driving face of the top distance, thus affecting the speed of driving. In addition, with the expansion of roadway excavation area, excavation volume will increase, affect the excavation, support, transportation and other processes, and ultimately will affect the tunnelling efficiency.

3.2 Support parameters

Whether the supporting parameters of roadway is reasonable or not will directly affect the supporting work time. The existing permanent way of support during the construction process, although all the anchor of roof and part of the bolt of roadside to achieve parallel operation, but the roof of the whole anchor (5 anchor cables) construction still takes a lot of time, irrational support parameter is an important factor affecting the speed of Zhaozhuang mine.

3.3 Construction technology

The fully mechanized excavation of coal roadway in Zhao Zhuang mine using boom-type roadheader with hydraulic drill carriage to complete the roadway tunnelling and support, although it has the advantages of flexible mobility and wide range of application, tunnelling and supporting cannot be carried out in parallel. In addition, boom-type roadheader and hydraulic drill carriage take time to perform frequent transpositions, which not only destroy floor rock strata, but also lead to long cycle work, ultimately lead to slow tunnelling.

4. Research on key technology of rapid excavation

4.1 Support parameter optimization

In order to reduce the support time under the precondition of ensuring the safety of heading face and improve the speed of tunnelling, according to the engineering geological conditions of the 53122# roadway, three different support schemes are proposed on the basis of the original support schemes, the support programme shown in Table 1.

Using FLAC3D to simulate the support effect of the above four kinds of support schemes respectively, the overall size of the model is 60 m × 60 m × 50 m (length × width × height), mechanical parameters of roof strata are shown in Table 2, support programme model is shown in Fig.1, the model's bottom and four sides are fixed with boundary conditions, the upper surface of the model is a free surface and a stress of 12 MPa is applied. Numerical simulation for the whole section of a excavation, the simulated excavation cycle footage is 2.4 m, the simulation results are shown in Table 3.

The simulation results show that, to meet the support strength and support body specifications under certain

Table 1 Support programme

Support programme	Differences in programmes
The original plan	Roof with full cable support, roadside from top to bottom in turn compiled for the 1 # (bolt), 2 # (bolt/ anchor), 3 # (bolt), 4 # (bolt / anchor), 5 # (bolt)
The first option	Roof with bolt and anchor for interval support, roadside from top to bottom in turn compiled for the 1 # (bolt), 2 # (anchor), 3 # (anchor), 4 # (anchor), 5 # (bolt)
The second option	Roof with bolt and anchor for interval support, roadside from top to bottom in turn compiled for the 1 # (bolt), 2 # (bolt/ anchor), 3 # (anchor), 4 # (bolt/ anchor), 5 # (bolt)

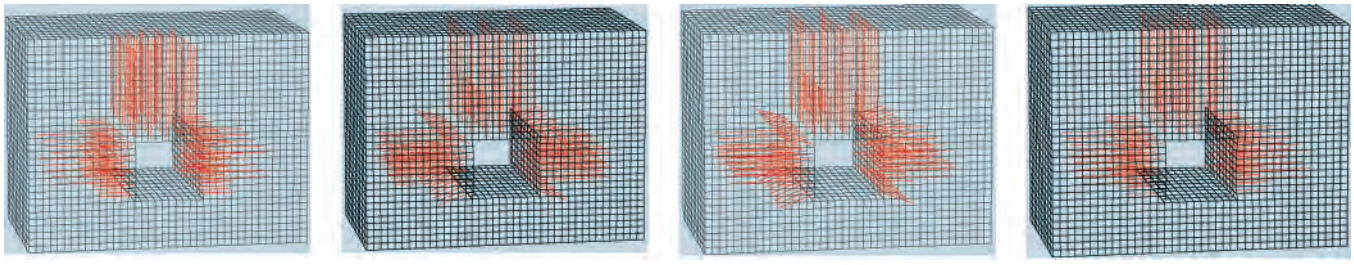
conditions, the interaction between the roadsides support and the top support is obvious in the roadway; roadway support should consider the coupling effect between the top and roadsides support parameters; the supporting principle of the anchor and the bolt is different, the control effect on the surrounding rock at different depths is quite different, and the effect on the different parts (the roof and the roadsides) in the same depth range is also different. Although the control effects of surrounding rock by different support schemes are slightly different, the number of roof anchor cables is reduced and the construction time of drilling holes will be shortened compared to the original scheme, considering the first programme to replace the original support programme, the roadway supporting section is shown in Fig.2, the specific support parameters are as follows:

