

# Roof Rupture Analysis of Stope Drift in Soft Thick Seam with a Large Angle

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**Abstract:** Described stope drift's roof rupture characteristics in soft thick seam with a large angle. With knowledge of structural mechanics, mechanical analysis of the roof found that the lower side of the roof area bear the largest moment and probably to be the starting point of the roof rupture; the support force change of the lower side coal face has a significant influence on the roof stress state. Software simulation of tunnel deformation and failure characteristics using FALC3D shows that both area and extent of roof damage of the lower side is much greater than that of the higher side; both sides' support to the roof plays an important role, large deformation of either side is the main induced factor of roof rupture especially the lower side's; to expand the drift has obvious disturbance on the roof, which will lead to the recurrence of plastic roof damage. Analyses the actual roof damage induced factors according to the actual situation on-site: soft coal, serious expansion and undercover, water spray, geological structure, poor quality of construction and mining impact and put forward corresponding countermeasures.

**Keywords:** inclined thick coal seam; stope drift; roof rupture; mechanical analysis; numerical simulation

## 1. Introduction

China's energy with features of "little oil much coal", which determines the coal has important economic and strategic position in China. As China's rapid economic development, energy demand increasing, at the same time, high efficiency coal technology's continuous progress and promotion, mining intensity and mining depth increased, the coal reserves in eastern China is drying up<sup>[1-5]</sup>, and a large number of declined and steep coal seam, which is hard to mine in the western region of China, has been increasingly attract attentions, however, it determines the difficulty of mining as the geological complexity, uncertainty of this type of coal seam.

As an important part of the process in inclined coal seam, the supporting type of coal roadway also shows many problems. As a mature and advanced support methods, bolt supporting has been widely applied to horizontal and inclined coal seam roadway, but there has few successful applications in the steep roadway<sup>[6-10]</sup>. In inclined coal seam, the rock bedding gravity increased the role along the direction of bedding, so that the surrounding rock displacement, form of falling roof and the surrounding rock deformation and failure characteristics is different from horizontal and inclined coal seam<sup>[5]</sup>, and in large steep soft and thick coal mining lane, the mechanism of

roadway deformation is more complicated.

## 2. Project Overview and Roof Rupture

The minelocates in Ningwu coalfield. The thickness of main coal seam 2# is 4.0–10.0m, an average of 7.13m, and is a thick coal seam; the dip angle of coal seam is 31–48°, an average of 33°, and is a high inclined seam; and it's soft rock areas since the hardness coefficient is about 0.1. False roof is clay rocks, with thickness of 0–1.2m, and have bed separation with the upper strata and easy caving. Immediate roof is siltstone, with thickness of 5–6.0m, and with much mud or clay and easy caving,  $f=4-6.14$ . immediate floor is mostly mudstone, siltstone, coal and carbonaceous mudstone, with less rigidity, easy to expand when contact with water, the total thickness is about 7m. the rock mechanical parameters shown in Table 1.

The 1201 south extracting face, the first face after the coal mine's reconstruction and extension, with fully mechanized mining technology, transportation Lane Driving along the roof, using cable anchor+ anchor support form. Roof and two sides are used  $\Phi=22\text{mm}$ , length 2.5m of L without longitudinal reinforcement rebar bolting, between row distance of 800mm×800mm, roof with  $\Phi=15.24\text{mm}$ , length 7m of cable to strengthen support, a "streaky" arranged between the row spacing 2400mm×1600mm. Tunnel initial support in driving is better, did not produce large deformation, supporting the completion of 3 months, two groups of volume and floor

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heave amount of convergence began to increase rapidly, especially under the help particularly severe deformation and floor heave. To ensure the required roadway section, have been from the bottom and the enlarged, in some places with the most thickness of 0.8m, total depth of 1m to help expand as much help in the expansion process, and does not help to make up for the next fight bolt for

support. The Lane in the recovery process from the mining side about 140m before the rupture of roof, falling under the direction of help skewed upward direction along the roof caving rock depth of about 10m, falling rocks almost filling the entire roadway section, schematic in Figure 1 shown.

