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Steeply Inclined Working Face Floor Damage Depth Analysis and Research of Prevention and Cure

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Abstract*:* In order to grasp the steeply inclined coal face "unbalanced" the influence of the surrounding rock stress distribution on the depth of floor damage situation, Combining with the theory of elastic-plastic mechanics related to establish the face to the mechanical characteristics of floor plastic destruction force model, And according to the empirical formula obtained under different stress concentration factor of plate damage depth formula, the mine working face a steep bottom grouting of the temporary support simulation at different positions of damage depth, it is concluded that the plastic damage area of support before and after the distribution. The results show that the steeply inclined coal face in upper, middle and the lowest floor damage depth is different, it is concluded that the depth of damage were 10.7m, 9.5m and 8.2m. Through numerical simulation analysis three locations without supporting condition floor damage depth of 11.5m, 10.2m and 7.3m, the corresponding error up to 0.9 m more reasonable. In the face three positions corresponding to a depth of floor temporary support, grouting results can effectively inhibit backplane; management of steeply inclined coal face slab has a realistic significance.

Keywords Steeply Inclined Working Face, "Unbalanced" Surrounding Rock Stress, Numerical Simulation

INTRODUCTION

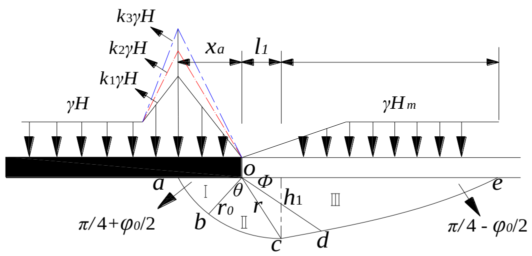
Technology industry of our country has been in the mining of deeply inclined coal is a problem, mainly restricted by the dip Angle of coal seam and the occurrence conditions. Due to the special situation of coal seam mining "unbalanced" surrounding rock stress distribution, the stress distribution is the main reason for the working face floor appeared different degree of damage.[Meng, *et. al.*, 2010] Backplane appear all sorts of irregular destroy directly affect the working face support, working face advancing, to improve the coal production and safety mining has an important influence.

In steeply inclined coal face support-rock system, many scholars carried out on the floor destruction and supporting a lot of research. Zhang young research is mainly combined with mechanics of elasticity steep seam floor are studied mechanical damage critical condition, the floor is obtained by numerical simulation the main reason of the pressure relief.[Zhang, *et. al.*, 2013] But also some scholars analyze the floor damage depth, Xu Yin-chun study of face slab destruction depth empirical formula is given. [Xun, *et. al.*, 2013] But these studies only the floor face caused by load stress damage, ignoring the steeply inclined coal face inclination direction due to the bottom "unbalanced" stress lead to the existence of different floor damage depth. In this paper, [Cao, *et. al.*, 1993], [Li, *et. al.*, 2019] through combining the theory of elasticplastic mechanics related to build toward the direction of mechanical characteristics of floor plastic failure stress model, the comprehensive study of the steeply inclined coal face slab in part, in the central and upper part of the different stress distribution, three different loading cases of base plate is deduced damage depth formula, further to accurate support of steeply inclined coal face slab, [Yang, *et. al.*, 2019] effective control of floor heave of bottom and slip.[Wang, *et. al.*, 2019]

Through the study of face slab management has a certain meaning, the technology has certain innovation.

MODEL OF PLASTIC FAILURE FORCE OF WORKING FACE TO BOTTOM PLATE

Due to steep face Angle is too large, makes the stress of surrounding rock mechanical characteristics "unbalanced". With the progress of the coal mining face, the face plate will also appear "unbalanced" deformation and failure. Led floor rock bottom drum, cracking and slide movement. [Cheng, *et. al.*, 2016] Through analyzing a large amount of data, the steep in the working face lower middle part, in the central and middle-upper part stress are obviously different, [Zhang, et. al., 2011] lead to face towards the direction of three different location of stress concentration coefficient, final floor damage depth is also different. [Zhu, *et. al.*, 2007] As shown in figure 1, Face toward the bottom plastic destruction force model.



Ⅰ—Active stress zone， Ⅱ —Transition zone， Ⅲ — Passive stress zone

Figure 1. Along the Steep Face Towards the Bottom Plastic Failure Zone Profile Model Diagram

Steeply inclined coal face stress concentration factor of k_1、k_2 and k_3. k1 for the face lower middle part, k_2 for the face middle part, k_3 for the face middle-upper part.[Xu, 2018] Because of the special factors in steep coal seam dip Angle is too large, makes the unbalance of the face slab stress and ultimately lead to stress concentration factor differences.

