STUDY ON THE DESIGN METHOD OF STRIP GROUTING FOR OLD LONGWALL MINING GOAF

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ABSTRACT

The residual movement and deformation of abandon goaf are the main factors causing the damage to building and structure over abandon goaf. Filling by grouting is the current main technology measurement to control the residual movement and deformation of abandon goaf. Based on analyzing the mechanism of the residual movement and deformation of abandon goaf, combined with the theory of mining subsidence, this paper presents the new method of strip grouting, gives the calculating formula of filling grouting borehole interval and the principle of grouting borehole setting. It provides viably and reliably technical method for economically and reasonably controlling movement and deformation of abandon goaf and ensures safety of buildings and structure on surface.

Key words: strip grouting, abandon goaf, grouting borehole design, grouting, mining subsidence.

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INTRODUCTION

According the incomplete statistic, the area of ground subsidence causing by coal mining are up to 600,000 ha in China. There are inevitably some buildings and structure to be set up above the abandon goaf with the development of national economic construction and expanding of coal-cities, However, it has to take some measures to guarantee the safety of these buildings and structure on abandon goaf. The current main problem faced with is how to dispose the abandon goaf economically and reasonably under the condition of guaranting the safety of buildings and structures .At present, grouting is the main method adopted to deal with abandon goaf. The existing problems about abandon goaf grouting design are how to grount, adopting which grouting manner, the grouting borehole design and so on. Combined with the theory of strip mining, this paper puts forward a new method of strip grouting and provides basic for the grouting borehole design.

DEFORMATION MECHANISM OF ABANDON GOAF

Underground mining contains longwall mining and shortwall mining. Generally, the former adopts full caving and the later adopts pillar support roof control. Most coal mines in China adopt longwall mining with full caving. Therefore this paper puts focus on the disposing problem of abandon goaf with longwall.

After longwall mining with full caving, the overburden strata formed three zones from the bottom to up, that is caved zone(regular and irregular), fractured zone(serious, common and slight) and continuous bending zone. Caved zone together with fractured zone are called fractured zone of water conductivity in subsidence. Figure 1 shows the character of strata damage and mechanical model of structure in abandon goaf of longwall mining [1].

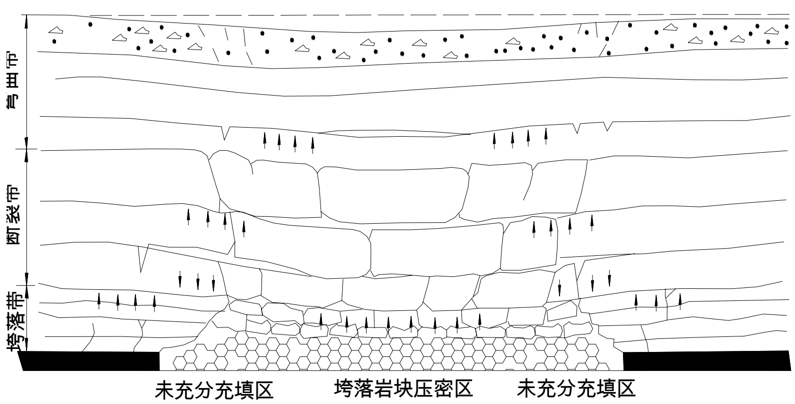

Figure 1.: The distribution of movement and deformation of overburden strata due to longwall

Figure 1. shows that three structures are formed in mining-induced overburden: (1) cracked rock mass: this part mostly locates in caved zone. Rock cracks into blocks and there are relatively large spaces among blocks. Rock mass in caved zone belongs to this kind of structure; (2) fractured rock mass: rock fractures but maintains the stratified beddings of strata. By the action of overburden stress, the rock mass forms fractured beam. with certain carrying capacity. There are strata separations. Rock mass in fractured zone belongs to this type; (3) continuous rock mass: this part of rock mass keeps the integrity of original rock mass and the characteristic of overburden is bending deformation. There are no exists of crack and fracture. Rock mass in bending zone belongs to this structure. Combined with the distribution of the overburden structure, the activation of abandon goaf with longwall mining can be divided into four types:

(1) With the action of load from overburden strata, spaces among cracked rock in caved zone go through a long period of compaction that gradually causes a slow deformation;
(2) The strength of fractured rock mass above mining zone is attenuated by long-time action of the underground water and weathering ,and it is re-compressed by the action of load from overburden strata;
(3) Because of the compaction and deformation of cracked rock mass and the weaken of the intensity of contacting points of fractured rock mass, fractured rock mass loses

stability and deforms under the action of load from overburden strata;

(4) Overburden rock mass structures lose stability and deform again due to outside forces. These forces include earthquake force, structure stress caused by area geologic structure movement, disturbing force by neighboring exploration or blasting, additional load force by surface buildings and so on.

