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DEFORMATION MECHANISM AND SUPPORTING TECHNOLOGY OF SURROUNDING ROCK FOR LARGE CROSS SECTION OPEN-OFF CUT UNDER COMPOUND ROOF

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Abstract: Previous researches have failed to consider the features of compound roof in large cross section open-off cut in coal mines.Thus,uncertainties still exist. The supporting results are unsatisfactory which leads to frequent accident in terms of sudden fall of thick compound roof stratum. In order to realize the safe and efficient,we aim to explore the feasibility of the deformation law under compound roof through using the combination of numerical simulation,theoretical analysis and field measurement based on the geological conditions of No.90103 open-off cut in Chenjiazhuang mine. Firstly,compare the the deformation and failure characteristics of open-off cut width of which is approximately 7m, find out the regular pattern of deformation .and then study the stress redistribution and seek for the key area of surrounding rock by verify support obstruction. Secondly, propose the reasonable design through analyzing the range of elastic and plastic zone in caving the process during the whole process. Lastly, taking the measures such as high pressure yielding anchor bolts with butterfly pallet,guniting and grouting and so on to implemented the stability of surrounding rock, strengthening support by hydraulic prop and hydraulic support. Field application,compared with former support technology, shows that control technology of surrounding rock proposed effectively, restrain the deformation of surrounding rock and guarantee the stability.

Key words: Open-off cut, Large cross section, Compound roof, Support technology.

1. GENERAL INTRODUCTION

With increasing demand for black coal in recent years, more and more huge equipment including coal mining machine, hydraulic support and others are used in modern mines. Compared with its effective, safety, and automation, the technical difficulties accompanied by in terms of support technology, in particular, under the compound roof for large cross section is becoming a primary threat in open-off cut.

Traditionally, the compound roof means that the upper strata consists of different layers and thick coal gangue. Considering the exist of the gangue and the soft surrounding rock due to the layered strata, the accident such as sudden fallen, and others seem to be more frequent than other roof condition.

Both in China and abroad, some experts and scholars do research on the deformation mechanism about the surrounding rock in terms of the roadway and promote the use of bolts as a main support technology. Bai [1] introduced the bolting support principle to support the roadways in extremely soft seam of coal mine with compound roof by using full-column resin bonded high-strength bolts and pre-stressed anchor ware and high water coagulative material grouting to keep maintenance of two side walls. Yue [2] carryout an experimental study on stability of surrounding rock of coal roadway with compound roof and large cross section test and found that the displacement of two sides is relatively smaller and the roof subsidence is greater. Professor Mao [3], LI [4] and Gao [5] analyzed the formation and failure characteristics of roadways with compound roof and obtained the main reasons of supporting failure. He [6] selected the typical mine with compound roof, used the equipment which is sealed two ends by capsules in borehole and realized that he fractures cluster region mainly focuses near the coal wall and the fractures density distribution curves of overlying strata are high at two ends and middle of working face just like wave-shapes. Professor Wu [7] discussed the distribution of shear stress, normal stress, and tensional stress to analyze the stability discrimination standards to select appropriate support structures.

However, there is no accurate mechanism which can explain the difficult issue merged in large cross section and the support technology promoted also could not meet the geological conditions in terms of the compound roof.

The paper analyze the deformation characteristics of large cross section with compound strata by theoretical analysis, numerical simulation and field test, reveals the mechanism of compound roof in open-off cut and proposes the technique of controlling floor heave of large cross section by adjust the width of span and arrange the layout of hydraulic support as well as increasing the support strength of the sides by bolts. All the above research results are directly applied in controlling the deformation of large cross section with compound roof of No.90103 working panel in Chen-jiazhuang mine, achieving the safety and effective, significantly reducing the surrounding rock deformation, meeting the basic requirements for using.

2. GEOLOGICAL CONDITION

Table 1: Histogram in working panel 90103

Columnar	Thick-ness	Accumu-lative	Rock name
	4.40	62.25	Limestone
	1.05	66.30	Mudstone
	6.30	72.60	Siltstone
	0.65	73.25	Siltymudstone
	0.40	73.65	Coal
	0.70	74.35	Mudstone
	0.85	75.20	Fine sandstone
	0.85	76.05	Siltymudstone
	0.80	76.85	Mudstone
	0.70	77.55	Gray sandstone
	0.80	78.35	Siltymudstone
	0.50	78.85	Gray sandstone
	1.15	80.00	Nine coal
	2.55	82.55	Fine sandstone
	0.45	83.00	Mudstone
	0.35	83.35	Coal
	1.65	85.00	Mudstone

No.90103 working panel in Chenjiazhuang mine, which buried at 500-545m in depth, located at Shan-xi Province, in northwestern China is a typical experiment open-off cut with 8m wide and 3.7m in the height of center line. The average thickness of coal seam (9#) is 1.15m, with inclination of $7\div 12^0$, 10^0 on average. The histogram (Table1) illustrates that the immediate roof consists of 9 kinds of strata (the maximum is 0.85m, the minimum is 0.4m), 0.75 m thick at average, above which is the basic roof, 6.3 m siltstone .

