

# The Research and Application of The Hard Roofs Forced Caving Technology in Short Wall Stopes

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## Abstract

Based on the analysis of the hard roofs movement law in the a mine short wall stope, a kind of caving technology combining the deep hole blasting and the shallow hole blasting is put forward. The advantage of this technology is to set deep hole blastholes in connection drifts so that the blasting down coal gangues fill completely the goaf under blastholes and isolate the working face from the goaf. For cutting fractures on roofs, shallow hole blastholes are set in the slices intraocular of sections, which changes the mechanical structures of roofs, reduces the limit hanging distances of the original roofs and makes roofs acaving under the mining pressure. This technology realized the roofs safety caving of the short wall stope and good filling of goafs, which can provide reference for similar working face mining.

**Key Words:** short wall mining face hard roof, forced roof caving, deep hole blasting, short hole blasting

In many mining areas of West China with the presence of hard roof, mined-out areas could have tens or even hundreds of thousands square meters of overhang areas<sup>[1-2]</sup>. These cases must be handled in time otherwise the roof will suddenly caving under the actions of inducing factors in the process of working face advancing, leaking out to hurt personnel

and destroy the working face equipments<sup>[3-5]</sup>. Most experts mainly study the migration law of longwall stope roof strata model, but for the hard roof migration law and control of short wall stope research less. The paper regards a mine 3105 short wall stope roof as research object to find a suitable way of forced caving with a small explosive consumption and workload.

**1. A profile of short wall coal face**  
A mine 3105 short wall stope is in the 3 coal seam, which thickness is changeful and with an average of 3.7 meters. The immediate roof of working face is grey mudstone, which thickness is 6.1 meters, integrity strong. The working face basic roof is the light gray argillaceous powder sandstone of 3.69 meters, which bedding is level and wave, joint undevelopment, integrity strong and belongs to the key layer of rock. The roof rock mechanics parameters are shown in Table 1.

Two concentrated drifts are arranged in the middle of mining area with hole drifts perpendicular to both sides. One section is composed of four hole drifts and there are 10 meters security coal pillar between sections. The width of coal pillar between hole drifts is 11.5 meters. The connection drifts connect hole drifts and divide section into three slices. These sections, stripes and hole drifts use two wings sumping for back stoping, with 7.5 meters left-wing adit, 11 meters right-wing adit, 40 °sumping angle and 0.3 meters coal pillar between adits, which are shown in Figure 1.

Table 1 The overlying rock strata mechanics parameters of a coalmine 3105 working face

Parameters Layer	Thickness h(m)	Poisson's ratio $\nu$	Tensile strength $\sigma_t$ (MPa)	Density $\rho$ (kg/m <sup>3</sup> )
Mudstone	2.75	0.28	10	2400
Main roof (Siltstone)	3.69	0.23	12	2400
Immediate roof (Mudstone)	6.1	0.3	5	2400

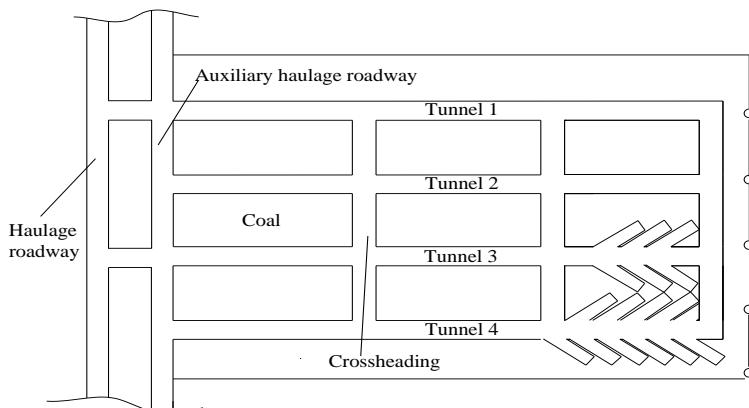


Fig.1 The mining technology process diagram of 3105 working face

## 2.The strata migration law of short wall stope roof

The abscission layer observatory is arranged in the stope in order to determine the stope overburden layers migration law. Through observation it is got that roofs have no caving after the recovery of the first piece coal pillar. However, there are abscission layers between sediment interbeds and

overburden layers, also in the 1.8 meters point of the direct roofs .From observations it can be concluded that the roof natural caving order is the bottom immediate roof of 1.8 meters, the upper immediate roof of 4.3 meters , light gray powder sandstone of 3.69 meters and mudstone siltstone interbeds of 2.75 meters, which is shown in Figure 2.