From analysis above, it is seen that the main factors causing abandon goaf active are the compaction of spaces among cracked rock in caved zone and the close of interspaces in fractured zone. Therefore, the point to control the residual movement and deformation of abandon goaf is to control the deformation of the rock mass in caved zone and fractured zone.

THEORY OF STRIP GROUTING DESIGN

According to the test results of Xinhe and Liuxin mine, on the process of grouting filling, slurry spreads a more extent along the incline way and a smaller extent along the longwall way because of the slantwise overburden, and the fact that grouting filling along the incline way forms strip distribution resembles strip mining in coal mine. The experiment of grouting concretion shows that the grouting concretion has more intensity than common coal seam. Consequently, the filling region can be treated as the strip mining while the region without filling can be looked as mining region and the thickness of mining equals the height of space without subsidence namely residual space.

Principles of strip filling

The goal of grouting filling is to make sure that the residual movement and deformation of abandon goaf is less than the critical deformation value of buildings and structure on surface, so that the safety of building and structure on surface can be guaranteed. On the process of strip filling, the following conditions must be satisfied:

(1) The grouting concretion has enough intensity to support the weight of overburden and can keep long time stability under action of the stress of overburden. Because the grouting concretion has more intensity than coal seam, it is safe that the grouting width is designed by the method of designing strip pillar and can be adopted.

(2) The strip formed by grouting concretion can sufficiently support the weight of overburden and make sure that once the grouting strip is formed, surface residual movement and deformation is less than the critical deformation value of buildings or structure. As a result, there will be no surface structural damage. The surface movement prediction method with strip filling of abandon goaf resembles the strip mining prediction. So the value of surface residual subsidence with strip filling can be predicted by the strip mining prediction method.

To achieve the results above, the overburden structure due to strip filling must be same as that due to strip mining. And generally in strip mining, the conditions followed should be satisfied:

(1) The strip mining width is 1/4~1/10 of mining depth, usually between 1/6 to 1/8;
(2) The strip mining recovery ratio usually is 40~60%, most 50%, that is the strip pillar width should be 1/4~1/10 of mining depth.

To ensure the safety of strip mining, it must be assured that the overburden structure due to strip mining can supports the weight of overburden rock mass effectively. It means that the bending zone is asked to have enough thickness. At the same time, on the process of grouting filling, it should be guaranteed that the acting depth caused by ground load can't exceed the height of bending zone. Therefore, some decision conditions are produced as followed:

(1) When the mining depth, H, satisfies the formula (1):

$$H \le h_{li} + h_c \tag{1}$$

Where H - mining depth, m;
h_{li} - height of fractured zone of conductivity water, m;
h_c - acting height caused by ground load, m.

On this condition, the overburden has lost its complete structure or the ground load has had effect on the cracked rock of abandon goaf and then it will result in the deformation of cracked rock mass. Hence the full grouting filling should be adopted, that is the grouting borehole interval is:

$$L = 2R \tag{2}$$

Where L - grouting borehole interval, m;
R - effective grouting spread distance, m.

(2) When the mining height, H, satisfies the formula (3):

$$H \ge h_{li} + h_c \tag{3}$$

On this condition, the overburden maintains the complete structure or the ground load has no effect on the cracked rock of abandon goaf and the overburden can support the load. Then the adoption of strip grouting filling can just control the surface deformation. And the grouting borehole interval is:

$$L = L_1 + 2R \tag{4}$$

Where L_1 -width of strip without grouting filling, m.

The width without grouting filling is determined by the factors of buildings' resisting deformation capacity, geological and mining conditions and so on. This paper will give a detail discuss on below.