For the original support patterns of the larg[…] section, Φ20×2200mm high-strength bolt is emplo[…] with inter row spacing of 800×800mm, both […] roof and two side. Besides, two additional […] Φ15.24×7300mm are installed at every two row[…] intervals. The original supporting sketch is show[…] Fig.1.

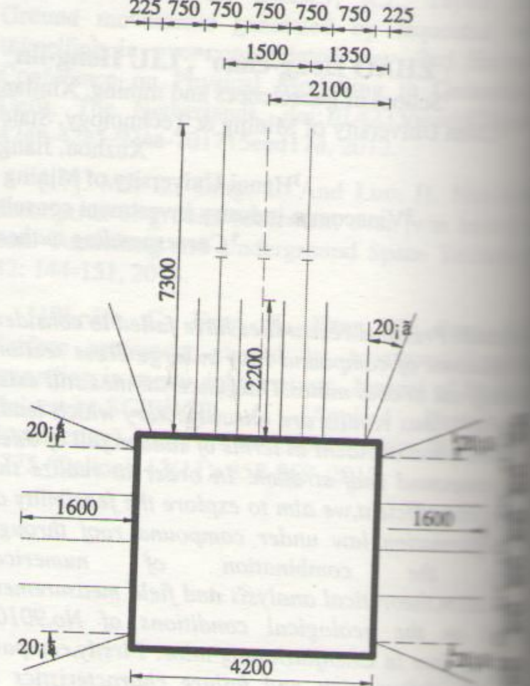


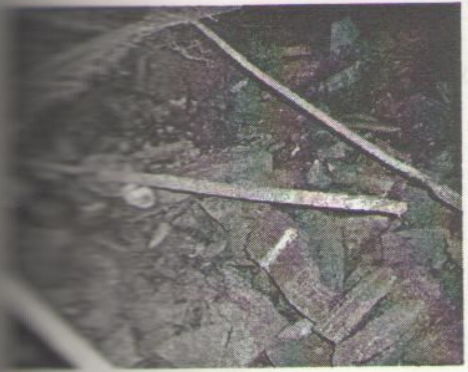
Fig. 1. Previous supporting sketch of No.9010[…] working panel

3. FALLURE MECHANISM MODES […] LARGE CROSS

3.1 Deformation characteristics of the large cro[…]

For the exist of the compound roof, in particul[…] the thickness of different strata under the basic […] the stability of surrounding rock is hard to be assur[…] it is a frequent accident to avoid the sudden failure[…] large deformation during the excavation […] working face, Fig. 2 shows the failure sketch […] with the original supporting for the first caving.

(a)



(b)

[illegible] Failure photos in field with original supporting

[illegible] find that: 1) The immediate roof can not [illegible] a short time and the strata broken to [illegible] 2) the supporting structure dose not play [illegible] role in filed, the bolts and cables are also [illegible] as well as the first using which means [illegible] supporting dose not work during the [illegible] time; 3) the deformation focus on the roof, [illegible] serious.

[illegible] the filed application used the original [illegible] we analyze the strength of the support is [illegible] cause for the failure of supporting [illegible] the high-strength bolts can also meet [illegible] requirement in theory. The mechanism of [illegible] plays a priority role in controlling the [illegible] of the surrounding rock.

[illegible] model of the large cross

[illegible] with the width of the whole working [illegible] cross can be regard as infinitely long, [illegible] focus on the roof other than the [illegible] consider the tension and shear strength [illegible] we can assume the upper strata meet the [illegible] of Natural equilibrium arch, which [illegible] by Pulo [8, 9]. In this paper, we bring [illegible] mode by Miu [9], who regards the [illegible] upper strata just do influence the stress [illegible] inside arch, and the arch does not pass [illegible]

[illegible] to analyze the mechanism of large cross [illegible] we take a unit length for study, assume [illegible] upper strata is limited for the exist of the [illegible] [11], and suppose the roof is clamped at [illegible] we use a to represent the width of large [illegible] the height of the upper strata; b_1 the [illegible] upper strata; b_2 the height of the upper [illegible] angle of the arch (Fig.3).