**Table 1 Mechanical parameters of rock**

attribute terrane	lithology	bulk modulus /GPa	shear modulus /GPa	angle of internal friction/°	cohesion /MPa	tensile strength /MPa	density / Kg/m <sup>3</sup>
Overlying rock	Sand rock	26.39	6.89	37	5.1	7.38	2740
Roof	Sandstone	11.51	5.62	40	6.1	4.85	2711
Immediate roof	Siltstone	6	3.47	36.2	0.57	1.39	2750
2 # coal	Soft coal	0.75	0.43	20	1.02	0.1	1850
Directly floor	Siltstone	7.69	4.84	35.3	2.6	1.32	2700
Old floor	Sandstone	61.11	7.64	40	6.4	6	2776

Figure. 2 Schematic model of the force

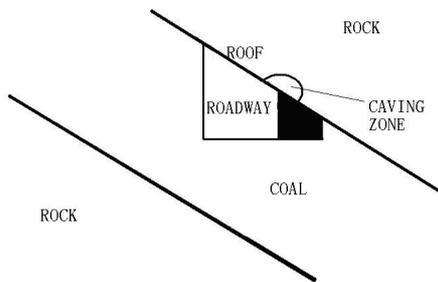
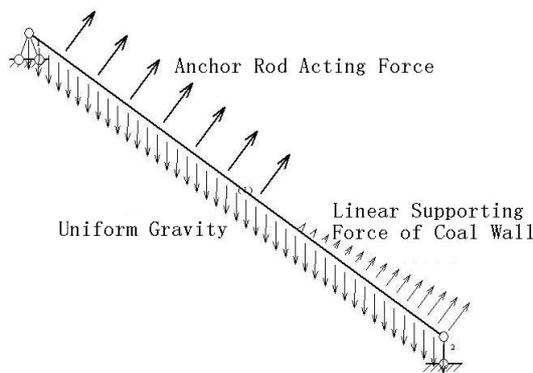


Figure1. Diagram of roof fracture

### 3. Stress Analysis

#### 3.1. Establishment of Roof Mechanical touch-type

By structural mechanics analysis, the roof is assumed to be beam, beam length of the roof can help the side under the scope of extension of 4.2m+2.5m. Within the roof of this modeling, the roof reduced to a simple beam, the two bearings were fixed hinge bearings, and chain link support. Simplifying the external force of roof bolt concentration, rock wall of uniform gravity and linear support coal power, shown in Figure 2.



#### 3.2. Roof Stress Analysis

Because the coal wall and its support has been simplified to linear supportive, so in the model, bearing 2 is not power, only to play the role of displacement constraints. Bolt and gravity concentration distribution P q for the known value of force, by force and torque balance, you can seek the coal wall, the linear distribution of power q', which can be obtained with the roof structure of the mechanical internal forces (shear and bending moment).

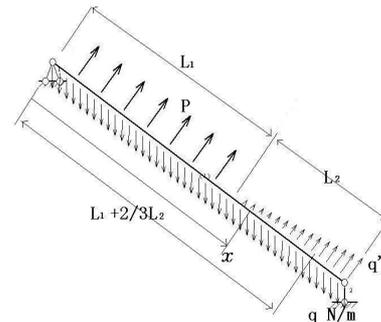


Figure. 3 Schematic diagram of the roof model for stress analysis

According to x direction, y direction by the force balance equation and the two bearings on the torque balance equation can be obtained by q' the expression:

$$q' = \frac{30PL \cos \theta (\cos \theta - \sin \theta)}{(3L - L_2)L_2} \tag{1}$$

It can be obtained at any point x Department beam shear is:

When  $0 \leq x \leq L_1$ ,

$$F_Q(x) = \frac{qL \cos \theta}{2} - \frac{7P(L + L_2)}{2L} - \frac{q'L_2^2}{6L} - qx \cos \theta + \frac{7P}{L_1}x \tag{2}$$