METHOD OF STRIP FILLING DESIGN

Determining of grouting borehole interval

If the intensity of grouting concretion is ensured, grouting concretion together with cracked rock mass supporting the overburden strata resembles the strip mining with bearing triaxial forces. To make sure the long time stability of filling, the width of filling strip and width of strip without filling must be determined by the method of analysis of triaxial bearing forces in strip mining design. According to the subsidence theory of strip mining, to get the aim that the surface deformation won't exceed the critical deformation value of buildings and structure, the maximal value of surface deformation must be calculated first. In the coursing of calculating, the final surface subsidence is thought to reach the ultimate residual subsidence, namely the final subsidence value will reach the mining thickness. Regarded the residual subsidence as the equivalent mining thickness, the following formula can be get:

$$m_{equivalent} = (1 - q\cos\alpha)m \qquad (5)$$

Where q - surface subsidence coefficient
m - total mining thickness, mm;
α - coal seam tilt angle.

Assuming that the width of grouting filling strip is a, the width of strip without filling is L_1, the parameters can be obtained by the surface subsidence prediction method of strip mining:

Subsidence coefficient: $$q_{strip} = \frac{H - 30}{5000 \times a / L_1 - 2000} \times q \qquad (6)$$

Tangent of main influence angle: $$tg\beta_{strip} = (1.076 - 0.0014H)tg\beta_{complete} \qquad (7)$$

Coefficient of level movement: $$b_{strip} = \frac{10000}{10750 + 7.6H} b \qquad (8)$$

The maximal value of surface movement and deformation with strip grouting filling can be calculated by formula (5) to (8):

$$r_{strip} = \frac{H}{tg\beta_{strip}} \qquad (9)$$

$$W_m = q_{strip} m_{equivalent} \cos\alpha \qquad (10)$$

$$i_0 = \frac{W_m}{r_{strip}} = \frac{q_{strip} m_{equivalent} \cos\alpha}{r_{strip}} \qquad (11)$$

$$\varepsilon_0 = 1.52 i_0 \qquad (12)$$

$$k_0 = 1.52 \frac{W_m}{r_{strip}{}^2} \qquad (13)$$

According to above formulas, the maximal value of surface movement and deformation with different strip grouting filling can be obtained. At the same time, the grouting filling width and borehole interval can be calculated by the critical deformation value of buildings and structure.

The formulas (9) to (13) show that the maximal incline, maximal level deformation and maximal curvature are close correlative. Therefore, the grouting filling strip width can be calculated only by one kind of deformations. Here the requested grouting filling width by maximal incline is presented.

According to formulas (5), (6) and (11), there is:

$$i_0 = \frac{(H-30)\times qm_{equivalent}\cos\alpha}{(5000a/L_1 - 2000)r_{strip}} \tag{14}$$

Then the width of strip without grouting filling is:

$$L_1 = \frac{5000 a i_0 r_{strip}}{2000 r_{strip} i_0 + (H-30)qm_{equivalent}\cos\alpha} \tag{15}$$

By the strip mining theory, the strip mining width should satisfy the following condition as well, that is:

$$L_1 \le (1/4 \sim 1/10)H \tag{16}$$

Then the grouting filling borehole interval L is calculated as:

$$L = L_1 + 2R \tag{17}$$

Determining of strip grouting filling width

When the strip grouting filling width is being determined, it should be considered that the strip with can support the overburden strata weight. Based on the calculating method of triaxial bearing forces, A.H wales thought that the key to determine whether the strip mining succeeds was the stability of strip pillar. And combined with indoor experiment and field researches, the strip pillar width, a , should be:

$$a \ge 0.01mH + 8.4 \tag{18}$$

Where m - mining coal seam thickness, m;
H - average mining depth, m.

Considered that in abandoned goaf parts of the rock mass especially those in caved zone have cracked and the capacity of supporting stress has reduced, the coal seam thickness should be taken as height of caved zone. Based on the theory of mining subsidence, height of caved zone is 3~5m. So there is:

$$a \ge (0.03 \sim 0.05)mH + 8.4 \tag{19}$$

The value calculated by formula (19) is the requested efficient width in strip grouting filling.