(1) Support parameters of tunnel roof

The use of anchor and bolt spacing arrangement to control the roof, that is, each row of three anchors and two anchors, with row and line spacing of 1100 mm × 1500 mm. The anchor cable is made of SKP22-1/1720-6400 mm high strength and low relaxation steel strand, the tail is matched with high strength lock and 300 mm × 300 mm × 16 mm high strength adjustable heart pallet; The bolt type is the MSGLW-500/22-2400 levorotation without longitudinal steel bolt. At the same time, between the bolt and anchor with T4500 × 80/ 14-100 × 80 steel beam connection, the grid for the 70 mm x 70mm diamond netting protection the roof.

(2) Support parameters of the roadsides

The MSGLW-500/22-2400 L-longitudinal non-longitudinal steel bolt is applied to apex angle and base angle of the roadway, the 150 mm × 150 mm × 10mm arch-type high strength pallet used for bolt tail. The anchor is SKP17.8-1/ 1860-5400 model, the arch-type high strength tray matching



(a) The original plan (b) The first option (c) The second option (d) The third option

Fig.1 Models of different support schemes

Table 2 Mechanical parameters of surrounding rock

Lithology	Density/ kg°m-3	Elastic modulus/GPa	Cohesion/MPa	Uniaxial strength/MPa	Internal friction angle/°	Tensile strength/MPa
Fine sandstone	2650	69.37	20.67	104.24	34	9.83
Sandy mudstone	2540	53.26	11.84	36.59	27	5.26
Mudstone	2500	35.40	3.85	23.78	25	2.74
Coal seam	1370	14.68	1.85	6.28	19	0.43

Table 3 Support effect of different support schemes

Support programme	Maximum sinking value of the roof/mm	The proportion of the sinking of the roof in the shallow part (the anchorage range of the bolt rod)/%	The maximum amount of two roadsides approaching/mm	The proportion of the approaching of the roadside in the shallow part (the anchorage range of the bolt rod)/%
The original plan	94.3	35.4	296.0	55.5
The first option	94.1	35.2	292.4	55.2
The second option	95.2	35.6	297.5	55.7
The third option	93.7	35.3	293.3	55.4

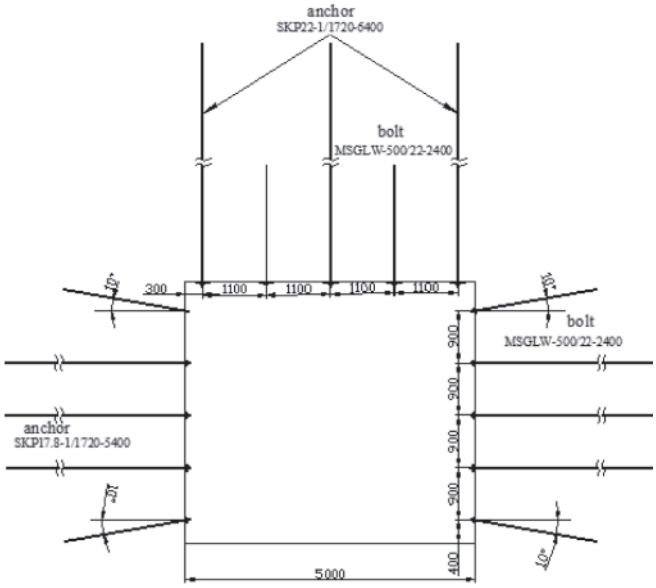


Fig.2 Support section of roadway

with the anchor is 300 mm × 300 mm × 16 mm. The tail of anchor and anchor cable is installed with 400 mm × 280 mm × 4mm of w-type steel band. The roadsides of roadway is protected by plastic net.