When  $L_1 \leq x \leq L$ ,

$$F_Q(x) = \frac{qL \cos \theta}{2} + \frac{7PL_1}{2L} - \frac{q'L_2^2}{6L} - qx \cos \theta + \frac{q'}{2L_2}(x-L_1)^2 \quad (3)$$

The beam bending moment at any point x is:

When  $0 \leq x \leq L_1$ ,

$$M(x) = 2qx(L-x) - \frac{14P}{L_1}x(L_1-x) - \frac{7L_2P}{2L}x - \frac{q'L_2^2}{6L}x \quad (4)$$

When  $L_1 \leq x \leq L$ ,

The actual situation at the scene, taking uniform gravity  $q=70560\text{N/m}$ , bolt concentration  $P=10000\text{N}$ , uniform linear power  $q'=159105\text{N}$ ,  $L_1=0.62687L$ . Draw the roof beam shear and moment diagram, as shown in Figure 4 and Figure 5.

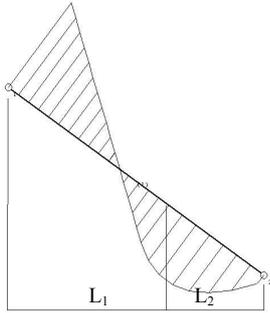


Figure 4 Shear suffered roof beams

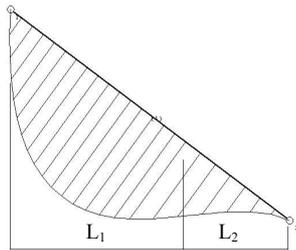


Figure 5 Suffered roof beam bending moment diagram

Suffered from the roof beam internal force diagram can be seen that the central beam, but suffered minimal shearing force is the greatest moment, the origin point of the roof damage is most likely the central beam, which is under the help of the vertex in the vicinity. As the continuously expanding and not in time to help support the right to help coal lost bolt supporting role, integrity and continue to reduce the loose, deformation, load capacity is bound to decline, that is,  $q'$  lower, according to the formula roof beams can be seen out that the size of moment  $q'$  a negative correlation between the size, with the  $q'$  of the lower roof beam suffered growing moment, when the moment to limit the damage when the roof beams, roof fracture causing a roof collapse.

## 4. Numerical Analysis

### 4.1. Numerical Model

By FLAC3D3.0 finite difference numerical simulation software to build model. Model size, the width of 53.5m,

high-56.3m, a total of 88,642 nodes, 83,720 units. Model range of 6 strata, from top to bottom order of sand rock, sandstone, siltstone, coal, siltstone, sandstone, model diagram shown in Figure 6.

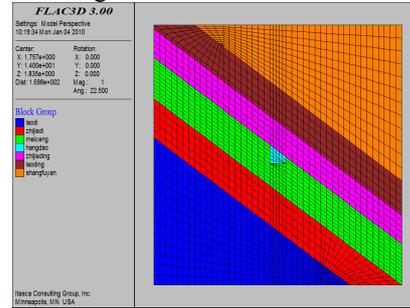
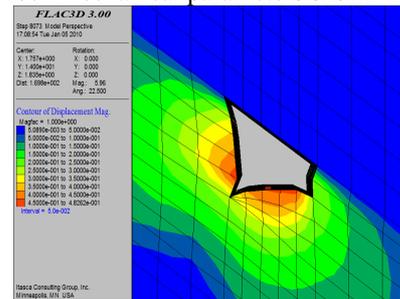