When the grouting spread distance is more than the requested efficient grouting width, the method of single line borehole grouting can be adopted. While in contrast, the method of multi-line boreholes grouting should be adopted. And the amount of lines, n, can be calculated by following formula:

$$n \geq \frac{a}{2R} \tag{20}$$

APPLICATION EXAMPLE

The west section of Jingfu speedway around Xuzhou city passes some mine's abandon goaf in Xuzhou. This abandon goaf had mostly mined 7# and 9# coal seam in 1987~1995. The average mining thickness are 2.0 and 1.0m respectively. The total mining thickness is 3.0m and the mining height is 75~200m. The mining subsidence parameters of this mine are: first subsidence coefficient q=0.7, repeat mining subsidence coefficient q=0.8, tangent of main influence angle $tg\beta = 0.2$, level movement coefficient b=0.3. The steep incline part of abandon goaf had been grouted in the test period. The incline angle of rest coal seam is 24°. And the mining depth of rest part is between 120m to 210m.

To ensure the safety, the first mining subsidence coefficient was taken as the calculating parameter, and then the equivalent mining thickness is obtained as:

$$m_{equivalent} = (1 - q\cos\alpha)m = 1027mm$$

Assuming the critical incline of speedway is 1mm/m, table 1 shows the value of different grouting strip width calculated by above formula under the condition of different mining depth. It is known from the test that effective grouting spread distance along the longwall way is 10~30m. Table 1 also presents the borehole interval L with the grouting spread distance of 20m.

Table 1.: Calculating list of grouting strip width.

Mining depth (m)	100	150	200
$tg\beta$	1.872	1.732	1.592
r	53.4	86.6	125.6
Grouting strip width a (m)	17.8, 23.4	21.9, 30.9	26.4, 38.4
Calculated by (15) L_1 (m)	31.1, 40.9	37.6, 53.1	45.6, 66.4
Calculated by (16) L_1 (m) (Average value)	25, 10 (17.5)	37.5, 15 (26.2)	50, 20 (35)
Width of strip without grouting L_1 (m)	25, 10	37.5, 15	45.6, 20
Grouting borehole interval L (m)	57.5	66.2	75
Amount of borehole line set up in every group	1	1	1

From the data of table 1, the grouting borehole interval changes between 57.5 to 75m along the longwall way, and along the slant way the interval can be adopted 40m according the slurry spread radius.

On setting up the borehole, according to the crack characteristic of overburden rock in abandon goaf, void and cracked rock mass's maximal height region generally present to following instances: (1) panel edge: because of the hanging roof, there is relatively large void in this region; (2) ascending way of steep incline coal seam: due to the local caving of coal seam, the void has affected the coal seam locating on upside of gob boundary; (3) roadway area: large cavity exist in the area because of caving of the roadway ; (4) fault area: the heights of caved zone and fractured zone in this region are large. The regions listed above are primary reasons causing surface deformation. To control the surface deformation, those regions' deformation must be controlled first. Considered that the roadway area is commonly small and mining depth is large, and the surface movement and deformation caused by void caving in these area is relatively small besides it's hard to drill and grout from ground to roadway, the filling of roadway can be cancelled. Based on above principles, the method of setting up grouting filling borehole in abandon goaf is as following:

(1) Considered the certain spread distance of grouting filling, the borehole should be set up within the range of 20m from panel edge so that the void and sub-compaction zone of gob edge can be filled;
(2) For the ascending way of steep incline coal seam, the grouting borehole should be designed on the goaf edge so that the void in the upside of goaf edge can be filled;
(3) It is necessary to lay grouting borehole in fault growth region so that the cracked rock mass of this part can be strengthened.

CONCLUSIONS

Based on the analysis of deformation of abandon goaf with longwall mining, combined with mining subsidence theory, the method of controlling residual deformation in abandon goaf with strip grouting filling is studied in detail and the following conclusions are obtained :

(1) The key to control the residual deformation of abandon goaf is to control the rock mass deformation in caved zone and fractured zone. Under a certain mining depth, grouting filling of abandon goaf can be applied with strip grouting filling method.
(2) When the mining depth is less than the height of fractured zone of water conductivity and height of load effect from surface buildings, the grouting borehole interval is twice of slurry spread radius. While the mining depth is more than the height of fractured zone of water conductivity and height of load effect from surface buildings, the grouting borehole interval can be calculated by formula (17).
(3) The borehole should first be set up within the range of 20m from panel edge, the ascending way of steep incline coal seam, and fault growth region so that the void and sub-compaction zone can be filled.
(4) The project example is present on the base of put forward theory.

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