1)In the analysis of working face part stress coefficient for k1 situation.

In Δoab,

$$ob = r_0 = \frac{x_a}{2\cos(\pi/4 + \varphi_0/2)} \quad (1)$$

In the formula, ϕ_0—The floor rock mass weighted average Angle of internal friction(ϕ_0=37°); x_a— Coal wall yield width in front of working face.

InΔocf, $h_1 = \gamma \sin\varphi$,$\varphi = \angle cof$,

$$r = r_0 e^{\theta \tan\varphi_0} \quad (2)$$

Type (1) as the logarithmic spiral equation, $\theta$is the Angle between the γ and γ_0.

$$\phi = \frac{\pi}{2} - \theta - \left(\frac{\pi}{4} - \frac{\varphi_0}{2}\right),\ \theta = \angle boc \quad (3)$$

type (1), (2), (3) into $h_1 = \gamma \sin\varphi$,

$$h_1 = \frac{x_a}{2\cos(\pi/4 + \varphi_0/2)} e^{\theta \tan\varphi_0} \cos\left(\theta + \frac{\varphi_0}{2} - \frac{\pi}{4}\right) \quad (4)$$

$dh_1/d\theta = 0$, It is concluded that

$\tan\varphi_0 = \tan(\theta + \varphi_0/2 - \pi/4)$, Therefore

$\theta = \phi_0/2 + \pi/4$plug (4),

$$h_{1\max} = \frac{x_a \cos\varphi_0}{2\cos(\pi/4 + \varphi_0/2)} e^{(\pi/4 + \varphi_0/2)\tan\varphi_0} \quad (5)$$

Face in front of the coal wall caving width x_a derived by the limit equilibrium condition, as shown in type (6).

$$x_a = \frac{M}{2K_m \tan\varphi_m} \ln \frac{k_1\gamma H + C_m \cot\varphi_m}{K_m C_m \cot\varphi_m} \quad (6)$$

In the formula, M — Mining of coal seam thickness,(m); α—Dip Angle of coal seam,(°); ϕ_m — Internal friction Angle of coal seam,($\phi_m = 28°$);C_mCohesion of coal seam,($C_m = 1.5MPa$);γ— The average density of rock,

(γ =9.8×2600×10-3kN/m^3);

$$K_m = \frac{1+\sin\phi_m}{1-\sin\phi_m} = 2.77,$$

$$F = \frac{K_m - 1}{\sqrt{K_m}} + \left(\frac{K_m - 1}{\sqrt{K_m}}\right)^2 \tan^{-1}\sqrt{K_m}.$$

x_a plug (5) can get the maximum damage depth in the working face floor rock mass.

In the same way,

2)Working face in the middle of stress concentration factor for k_2 formula of the maximum damage depth,

$$h_{2\max} = \frac{x_{a1} \cos\varphi_0}{2\cos(\pi/4 + \varphi_0/2)} e^{(\pi/4 + \varphi_0/2)\tan\varphi_0} \quad (7)$$

3)Working face in the middle of stress concentration factor for k3 formula of the maximum damage depth,

$$h_{3\max} = \frac{x_{a2} \cos\varphi_0}{2\cos(\pi/4 + \varphi_0/2)} e^{(\pi/4 + \varphi_0/2)\tan\varphi_0} \quad (8)$$

FACE PLATE DESTRUCTION IN-DEPTH ANALYSIS

This article selects another empirical formula for the maximum damage depth working face floor rock body. As calculating section, the method to face sloping direction and combination of Saint Venant principle to static equivalent force system instead of the section, Finally combining with Mohr-Coulomb criterion face slab maximum damage depth calculation formula is deduced.

$$h = \frac{(n+1)H}{2\pi}\left(\frac{2\sqrt{k}}{k-1} - arccos\frac{k-1}{k+1}\right) - \frac{R_c}{\gamma(k-1)} \quad (9)$$

In the formula, n — the maximum stress concentration factor; H — mining depth; $k = (1+\sin\phi)/(1-\sin\phi)$,$\phi$ —internal friction Angle of rock mass; R_c — unidirectional compressive strength of rock mass;γ—rock mass density.

Table 1. Damage depth formula of parameter table

H(m)	ϕ (°)	Rc(MPa)	γ (kN/m^3)
495	28	2.9	9. 8×2600×10-3

Due to the steeply inclined coal face lower middle part, the face middle part and the face middle-upper part of the stress concentration factor is different. So, the stress concentration factor, n_1=1.6,n_2=2.0,n_3=2.4.