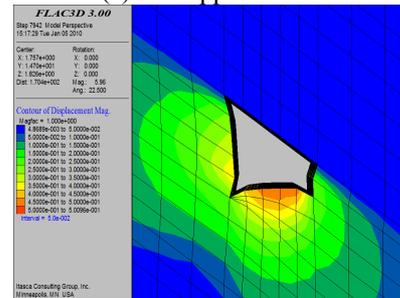
Figure 6 Calculation model

### 4.2. Numerical Analysis of Fracture Failure of Roof

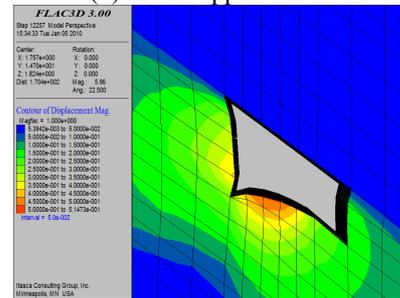
4 groups were simulated deformation after the tunnel excavation, loading conditions, namely: 1) no state support; 2) practical support site states; 3) newcomer support the end of the scene, after the state expanded to help; 4) used to strengthen bolt After the state protection. According to the site of borehole data and mechanical calculations. the rock mechanical parameters shown in Table 1.



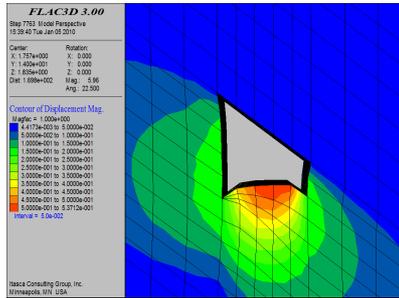
(a) No support status



(b) Field support status



(c) The status of widen the sides and excavate the ground



(d) Reinforced support status

Figure. 7 The deformation in the four status

Figure.7 shows that no support state, and sides and roof of the roadway have had a great deformation, roof deformation is relatively small, the largest roof subsidence of 53mm, maximum floor heave amounted to 461mm, to help the next left foot to be the highest level closer to the amount of 482mm, the maximum horizontal displacement of the right amount of help middle 211mm, therefore, no state can not guarantee support normal use of the roadway; site support conditions, the maximum roof subsidence of 30mm, the maximum amount of floor heave 495mm, Left level closer to the maximum amount of help 395mm, the maximum horizontal displacement of the right to help

195mm, after the tunnel for bolting, roof subsidence and the two have helped mount with much smaller, but the bottom heave increased, thus supporting the scene care to some extent limited the roadway deformation, but still can not meet the normal demand section; roadway expansion to help, from the bottom after the subsidence of the roof the largest 55mm, the maximum amount of floor heave of 514mm, the maximum level of the left to help mount with 415mm, Right to help the maximum horizontal displacement 161mm, contrast expansion to help, starting by the end of the roof subsidence increased 25mm, left to help increase closer to 20mm, increasing floor heave of 20mm, the relative state of deformation of the original support more serious; raise the bolt support intensity in the future, the largest roof subsidence of 30mm, the maximum amount of floor heave of 537mm, the maximum level of the left to help mount with 203mm, the right translation to help the largest and most recent volume of 146mm, can be seen to strengthen the support after the subsidence of the roadway roof and two sides A mount effective control, but the amount of floor heave increased. Deformation of the four state statistics shown in Table 2.

Table 2 Statistics roadway deformation

deformation roadway status	roof subsidence /mm	floor heave amount /mm	left side displacement /mm	right side displacement /mm
no support	53	461	482	211
field support	30	495	395	195
after widen the sides and excavate the ground	55	514	415	161
reinforced support	30	537	203	146

It can be seen from Table 2, on-site help by expanding, from the bottom section of the methods used to maintain roadways to ensure the temporary though normal use, but also exacerbated the amount of roof and floor and left to help closer to the displacement of roadway increased the total deformation, will inevitably lead to increased rock loose ring, such as exists in the real weak roof structure, roof most likely to rupture. And through the use of high strength bolt, improve methods of anchoring strength after strengthening support, to more effectively control the subsidence of the roof and two groups of displacement, although the amount of floor heave conditions than the existing support increased from just over end can maintain roadway.