4.2 Determination of the cycle step

The size of the cycle step plays a decisive role in the rapid excavation of the coal roadway. In the uncovered bare alleyway, the stability of the rock formation under the roof of the roadway plays a key role in the entire roof. For the rectangular roadway with large section and composite roof, the lower part of the roof in the empty-support can be simplified as a rectangular plate with a four side fixed support, the mechanical model is shown in Fig.3.

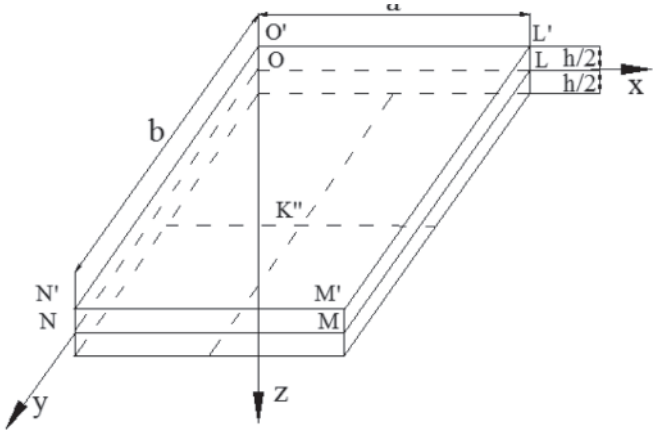


Fig.3. Mechanics model of roadway exposed roof

The failure of the roof of the roadway on the two long boundaries is related to the stability of the whole plate. According to the theory of the thin plate, under the uniform load, the stress distribution at the plate z = –h/2 is as follows:

$$\begin{cases} \sigma_x = -\dfrac{4\pi^2 AEh}{a^2(1-\mu^2)}\sin^2\dfrac{\pi y}{b} \\ \sigma_y = -\dfrac{4\pi^2 \mu AEh}{a^2(1-\mu^2)}\sin^2\dfrac{\pi y}{b} \\ \tau_{xy} = 0 \end{cases} \quad \text{... (1)}$$

where, E is the modulus of elasticity of the board; μ is the Poisson's ratio of the plate; α is the span of the roadway; b is the unsupported length of roof in heading direction; h is the thickness of the rock under the roof, and there,

$$A = \frac{qa^2}{4\pi^4 D\left[3+3(\frac{a}{b})^4+2(\frac{a}{b})^2\right]} \quad D = \frac{Eh^3}{12(1-\mu^2)} \quad \text{... (2)}$$

Among the above stresses, the tensile stress σ_x that is decisive for the fracture of the applied boundary. When y = –b/2, the maximum tensile stress σ_{xmax} in the x direction on the boundary between (0, y, –b/2) and (a, y, –b/2) can be obtained from equation (1):

$$\sigma_{x\max} = \frac{4\pi^2 AEh}{a^2(1-\mu^2)} \quad \text{... (3)}$$

If $\sigma_{xmax} < \sigma_t$, (σ_t is the tensile strength of the plate), the plate is safe and substituting for the relevant parameters, that is:

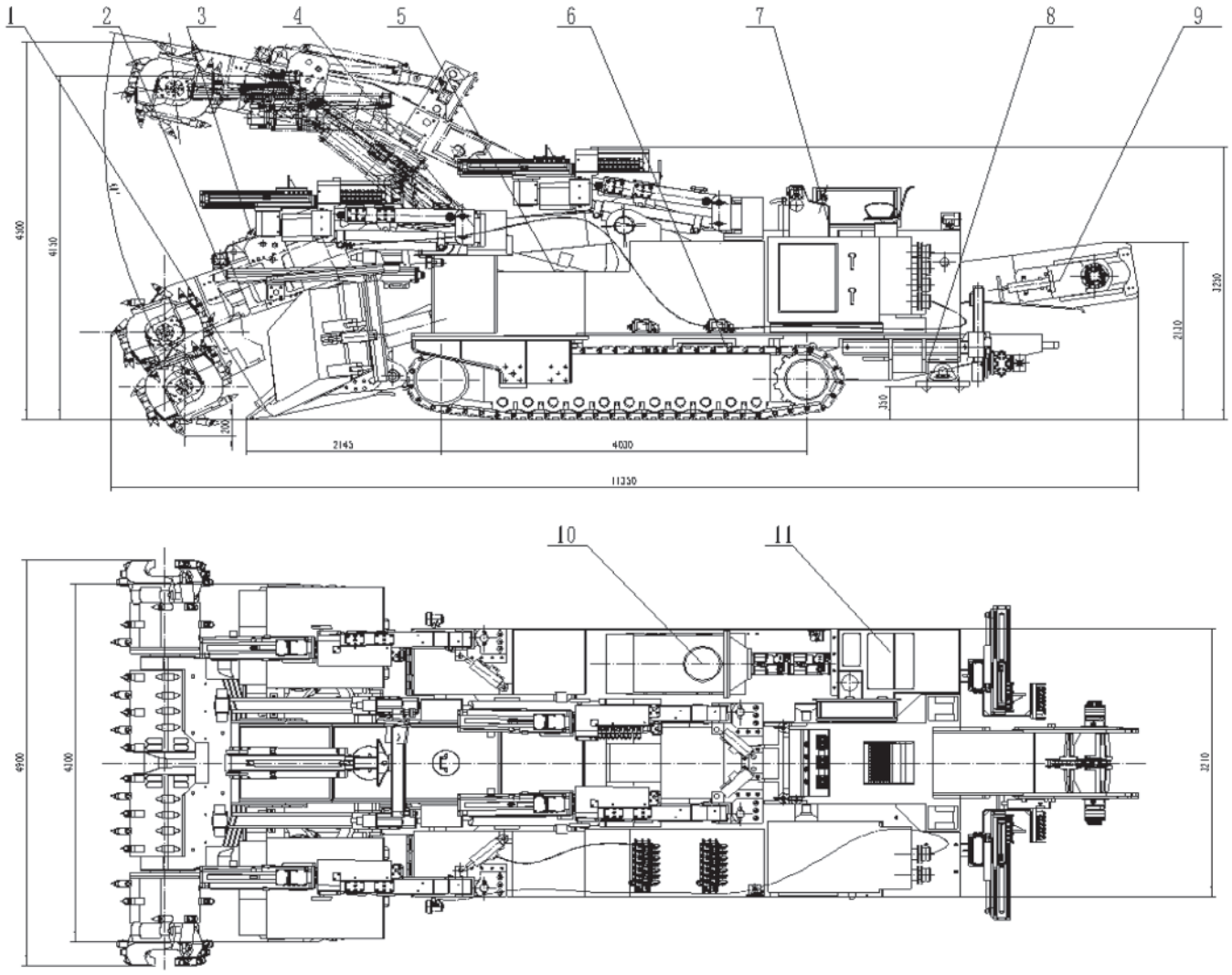
$$(12qa^2 - 3h^2\pi^2\sigma_t)b^4 - 2h^2\pi^2a^2\sigma_t b^2 - 3h^2\pi^2a^4\sigma_t < 0 \quad \text{... (4)}$$

The maximum value b that satisfies the formula (4) is the maximum cycle step of roadway excavation. the related data of the 53152# roadway in Zhaozhuang mine are brought in and b is 3.87 m, combining with the row and line spacing of roadway support and considering the safety factor of 1.3, roadway is carried out according to the cycle step of 3.0 m (2 times of row spacing).

4.3 Excavating equipment

The working efficiency of tunnelling equipment has a direct impact on the speed of tunnelling, at the same time, different tunnelling equipment determines the exposure time of roadway roof, especially for the stability of large section and compound roof coal roadway. Zhaozhuang mine existed boom-type roadheader with hydraulic drill carriage to complete the process of coal cutting and support, need to retreat operation of roadheader and frequent movement of hydraulic drill, not only takes up a lot of cyclic operation time, reduce tunnelling efficiency, and temporary support lag, increase the empty-support time, unable to effectively control the roof initial displacement, separation and two roadsides deformation, there are some security risks.

