Study on Stability of Surface Mine Slope Influenced by Underground Mining below the Endwall Slope
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Abstract

Aiming at the practice of the unifying of surface mining and underground mining and the interaction, the thin plate model of mined slope was established with the influence analysis of underground mining to slope, distortion and stress distribution law studied. Combining the rock characteristic in practice, the modified method was put forward. Basing on the roof breaking law of mined slope, the calculating method of slope stability coefficient and the minimum width of protecting coal pillar was elicited. Subsequently the paper took the united mining practice of AnJiaLing surface mine as example to study the subsidence law of roof and the influence of mined 902 working face to surface mine slope. The research conclusion indicated that the deformation and subsidence of overlying strata is obvious, and it has a clear lag. The distortion of mined slope under open-pit and underground mining was drew from strata angle alter evoked from ceiling distortion, which can be used as the theory sustainment to stabilization of mined slope under open-pit and underground mining.

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1 Introduction

As the important strategic resource of our country, coal plays a significant role in the development of our national economy. Along with the continuing discover of huge coalfield in the west of our country and the gradual familiarity to advantages of surface mining, the number of surface mines grows rapidly. However, it is extremely important to mine and utilize the resources sufficiently, such as the coal.
Because of the safety and benefit factors, surface mining can’t be applied to mining the coal below the endwall. As a result, underground mining is often used.

The endwalls of surface mines will suffer double disturbance of surface mining and underground mining, with the coal mined by the latter. And it will influence the slope stability, surface mining and transportation safety, bringing a new research topic of surface and underground mining. On the basis of theory analysis and investigation, the paper attempts to Research it preliminarily.

2 Model foundation of underground mining below endwall

Assuming the strata bury horizontally, then the strata angle is 0°. The slope angle of surface mine is b, the height of coal is h, with the height of overburden strata is \( h_i \) (i=1,2,…n from bottom to top). Along with the different layouts of underground mining working face, the models can be established as follows.

If the underground mining working face lays transversely that means it goes forward or backward facing the slope, the mining model can be established as fig. 1.

![Fig.1 Sketch of underground mine working face laying transversely below endwall slope](image)

If the underground mining working face lays lengthways that means it parallels with slope tend towards, the mining model can be established as fig. 2.

![Fig.2 Sketch of underground mine working face paralleling with slope tend towards below endwall slope](image)
What the surface mines disclose and mine are all belong to sedimentary rocks, with weak physical and mechanical properties. The thin plate theory can be applied to instability and collapse mechanism of overburden strata caused by underground mining, and then the mechanical model of roof rock subsidence can be established. With the adjustment according to practice, the subsidence rule of weak sedimentary roof can be drawn after numerical analysis.

In condition of mining single thick coal seam, full collapse mining can be applied to mine the coal below the endwall slope. But it should be enhanced to monitor the strata subsidence and prevent air leakage. Whether the underground mining working face goes towards to or parallels to slope, it is appropriate to take a unit length along the advancing direction. Then the simply supported thin beam model is established as fig. 3[2].

![Fig.3 Roof mechanical model of underground mining working face](image)

The cross-section moment is:

$$M(x) = \frac{qx}{2} + \frac{qlx}{2} (0 < x < 1)$$

(1)

Where $q$ is the unit uniform load, $l$ is the plate girder length.

The maximum bending moment presents in the middle section of beam which is also the middle of underground mining working face advancing direction. The maximum bending stress presents in the middle of the upper and lower beam section of the edge, and the value can be expressed as:

$$\delta_{\text{max}} = \frac{M_{\text{max}}}{bh^2 / 6}$$

(2)

Where $b$ is the calculating width, $h'$ is the roof thickness which can be seen as the thickness of overlying immediate roof.