Figure 8 is a roadway of four state distribution of the plastic zone. None, shear, tension, representing no ductile failure, shear failure and tension failure, the suffix-n,-p, respectively on behalf of the occurrence taking place in and have. Comparison of plastic zone size can be seen, on-site support to some extent, limit the development of plastic zone; expansion to help, starting after the end of

the plastic zone to help with the expansion direction, widen the range; used to enhance support, the plastic zone significantly reduced, especially at the top reduced more significantly. The distribution of parts from the plastic zone can be seen, a variety of state, the right side of the roof to help the plastic zone is much larger than the left side of the roof to help this situation to help in the expansion after the more prominent, so the roof to help in the right side more easily broken. Cell damage from the failure mode can be seen, the majority of roadway is shear failure, only in the bottom, and left to help foot part of the end of tension failures. Damage can be seen from the number of times, did not spread to help, from the bottom, the roof did not happen many times destroyed, and later expanded to help the right side of the roof to help recreate the plastic damage, destruction coincides with the scope and range of roof fall.

Numerical simulation showed that the large angle soft thick seam along the roof under the heading of the roadway side of the roof to help scope and extent of the damage are much greater than on the help side of the roof;

two groups is very important supporting role on the roof, support should be attached great importance to the two Gang support, help, especially under the two constraints help generate large deformation; roadway expansion to help on the roof of the disturbance, clearly, had to expand the case to help in time of the extended roof and coal to help the region to help to support.

Through analysis and numerical simulation of the mechanical model and with the actual situation, that this breakdown of 1201 South pit floor as the result of multiple factors. Mainly the following factors:

1) The effect of low intensity soft coal

A according to national standards to test the strength of coal2#. Point load test method with the measured strength of coal of uniaxial antigen 1.08MPa, the general hardness factor of 0.1. After tunnel excavation, rock stress redistribution, the peak stress of continuing to rock the deep development, the gradual increase in plastic zone appears to increase roadway loose circle, after bolting, to a certain extent, inhibit or slow down the loose circle development area is still in the original anchoring elastic stress state. Uniaxial compressive strength of the rock fall at 2.5MPa the following areas of soft rock, soft rock and the creep characteristics of a lot stronger than the average rock mass, therefore, the coal roadway and the bottom creep, two groups closer volume and the growing amount of floor heave, roadway continually. Since the end of the renovation and expansion to help maintain the roadway way though, it makes the plastic zone surrounding deep in the further development of the final or even beyond the scope of bolting.

2) Expanding and undercover serious

Roadway from the bottom after the bottom under the help of nearly 800mm of height in the non-support status. Coal in the two states continue to stress to the free surface expansion, helped by the lower end of the foot began to yield to the area around the development, so much so that the next to help support under the roof of coal also produces subsidence.

3) Roof Spraying

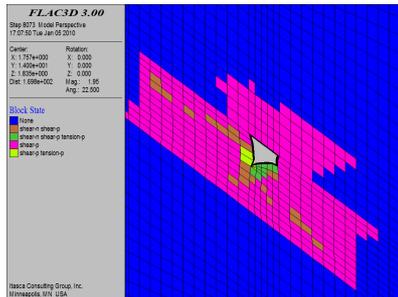
Observations from the field of view, there is watering of the roadway section. After a long period of coal roof and soaked in water, the intensity of magnitude lower, making it easier to yield coal and destruction.

4) Roof structure

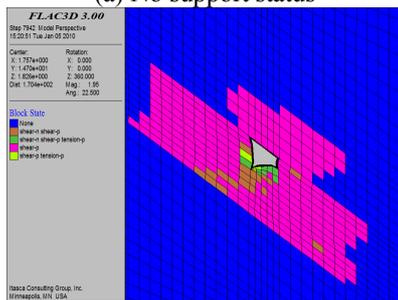
Falling observed in the field at the junction of roof and coal around the surface of 2-3m department 200mm thickness of the coal line, as opposed to the roof of the rock, this is a weak structure, after the subsidence of the roof structure easily generated from the Department layer, while the bolt anchorage zone is in the region, therefore, the role of roof bolt anchor greatly reduced. Roof separation resulting from breakage or shear failure, the roof is no longer a whole had only a supporting cable bolting from the reinforcement of the role of the supporting cable alone can not inhibit the roof separation thickness of gravity.