Therefore, in order to solve the above defects of the original excavating equipment, during the industrial test, the EJM270/4–2 header with bolting machine is chosen instead



1. Shovel board department; 2. Cutting department; 3. Front support; 4. Anchor drilling department; 5. Body part; 6. Travel unit; 7. Control section; 8. Rear support; 9. Conveying department; 10. Pumping station; 11. Tank department

Fig.4 The overall structure diagram of the EJM270/4-2 header with bolting machine

of the original boom-type roadheader and hydraulic drill carriage, the unit adopts the technology of the wide cutting drum of the continuous miner, and can complete the cutting operation on the face from top to bottom, at the same time, the drill arm mechanism on the unit can meet the requirements of different geological conditions, and achieve the zero empty-support operation, the existing boring mode has been changed through the cooperation of cutting and bolting support operation, six drilling arm operation at the same time can greatly improve the efficiency of excavation support, the overall structure of the EJM270/4–2 header with bolting machine is shown in Fig.4.

5. Field practice

In order to test the influence of support parameters and cycle step optimization on the driving speed, industrial test was carried out in the 53152# roadway.

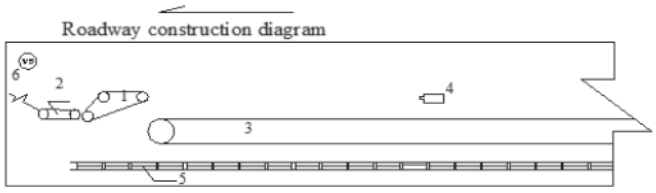
5.1 Construction technology

(1) Excavation process

The heading face is equipped with the EJM270/4-2 header with bolting machine, transfer machine, belt conveyor and so on, the construction drawings is shown in Fig.5, the header with bolting machine to complete top-down while coal cutting to achieve coal charging, excavation cycle step of 3.0 m, coal through the transfer machine into belt conveyor.

(2) Support technology

In the temporary support under the protection of permanent support, permanent support row by row construction, permanent support operations rely on drilling arm attached to the header with bolting machine to complete the specific process: determine the drilling location → drilling and hole cleaning → install anchor agent → stirring anchor agent → preload, construction quality should meet the design requirements.



1. The EZQ-300 transfer machine; 2. The EJM270/4-2 header with bolting machine; 3. Belt conveyor of 1m; 4. Laser orientation instrument; 5. Fan drum; 6. Methane sensor
Fig.5 Roadway construction diagram

5.2 Other measures

Based on the selection of new heading equipment, optimization of roadway support parameters and increase of cycle step, the tunnelling technology of the roadway has changed, through standardized tests such as theoretical exams and skill competitions, standardized operation procedures for header with bolting machine and standardization of construction technology are enhanced to promote the enhancement of workers' theoretical and operational proficiency and to improve tunnelling efficiency. At the same time, the management system of special maintenance, special maintenance and special operation is established to ensure the good running state of the excavating equipment.

5.3 Practical effect

The 53152# roadway has been constructed for 7 months. and the monthly mean construction was 25d. Since the header with bolting machine does not need to move back and forth and reduce the number of roof anchor cables, the saved time can be used to cut the coal within enlarge empty-support distance, therefore, the average daily footage from 8.4 m of the original construction programme increased to 10.5 m, the average monthly footage of the tunnel reached 262 m, and the amount of tunnelling per month increases by 52 m. At the same time, the roadway molding effect is better, the labour intensity of workers is reduced, the construction safety factor is obviously improved, and the economic benefits and safety benefits are remarkable.

6. Conclusions

(1) Support for a long time is the main reason leading to fully mechanized winning slowly in Zhaozhuang mine, and the longest time in the support process is drilling, through the cycle step and support parameters optimization to ensure the safety of the premise to reduce the number of roof anchor cables is reduced, thereby reducing the time of drilling, effectively improve the speed of driving.

(2) During the excavation cycle, the coal cutting speed has a direct influence on the tunnelling efficiency, in order to improve the drive speed, a header with bolting machine with higher tunnelling efficiency is selected, and the connection time between coal cutting and supporting process is saved, so as to shorten the excavation cycle time and improve the tunnelling efficiency.

(3) Through field practice, the footage of large section coal roadway reached 262 m/month, which was 24.7% higher than the original construction speed and achieved good economic and safety benefits.

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