[illegible] the natural equilibrium arch as Fig.3 by [illegible] we can get the equilibrium arch [illegible]

$$\frac{x^2}{a_2^2}+\frac{(y+l)^2}{b_2^2}=1 \qquad (1)$$

Where λ is the of upper strata and

$$a_2^2=\lambda b_2^2\ ,\ b_1=b_2-l$$

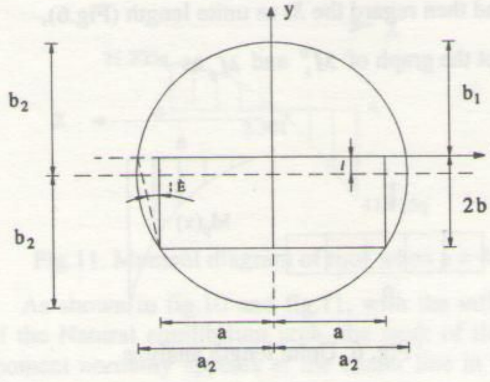


Fig. 3. Natural equilibrium arch

Which can be said: $x^2+\lambda(y+l)^2=a_2^2$

Application condition

$$y=-2b\,,x=\pm a\,,y=0\,,x=a+2b\tan\theta\,,$$
$$x=0\ \ y=b_1;\ y=-(b_2+l)$$

That also means:

$$l=\frac{\lambda b-a\tan\theta-b\tan^2\theta}{\lambda}$$

$$b_2=\sqrt{\frac{a^2+\lambda(l-2b)^2}{\lambda}}$$

Simplifying Eq.(2),we can get

$$b_2=\sqrt{\frac{(a+2b\tan\theta)^2+\lambda l^2}{\lambda}}$$

3.3 Solution for the mechanical model

(1) Symmetric constraint condition with opposite boundary

According to the mechanism model of large cross, we use the elastic theory analyze the Supporting strength of the roof (Fig.4).

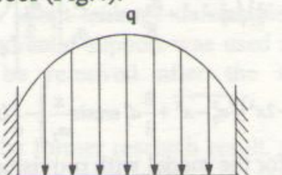


Fig. 4. Supporting strength of the roof

For the Symmetric condition, we take half of which in to consideration (Fig. 5).

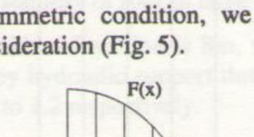


Fig. 5. Half of the Supporting strength

$$F(x)=y=\sqrt{\frac{a_2^2-x^2}{\lambda}}-l\,,x\in(0,a) \quad (2)$$

and then regard the X_1 as unite length (Fig.6), got the graph of M_1^0 and M_p as

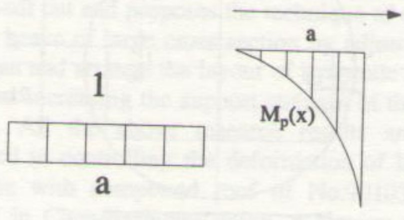


Fig. 6. Unite length analyze

where $\delta_{11}=\frac{1}{EI}(a\cdot 1)=\frac{a}{EI}$

The solutions for Eq. (2) is made of two parts:

$$\Delta_{1P}=\frac{1}{EI}\left(\int_0^a M_p(x)dx\right)\cdot(-1)=-\frac{1}{EI}\int_0^a M_p(x)dx \quad (3)$$

Taking the boundary conditions into consideration, that is

The displacement at the conner is 0. then we can get the flowing equation:

$$\delta_{11}X_1+\Delta_{1p}=0 \quad (4)$$

Substituting Eq.(4) into Eq.(3), the solution is :

$$X_1=\frac{\int_0^a M_p(x)dx}{a}$$

$$\int M_p(x)dx=$$

$$q\left\{\frac{1}{2}\sqrt{\frac{1}{\lambda}}\left[\frac{x}{8}(2x^2-a_2^2)\sqrt{a_2^2-x^2}+\frac{a_2^4}{8}\arcsin\frac{x}{a_2}\right]+\frac{a_2^2}{2}\left[\begin{array}{l}\left(\frac{x^2}{2}-\frac{a_2^2}{4}\right)\arcsin\frac{x}{a_2}\\+\frac{x}{4}\sqrt{a_2^2-x^2}\end{array}\right]\right.$$

$$\left.+\frac{1}{3}\sqrt{\frac{1}{\lambda}}\left[\frac{x}{8}(5a_2^2-2x^2)\sqrt{a_2^2-x^2}+\frac{3}{8}a_2^4\arcsin\frac{x}{a_2}\right]-\frac{1}{6}lx^3-\frac{1}{3}\sqrt{\frac{1}{\lambda}}a_2^3x\right\}$$