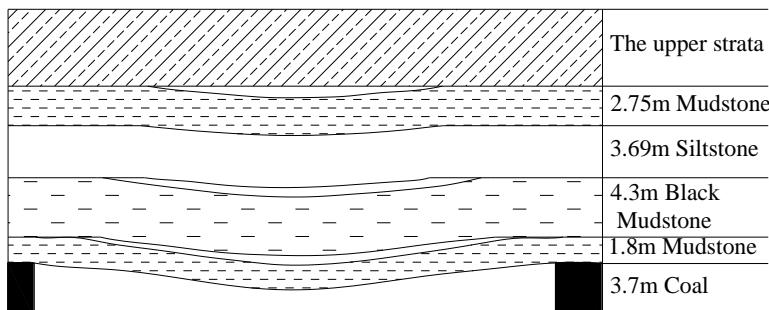


Fig.2 3105 continuous working face roof abscission layer and composition movement

As a result of the working face without caving after the recovery of the first piece

coal pillar, forced caving must be taken to ensure the safety of working face in the

recovery of the second piece coal pillar by arranging deep hole blastholes in the roofs of connection drifts.

### 3.The scheme and implementation of blasting forced caving

When the working face is taking the deep hole blasting, the immediate roofs without explosion can be calculated by using the cantilever beam model. The torque at the fixed end of cantilever beam is  $M_A=qL^2/2$ . While the maximum torque that cantilever beam fixed end can bear is  $M_0=W\sigma_t=\sigma_t \cdot h^3/12$ . Only when  $M_A>M_0$ , that is to say  $L>h\sqrt{\sigma_t/6\gamma}$ , can cantilever beam caving. By plugging in these parameters of immediate roofs in table 1,  $L$  can be obtained the minimum value of 35.9 meters, more than the length of first piece. So after deep hole blasting, the remaining immediate roofs will not caving.

Combining with the field , we decided to take kerf blasting by setting shallow hole blastholes in the intraocular of slices. The

specific implementation plan is that:

- (1) a row of deep hole blastholes are setting inside these connection drifts in order that the blasting down coal gangues can fill completely the goaf under blastholes;
- (2) at the same time, it takes to blast by arranging shallow blastholes in the intraocular of slices and to open a slot at immediate roofs above the intraocular of slices for changing the mechanical structure of immediate roofs. In this case, immediate roofs can all caving after the deep-hole blasting of roofs.

The effect of deep hole blasting is ensuring the safety of production by filling completely the goaf under blastholes with blasting down coal gangues and separating these not complete caving goafs of the working face and roofs. Figure 3 shows the expected effect of blasting.

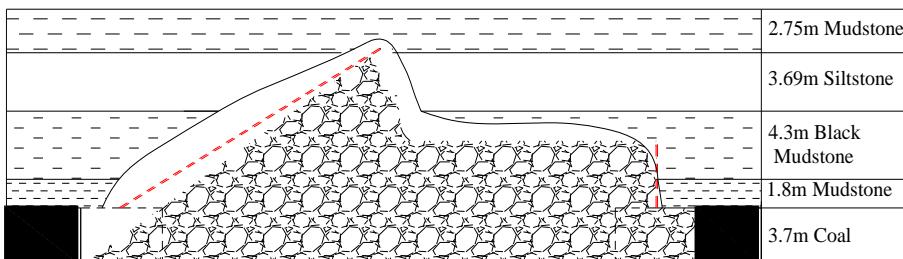


Fig.3 Blasting design effect diagram

#### 3.1 Blasting impact range calculation

Radial fracture zone of rock is the main form of rock blasting damages and its extended range has important significance in engineering blasting design. Now the formula commonly used to calculate the radius of fracture zone is<sup>[6]</sup>:

$$R_T = r_b \left( \frac{\lambda P_d}{\sigma_t} \right)^{\frac{1}{\alpha}} \quad (1)$$

where  $P_d$ — the initial shock pressure effecting on the hole wall rock by shock

$$\text{wave and } P_d = \frac{\rho_0 D^2}{8} \cdot \left( \frac{r_c}{r_b} \right)^b \cdot n$$

when not in coupling charge;

$r_b$  – the radiu of blasthole;

$r_c$  – blasting charge radius;

$\sigma_t$  – the tensile strength of rock;

$\rho_0$  – explosive loading density;

$D$  – detonation velocity and is 3500m/s;

$n$  – the pressure ratio caused by the collision of detonation gas products on hole wall and is 10;

$\lambda$  – the coefficient and  $\lambda = \frac{\nu}{1-\nu}$ ,  
where  $\nu$  is the poissons ratio of rock;  
 $a$  – the stress wave attenuation exponent  
and  $\alpha = 2 - \frac{\nu}{1-\nu}$ ;

$b$  – a constant determined by the test and is 1.34 for mudstone, 1.78 for siltstone.

### 3.2 The design of shallow hole blasting parameters

The effect of shallow hole blasting is to blast the immediate roofs into a cut seam along the intraocular of the first slice, so the hole must be perpendicular to the roof. In order to achieve the best blasting effect, we must adopt a shaped blasting [7]. It is easy for controlling blasting to put the mineral water gel explosive not coupling into PVC pipe, which both sides are thin seams.

(1)The determination of blastholes depth  
After the shallow hole blasting, the immediate roofs above the blastholes thin and blasting cracks are produced around the hole, which could change the mechanical structure of mudstone, shorten the limit caving step distances of the immediate roofs, so the depth of shallow hole blastholes does not need to reach the thickness of immediate roofs. We set the depth of the hole for  $H_p$ , the residual thickness of immediate roof for  $H_c$ , the limit overhang distance of immediate roof after cutting for  $L_x$ . The roof mechanical model is shown in figure 4.

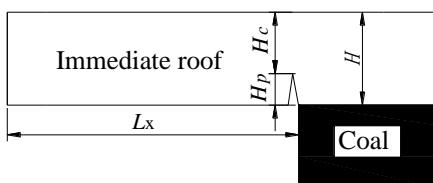


Fig4 The end groove rock beam mechanical model

Because the cantilever beam can caving, the torque at the fixed end of cantilever

beam  $M_A$  is equal or greater than the maximum torque  $M_0$  that cantilever beam fixed end can bear. Then, the bending moment of rock beam at slot is expressed

as  $M_A = \frac{\gamma H L_p^2}{2}$  and the maximum torque that rock beam fixed end can bear is expressed as

$$M_0 = W \cdot \sigma_t = \frac{b(H - H_p)^3}{12} \sigma_t$$

So we get

$$L_x = (H - H_p) \sqrt{\frac{\sigma_t(H - H_p)}{6\gamma H}} \quad (2)$$

Because the immediate roof remaining span after deep hole blasting is only 15.57 meters, we bring  $L_p$  and the parameters of the immediate roof in table 1 into formula (2) and calculate  $H_p$  to be 2.6 meters. In order to ensure the quality of blasting, the depth of the blasthole in the field is designed be 3 meters.

(2)The determination of the blasthole spacing.The radius of blasting fracture in mudstone is 3.1 meters. And the shallow hole adopts the shaped blasting, which directionality is strong. As a result that the cracks generated by the shaped blasting in the given direction of bursting is bigger than others. We take the blasthole spacing for 3 meters so as to ensure the quality of blasting.