Three position corresponding to the slab damage depth were calculated,

$h_{lower\ middle\ part}$=10m; $h_{middle\ part}$=11.7m; $h_{middle\text{-}upper\ part}$ =13.6m

Three location corresponding to the base damage depth according to the formula (5), (7), (8) is calculated,

h_1=6.4m；h_2=7.3m；h_3=7.8m

According to the two values of working face lower middle part, the face middle part and the face middle-upper part floor damage depth, take the average value as shown in Table 2.

Table 2. Steeply inclined working face floor damage depth list

Project	lower middle part （m）	middle part （m）	middle-upper part （m）
According to the calculated formula (9)	13.6	11.7	10
According to the calculated formula (5),(7),(8)	7.8	7.3	6.4
The average （H）	10.7	9.5	8.2

THE NUMERICAL SIMULATION

The Establishment of the Model

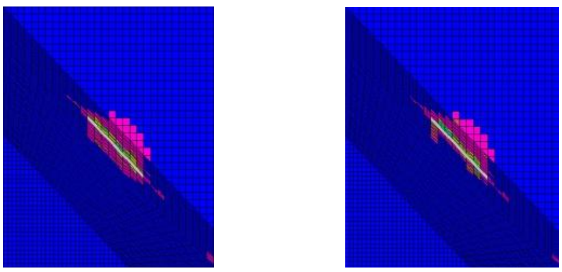
In order to study the steeply inclined coal face plastic damage, using FLAC3D simulation software to establish three-dimensional numerical model of the mine steeply inclined working face. Length of 150m tilt direction, Toward the direction of length of 960m, the total height is 520m, average depth of 495m, Basic roof applied vertical load 12.5MPa. In the model is mainly to research the base plate, the main research damage distribution of the floor rock mass produce plastic and the support before and after the simulation results are analyzed. Mechanical characteristic parameters of roof and floor of coal seam as shown in Table 3.

Table 3. Characteristic parameters of coal seam roof and floor mechanics

The lithology	Density / (kg.m^{-3})	Bulk modulus (GPa)	Modulus of rigidity (GPa)	Angle of internal friction (°)	Cohesive strength (MPa)	Tensile strength (MPa)
Medium coarse sandstone	2500	8.2	7.2	30	3.8	4.2
Fine sandstone	2400	7.8	7.1	31	3.9	4.1
Mudstone	2200	5.9	5.2	33	2.1	1.4
Coal	1470	2.2	2.0	28	1.8	0.8
Mudstone	2200	5.9	5.2	33	2.1	1.4
Siltstone	2530	8.3	7.4	35	3.1	3.4
Post stone	2500	10.6	9.0	35	4.5	3.8
Medium coarse sandstone	2510	8.3	7.4	31	3.6	3.2

The Plastic Failure Analysis of Floor without Supporting Condition

As shown in figure 3(a),Steeply sloping face floor destruction is mainly shear failure, It can be seen in the middle upper plastic damage more serious and floor damage depth is larger; Face plate in the middle of the plastic failure depth is greater than the working face in the lower middle part. Because of the working face of coal extraction, excessive steep coal seam dip Angle on the special geologic factors, makes the floor "unbalanced" mechanics of surrounding rock stress effect.



a. Support before *b. After supporting*

Figure 2. Working face floor support before and after the distribution of plastic zone

Bottom Support after Analysis of the Plastic Area

1) Bottom support mode

Accord with Mohr-Coulomb criterion floor rock mass：

$$\tau = c + \sigma_n \tan\phi \qquad (10)$$

In the formula,$c$is the cohesion of rock mass. Coal mine grouting reinforcement method, increase the cohesion of c rock to improve the overall floor rock mass strength further control bottom plastic damage.

Mine steeply inclined working face length of 150m, between the coal wall and scraper conveyor grouting and construction of drilling holes perpendicular to the floor. As shown in Table 4, according to the theoretical calculation, it is concluded that the three location floor damage depth and the depth of the numerical simulation analysis, there are some error and error up to 0.9m, this kind of error in a reasonable range.

Table 4. Steep face bottom plate damage depth error analysis table

Project	middle-upper part（m）	middle part （m）	lower middle part （m）
The average(H)	10.7	9.5	8.2
Simulation numerical	11.5	10.2	7.3
The error value	0.8	0.7	0.9

In combination with the practical situation of working face, respectively, in the face of the upper floor depth of 10.7m, 8.2m in the lower middle place face, 9.5m in the middle place face part on bottom grouting reinforcement measures.