5) Anchor quality

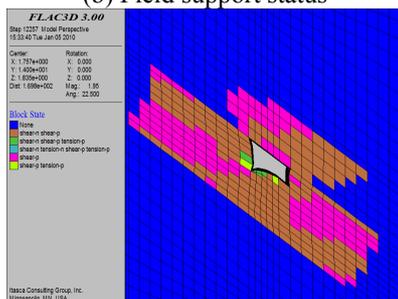
Run the floor, and paragraph description anchor was completely pulled down the anchor cable quality problems. In general, as long as the anchor of acceptable qual-



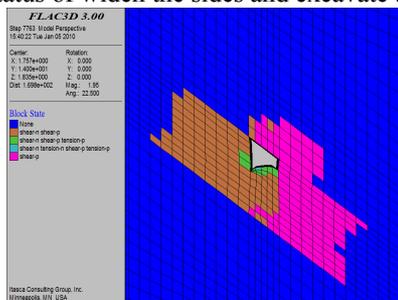
(a) No support status



(b) Field support status



(c) The status of widen the sides and excavate the ground



(d) Reinforced support status

Figure. 8 The four state distribution of the plastic zone

## 5. Roof Fracture Instability Factors and Countermeasures

### 5.1. Roof Steady Failure Analysis

ity, even if there is falling, cable is not pulled down or pulled out the general, this situation may be an anchor hole deep enough or not enough anchoring agent caused the number of anchor substandard construction quality.

#### 6) Mining impact

Mining the impact of abutment pressure range is generally 40-60m, a small number of up to 60-80m. However, the working surface of caving height greater than the impact of the bigger, may be greater than 100m. This section of roadway roof fall from the mining area 140m, mining little effect, should be a secondary factor.

Roof of the reasons for this conclusion summarized: coal soft surrounding rock caused by loose ring is relatively large; roadway expansion to help and undercover rock caused deep damage region continues to develop and expand the range of loose coal wall; roof watering and construction led to the rock strength and to reduce the separation caused by bolting failure; cable construction of poor quality; face abutment pressure recovery possible impact.

### 5.2. Roof Damage Instability Countermeasures

To prevent similar roof damage, when support and maintain the roadway, taking the following measures:

1) By replacing the existing bolt support form of grouting anchor

As for the 2# soft thick seam of coal, the existing bolting basic form can not restrict the development of loose ring. If using the bolting form of grouting, grouting after the coal is expected to increase the strength of the wall, limit the coal to the depth of plastic zone development, and reduce roadway caused by coal and rock creep phenomenon of large deformation, thereby reducing roadway renovation, to prevent caving roadway and the occurrence of rupture.

#### 2) Strengthen support

To strengthen support of the serious part, such as the above side corners and the bottom side corners. Increased support strength, such as: reduce row spacing between bolts, anchor prestress increases, with longer or full length form of anchoring.

#### 3) Strengthening measures to timely enhance roadway

Use the cable to supplement support to reduce the roof separation phenomenon. Particular geological changes in the roadway, such as during fracture zone, roof tricking other phenomena, but also should make use of tunnel reinforcement measures, that is, increased support by way of strength.

#### 4) Normalization of pressure observation

Pressure observation can be optimized for the mine roadway design, production safety, provide the basis for safe and efficient in coal mine construction is of great significance, it is essential to tunnel excavation process management normalized pressure observation.

### 6. Conclusions

1) The roof of bottom side in the roadway is under large bending moment, it is the breakdown of the origin point of the roof. The supporting quality of bottom side greatly affected the stress state of the roof.

2) The scope and extent of the bottom side roof is much greater than the above side roof.

3) Two sides play an important supporting role on the roof, pay attention to the support of the two sides, Restrict the deformation of two sides ,especially the bottom side.

4) Expanding the roadway obviously affects the disturbance of the roof. If it must expand the side , timely support to the roof and sides is very important.

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