### 3.3 The parameters design of deep hole blasting

In order to make the blasting down coal gangues fill completely the goaf under blastholes, the parameters designs of deep hole blastholes are as follows:

a) The 3105 working face average mining height  $H$  is 3.7 meters. The hulking coefficient  $k$  of roof rock is 1.3. The roof caving thickness  $H_x$  is 12.33 meters calculated by the formula  $H_x \cdot k = H + H_x$ . Because the basic roof and the overlying mud interbed caving together, the blasthole should reach the below of the

mud interbed, that is to say 9.79 meters. So the scene blasthole height is 10 meters.

b) The radius of blasthole is 90 millimeters determined by the drilling model, the bit and the bolt size of a mine. Based on previous deep hole blasting practice experiences, the mine water gel explosive volume of software package is used. The explosive loading density is  $1.3 \times 10^3 \text{ kg/m}^3$ . The cartridge diameter is 70 millimeters and its length is 200 millimeters. According to the theoretical calculation and production practice, a pair of blast holes are set above intersections between each connection drifts and hole drifts. And the hole spacing is 2000 millimeters.

The distance from the bottom of the bore to the roof is 10 meters. The elevation is  $30^\circ$ . The depth of blasthole is 20 meters.

c) Plugging blasthole and explosive parameters and the roof strata parameters in table 1 into type (1), we can calculate blasthole blasting fracture radius in the mudstone and siltstone layer, respectively

to be 3.1 meters and 0.8 meters. Because that the bottom strata of blastholes are powder sandstone layers and the blasting fracture radius is 0.8 meters, the distance between the bottom of two blastholes within the same coal pillar is designed to be 1.8 meters in order to make full use of blasting cracks. The angle is  $\vartheta = \arcsin\{[(11.5-1.6)/2+1.7]/20\}=21^\circ$ . The blasting charge coefficient is 0.7 on the scene. The blasting charge length is 14 meters. The explosive volume diameter is 50 millimeters. And single blasthole charges 35 kilograms explosives.

### 3.4 Blasting order

To make the immediate roof caving with the blasting of the deep hole, the shallow hole blasting should come before the deep hole blasting. So the shallow hole uses instantaneous detonator, the deep hole millisecond delay electric detonator. The shallow hole blasting can pull out a groove on the immediate roof. Therefore, the immediate roof can simultaneously caving with the deep hole blasting. The blasthole arrangement is shown in figure 5.

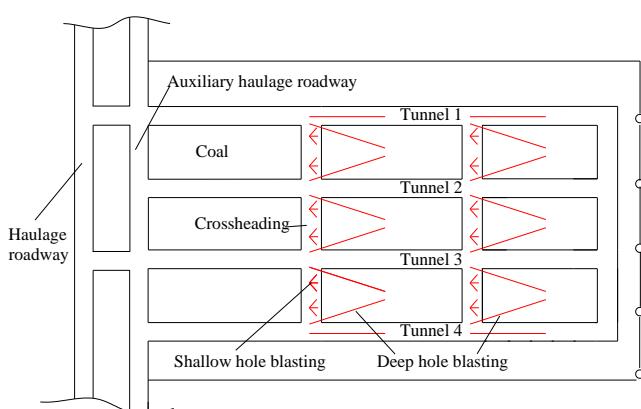


Fig.5 The blasthole layout drawing

## 4. Conclusions

(1) The immediate roofs of 3105 short wall stope belong to the compact mudstone with undeveloped joint fracture and strong integrity, which show the characteristics of the hard roofs. The

basic roofs are solid powder sandstone layers. The forced caving measures must be taken.

(2) If the working face only takes the deep hole blasting, the roofs after blasting will still threaten the face.

(3) The superiority of the blasting design is the combination of deep hole blasting and shallow hole blasting. The blasting down coal gangues fill completely the goaf under blastholes. The shallow hole blasting changes the mechanical structures of the immediate roofs to make them caving fully. It not only achieves the expected effect but also reduces the worker labor intensity and the usage of explosives.

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