2) After the grouting supporting plastic range analysis

As shown in figure 3 (b), working face in the designated area in the middle upper part, middle part, lower middle part in grouting reinforcement measures, after again for numerical simulation. Working face floor tilt direction significantly reduce plastic area, floor adopts after grouting support, cohesion and strength of rock mass increases, the damage of floor heave of bottom supporting method can effectively control the floor.

FIELD APPLICATION EFFECT

Mine working face length of 124m, the mine coal seam dip Angle 50 °on average. As shown in figure 3, figure 4 and figure 5, during working face bottom plate to press, according to the working face in the lower middle part, the middle part and the middle upper part floor damage depth after grouting reinforcement and significant changes in the amount of drum at the bottom. [Yunyan, *et. al.*, 2019] Because of the working face length of 150m, this paper respectively in the lower middle part, the middle part and the middle upper part in the working face is divided into 50m distance for data analysis. Because affected by mining, the middle upper face in front of the support of the maximum floor heave quantity is 410.5mm, support after the maximum floor heave quantity is 89mm, the floor heave quantity decreased by 78.32%;the middle working face in front of the support capacity of 223mm, Support after the bottoms of drum is 56mm, floor heave amount decreased by 74.89%; the lower middle working face in front of the support capacity of 130mm, Support after the bottoms of drum is 35mm, floor heave amount decreased by 73.08%.

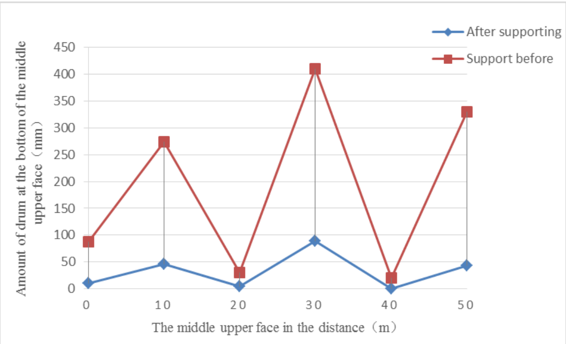


Figure 3. In the middle upper floor support before and after the displacement map

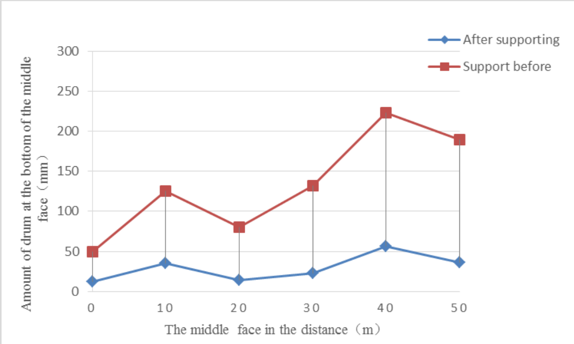


Figure 4. Before and after the central bottom support displacement diagram

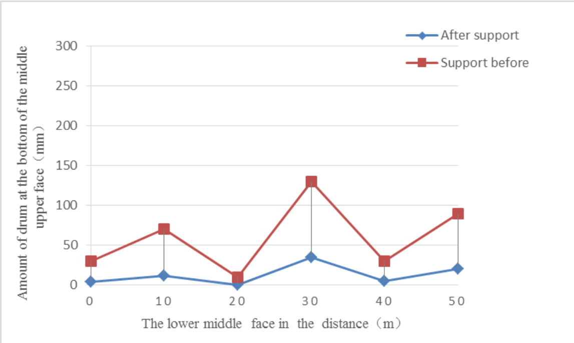


Figure 5. The lower middle floor support before and after displacement diagram

Therefore, in the face of the middle upper, middle and lower middle part according to the corresponding floor destroy depth of grouting support can effectively control the floor damage amount.

CONCLUSION

(1) Surrounding rock stress exists "unbalanced" mechanics characteristics, therefore, in the face of middle upper, middle and lower middle part in front of the stress concentration factor is different, three position corresponding to the slab damage depth is different also.

(2) According to the formula of calculation and analysis, it is concluded that corresponds to the middle upper, middle and lower middle part in the mine working face slab maximum damage depth of $h_{lower\ middle\ part}$=8.2m; $h_{middle\ part}$=9.5m; $h_{middle\text{-}upper\ part}$ =10.7m respectively.

(3) By damage to the mine working face three position corresponding to the slab depth of grouting reinforcement, can effectively control the floor damage.Amount of drum at the bottom of the control efficiency increased by 78.32%, 74.89% and 73.08%.

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