(2) Solution for the model with provisional support

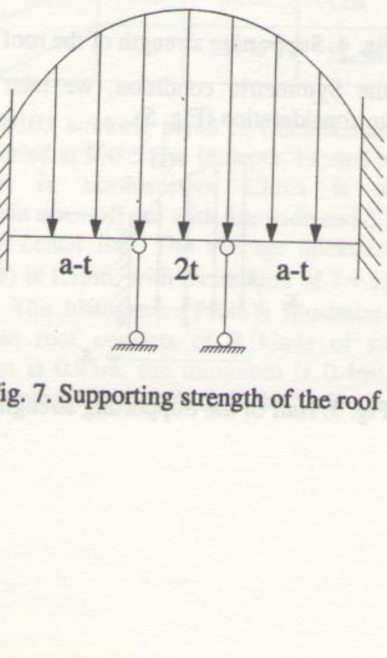


Fig. 7. Supporting strength of the roof

Considering the symmetrical distributio[n] ... and restrain condition, we select half of the ... analyze (Fig.8).

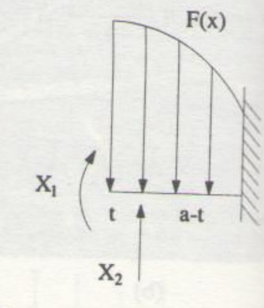


Fig. 8. Half of supporting strength of the roof ... regard the X_1 and X_2 as unite length respectively, ... can get the graph which different from the former (Fig.6)

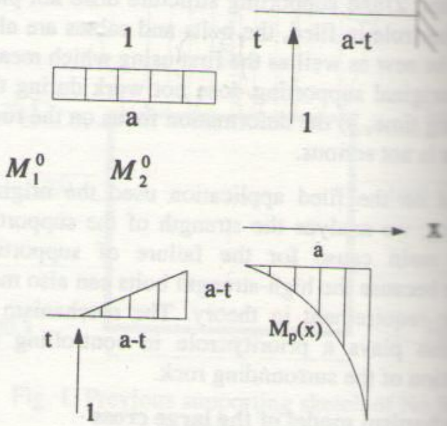


Fig. 9. Unite length analyze

We can get the equation based on the elastic ... as following:

$$\delta_{11}=\frac{a}{EI}$$

$$\delta_{12}=\delta_{21}=\frac{(a-t)^2}{2EI}$$

$$\delta_{22}=\frac{1}{EI}\cdot\frac{1}{2}(a-t)^2\cdot\frac{2}{3}(a-t)=\frac{(a-t)^3}{3EI}$$

$$\Delta_{1p}=-\frac{1}{EI}\int_0^a M_p(x)dx\,,\ \Delta_{2p}=\frac{1}{EI}\int_t^a M_2^0(x)\cdot M_p(x)dx$$

$$M_2^0(x)=x-t\,,x\in(t,a)$$

Considering the equation and the constrain[t] condition where the value at angle (X_1) is 0, and the vertical displacement is 0, and can get the equation:

$$\begin{cases}\delta_{11}X_1+\delta_{12}X_2+\Delta_{1p}=0\\ \delta_{21}X_1+\delta_{22}X_2+\Delta_{2p}=0\end{cases} \quad (7)$$

$$a\cdot X_1+\frac{(a-t)^2}{2}\cdot X_2-A=0$$

$$\frac{(a-t)^2}{2}\cdot X_1+\frac{(a-t)^3}{3}\cdot X_2-B=0$$

... :

$$B=\int_t^a (x-t)M_p(x)dx \qquad (8)$$

$$\ldots \arcsin\frac{x}{a_2}+\frac{1}{18}a_2^2\left(x^2+2a_2^2\right)\sqrt{a_2^2-x^2} \ldots -\frac{2}{15}\sqrt{\frac{1}{\lambda}}a_2^2\left(a_2^2-x^2\right)^{\frac{3}{2}}-\frac{1}{8}lx^4-\frac{1}{6}\sqrt{\frac{1}{\lambda}}a_2^3x^2\Big] \qquad (9)$$

Then put Eq.(9), and Eq.(8) into Eq.(3), the results shown:

$$X_1=\frac{\ldots-6B}{(a-t)(a+3t)}\ ;\ X_2=\frac{12aB-6(a-t)^2A}{(a-t)^3(a+3t)} \qquad (10)$$

CONTROLLING FACTORS DISCUSSION

Based on the geological conditions of Chen - ... coal mine, we analyze the appropriate span ... and caving, and then propose one of the ... support technology.

4.1 The influence of the span size for roof stability

For meeting calculation requirement, simplifying ... parameters as follows:

$$\lambda=1,b=1.8m,\varphi=24^0$$

Thus, we can get

$$\theta=\frac{\pi}{4}-\frac{\varphi}{2}=33^0$$

Regardless of the units, and suppose that the ... exist in one side, and then put the data in ... the analyze model, we can get the results as follows:

Condition 1: the width of open-off cut is 4 m, a = 2m

Put these data into Eq.(10), got $X_1 = 3.035q$

For its symmetrical distribution of loads and restrain condition, we got the moment diagram along ... half of roof center (Fig.10).

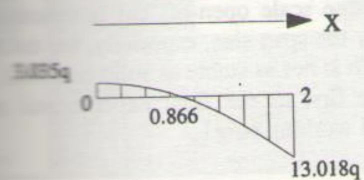


Fig.10. Moment diagram of roof when a = 2m

Condition 2: the width of open-off cut is 8 m, a = 4m

Put these data into Eq.(10), got X1 = 21.205q.

Consider its symmetrical distribution of loads and restrain condition, the moment diagram along with half of roof center as Fig.11shows.

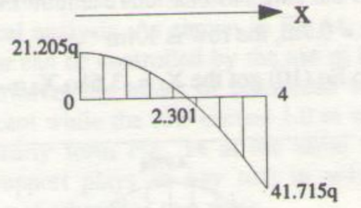


Fig.11. Moment diagram of roof when a = 4m

As shown in fig.10 and fig.11, with the influence of the Natural equilibrium arch, the peak of the flex moment normally appears at the center line in which the distribution of the stress is likely to be contraction in upper and stretch under the bottom and the boundary of the roof. In fact, the maximum stress arise at the boundary of the roof, and the rule of the stress distribution is adverse compared with which emerge at center line. Besides, the increase of stress is not as well as the width of open-off cut, the maximum stress when the width is 8m nearly added seventh as well as it while the width is 4m relatively. Thus, it is obvious that the key site for large scale open-off cut supporting focus on the center line and the boundary and also, reasonable support parameters paly an irreplaceable role as well as the support strength for large scale open-off cut.

4.2 The influence of the reinforced support for roof stability

With the increase of section size, the flex moment increase sharply as well as the stress in main roof, accompany by the striking subside of upper strata. The tiny structure existing in the different thin strata upgrowth form small deformation to sudden fallen down for shear stress added.

In order to adopt to large deformation and stress adjustment, hydraulic support was used as reinforced support can be removed after the open-off cut arrangement.

Based on the former research result, the hydraulic support can provide appropriate concentrate load for upper strata and adjust the stress distribution, decrease the subside, weaken the movement of different strata and control the stability of roof in large scale section.

While the width of section is 8m, we analyze the effect provide by hydraulic support through adjust the row from 0.6m to 1.2 respectively.

(1) t= 0.3m,the row is 0.6m

Put t into Eq.(10) got the $X_1 = -6.4q, X_2 = -16.13q$.

(2) t = 0.4m, the row is 0.8m

Put t into Eq.(10) got the $X_1 = -5.29q, X_2 = -16.36q$.

(3) t = 0.5m, the row is 1.0m

Put t into Eq.(10) got the $X_1 = -4.27q, X_2 = -16.64q$.

(4) t = 0.6m, the row is 1.2m

Put t into Eq.(10) got the $X_1 = -3.32q, X_2 = -16.67q$.

(5) t = 0.7m, the row is 1.4m

Put t into Eq.(10) got the $X_1 = -3.68q, X_2 = -17.32q$.

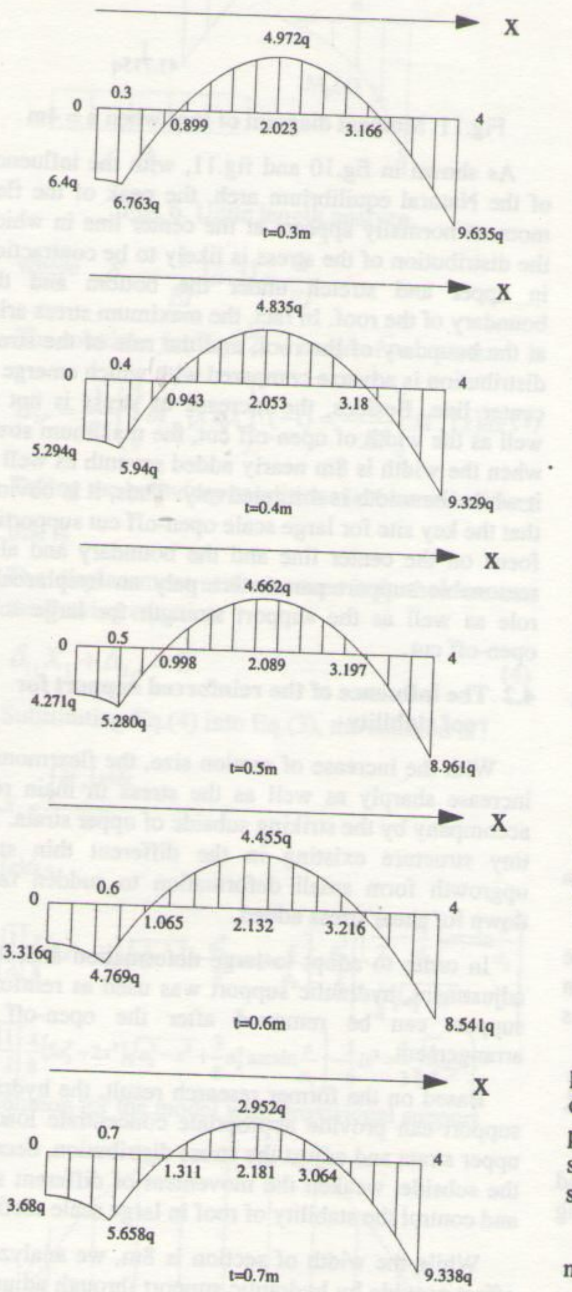


Fig.12. Moment diagram of roof when a = 4.0m,

t = 0.3,0.4,0.5,0.6,0.7m

As shown in fig.12 and the solution of the calculation, the maximum flex moment appear at two sides of the open-off cut and the main flex moment focus on the center line, boundary and the 1/4 width of working panel.

Compared with the former support, hydrau[illegible] support reduce actual span which can adjust [illegible] distribution of stress for compound roof and provi[illegible] initiative compress support to prevent the emerg[illegible] sudden fallen of compound roof. Of course, the effe[illegible] played by each row of hydraulic support is large[illegible] different, and the appropriate row is between 1.1m [illegible] 1.2m.

4.3 Numerical analyze and discussion

The influencing rules of reinforcing compou[illegible] roof in large scale open-off cut are analyzed throug[illegible] numerical simulation software FLAC^{3D} which [illegible] suitable for analyzing large deformation problems.

The conditions for simulating model are base[illegible] on actual geological conditions of No.90103 working panel in Chenjiazhuang mine. The model is divided into 16 layers and the dimension of model is 60m[illegible] x60m (width x length x height). Based on the buried depth, the vertical stress applied on the upper boundary of the model is 6.25MPa, lateral pressure coefficient 1.2 and strata inclination 10^0. For bottom boundary, vertical displacement is fixed while left and right boundaries are set in horizontal direction. The model adopts Mohr-Coulomb criterion, and roof and floor physical parameters of mining face are based on the lab experiment in China University of Mining and Technology. In order to explore the scientific layout and appropriate support technology, the caving procedure and support structure are analyzed by numerical model.

4.3.1 The selection of caving procedure

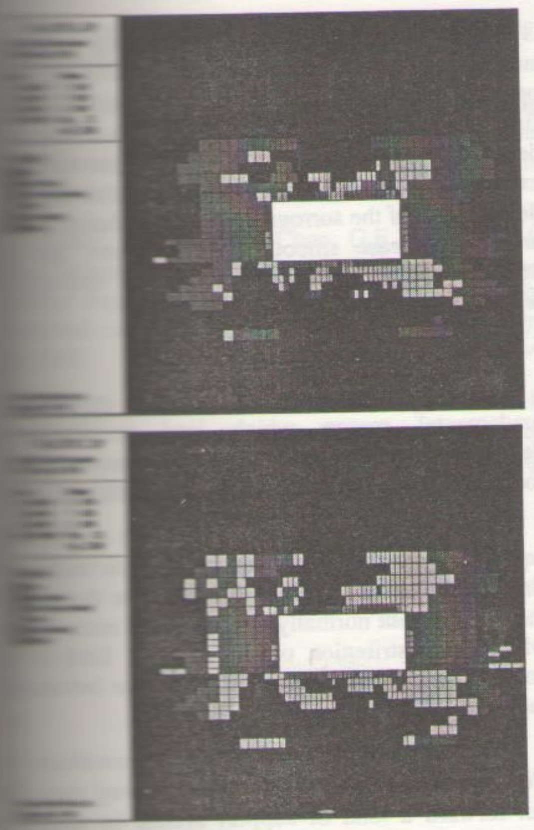
Traditionally, the open-off cut produced once time, however, with the span increase, the procedure should be adjusted for the lager scale and the compound roof condition. Thus, we analyze the proper caving subsequence.

Scheme1: caving 4 m and then 4 m expansion.

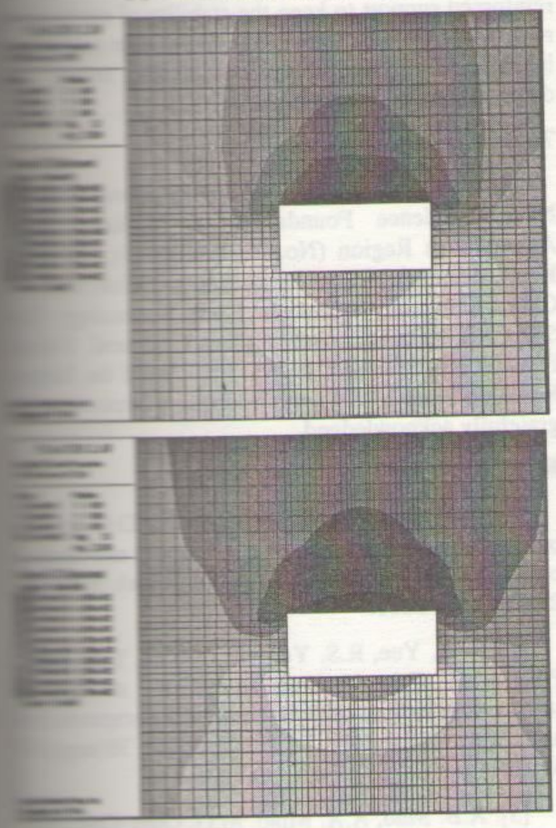
Scheme2: caving 5 m and then 3 m expansion.

Fig.13. represents relationship between caving procedure and plastic zone distribution as well as the displacement. As can be seen from Fig. 13, caving procedure significantly affects the stability of surrounding rock, it is more equitable to adopt the first scheme which can be reduce the large deformation.

According numerical analysis, the difficult for the normal large scale open-off cut is concentrate stress caused by the span size, especially, for the compound roof which is not as stable as solid coal roof. Thus, we chose the first as the final experimental scheme in No.90103 working panel .



(a) Plastic zone distribution



(b) Displacement between roof and floor

Fig.13. Numerical analyze solution about the plastic zone and displacement

4.3.2 The selection of reinforced support structure

Based on the mathematical analysis in 4.2, in this part, the relationship between the row and the displacement both the roof and two side are compared by numerical analysis. As shown in Fig.14. the large deformation can be controlled by the use of hydraulic support, however the effect of reinforced support is not significant while the row exceed 1.0 m which can be seen clearly form Fig. 14 at the same time, the initiative support plays an key role in reducing the subside of roof other than two sides.

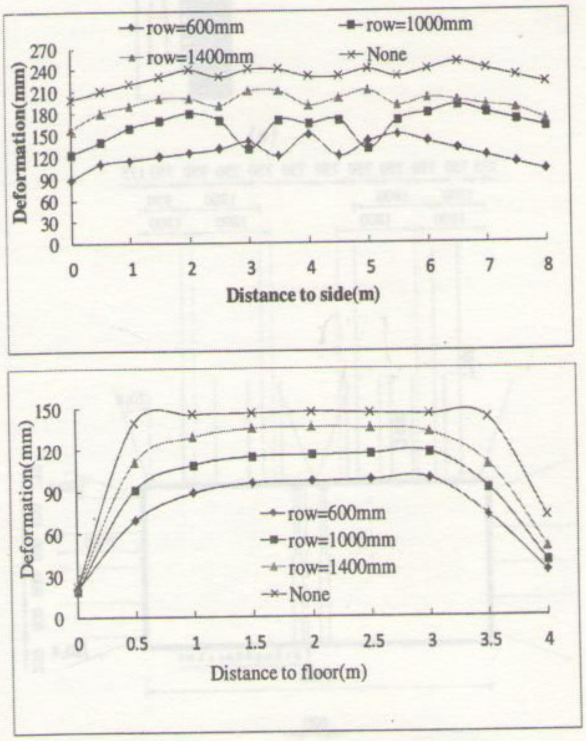


Fig.14. Relationship between the support structure and the distance

5. ENGINEERING EXAMPLES

By both mathematical and numerical simulation analysis, reinforcing roof of pen-off cut plays an important role in controlling the stability of surrounding rock. Based on the research, new support technology is put forward, including high strong screw-thread steel bolts, hydraulic support as additional reinforced and adjust the caving procedure.

As shown in Fig.15(a), When the distance from working panel to open-off cut was 3700mm, in order to prevent the fracture evaluation, the reinforced support was used as shown in Fig.15(b). Then, for another 4300mm to be expansion, the hydraulic stand machine is arrangement with the movement of the open-off cut.

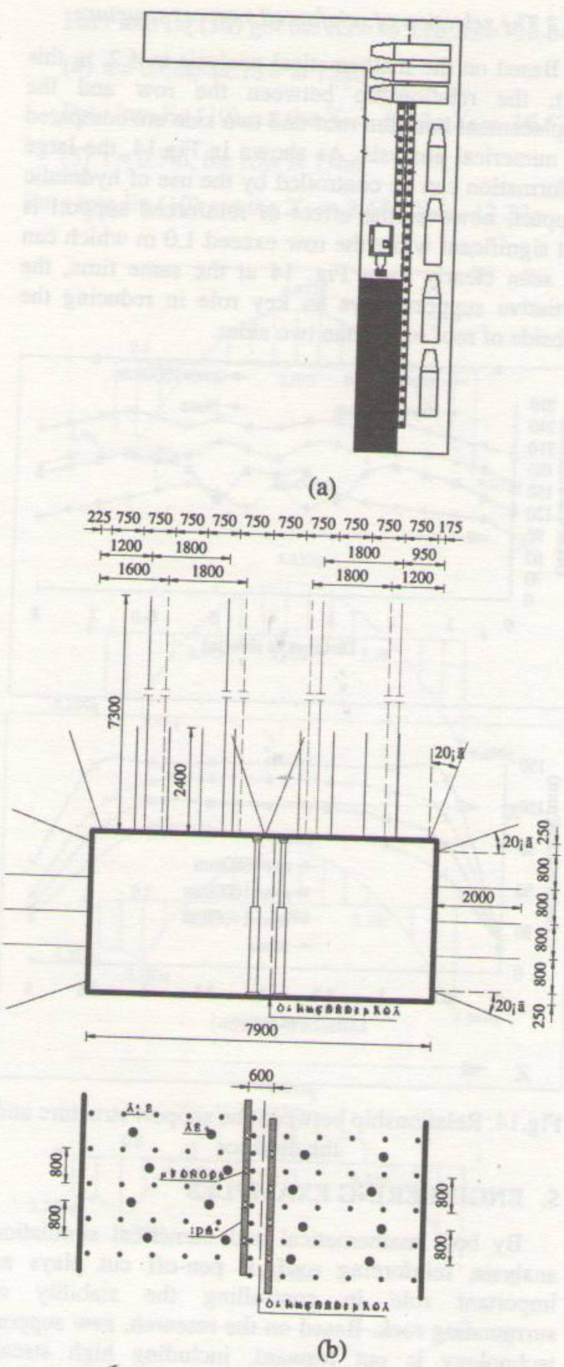


Fig.15. Sectional drawing of 90103 open-off cut

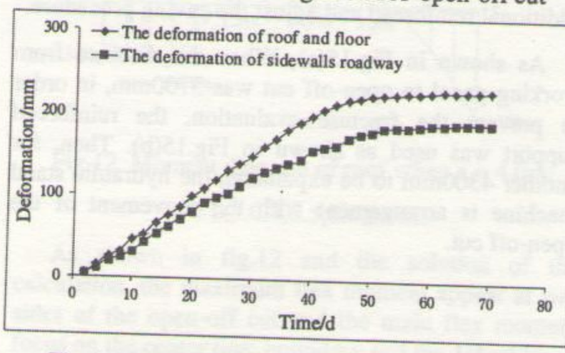


Fig.16. Relationship between the deformation and time

Fig.16 illustrates the relationship between surrounding rock deformation and the time after the open-off cut start until the whole working panel finished which means the width reach to 8000mm in design. During the period of the second span expansion, it can be seen from Fig.16 that the total deformation of the surrounding rock is relatively small and the increase smoothly which means that the design support technology and layout of open-off cut is reasonable and effective.

6. CONCLUSIONS

(1) Shear stress emerged in large cross is the fundamental reason which lead to significant deformation under complex roof condition including roof sudden fallen and failure of supporting structure.

(2) Based on the natural Equilibrium arch equation, set up the mathematical analysis model and find out the stress distribution rule is that the peak of the flex moment normally appears at the center line in which the distribution of the stress is likely to the contraction in upper and stretch under the bottom and the boundary of the roof.

(3) According to the geological conditions of No.90103 working panel in Chenjiazhuang mine, we put forward a kind of support system by using the hydraulic support and hydraulic stand machines as reinforced support to keep the stability of surrounding rock. Field practice shows that the support technology is scientific and economic which reduce the deformation and guarantee safety.

7. ACKNOWLEDGMENTS

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