It can be included from above two formulas as follows:

$$\delta_{\text{max}} = \pm \frac{3ql^2}{4bh^2}$$

(3)

The interaction of every strata should be considered in practice, especially the rock cohesion between the particles will influence the maximum moment, maximum bending stress and the subsidence. However,
the rock cohesion difference of particles between different strata is great which can’t be expressed with exact value. So the paper puts forward an amending method by using a coefficient as follows:

\[ M(x) = a_i \left( \frac{qlx}{2} + \frac{qx^2}{2} \right), (0 < x < 1) \]

\[ \delta_{\text{max}} = \pm \frac{3a_iql^2}{4bh^2} \quad (4) \]

Where \( a \) is the moment correction coefficient which differs according to different rock properties. For example, \( a \) can take a large value if rock cohesion is great such as sandstone, otherwise takes a small value. It should be noticed that \( a_1 \) is applied to the moment and stress distribution of the first stratum, and \( a_2 \) to the second stratum, and so on.

FLAC\(^3\) analysis software is applied to simulate it. There are 5 paces along advancing direction of underground mining working face to show the regular intervals of roof collapse. The stress distribution contours of overlying strata can be educed which is caused by underground mining below endwall slope\(^1\).

Fig.4 Vertical stress distribution of section plane of the underground working face vertical to advancing Direction

Fig.5 Vertical stress distribution of section plane in working face with 150m protecting coal pillar
From the stress distribution contours above it can be known that there is a clear lag of the stress diversification and subsidence in overlying strata after the underground mining working face advanced, which inosculates to the field observations. And the modified theory is also validated.

3 Mining stop line

The position of underground mine working face laying transversely or distance between the working face paralleling to slope and the surface mine bottom is called mining stop line, which is also called width of protecting coal pillar. From above analysis outcome we also know that the collapse or subsidence of overlying strata will impact the safety of slope, buildings, transportation roads and equipment seriously. Consequently, it is necessary to determine the mining stop line to surface mine or underground mine\(^{[3,4]}\).

The determination principle of mining stop line is the subsidence area will not harm the safety of surface mine slope or transportation roads.

Large subsidence area shapes behind the slope after the underground mining. So the subsidence rock will bring positive pressure to slope, as shown in Figure 7.

For slope stability calculations, there is a circular surface most likely to slip which is exposed on slope top. The distance between the exposing point and the slope top is \( L_0 \). Then the coordinate system can be established. Slope toe is the coordinate origin, \( x \) axis is the right extension direction. Assuming the mining stop line \( x_s \) is \( \alpha \), subsidence angle is \( \alpha \), the conclusion is followed:
• When $\alpha$ is bigger than $L_h + H \cot \alpha$, subsidence area keeps away from the face most likely to slip, and it has no influence on slope stability.

• When $\alpha$ is equal to $L_h + H \cot \alpha$, subsidence area just begins to enter the face most likely to slip, and it has little influence on slope stability.

• When $\alpha$ is smaller than $L_h + H \cot \alpha$, subsidence area is in the face most likely to slip, and it has great influence on slope stability. The coefficient of slope stability is:

$$F_s = \frac{\sum (Cl_i + \tan \phi W_i \cos \beta_i)}{F_r + \sum W_i \sin \beta_i}$$  \hspace{1cm} (5)

Where $F_r$ is the part strength of N entering the sliding area, $C$ is the rock cohesion, $W_i$ is the gravitation of strip No. $i$, $\phi$ is the internal friction angle of rock, $\beta_i$ is the sliding face angle of strip No. $i$.

4 Case study

The paper takes it as the example that is the mining stop line of united surface mining and underground mining in AnJiaLing surface mine. AnJiaLing surface mine and underground mine locate in the south-central PingShuo mine area. There are three coal seams: 4#, 9# and 11#. Actual production capacity of surface mine has reached 15Mt/a. Underground mine exploits 4# coal seam mainly, and the raw coal output reaches 8Mt/a.

Based on the engineering geological materials that have already been collected, calculation parameters are selected as follows: bulk density of sandstone is 24.8 kN/m$^3$, cohesive force is 350 kPa, internal friction angle is 31°; bulk density of coal seam is 14.9 kN/m$^3$, cohesive force is 149 kPa, internal friction angle is 26.5°; bulk density of mudstone is 23.7 kN/m$^3$, cohesive force is 318 kPa, internal friction angle is 27°; bulk density of loess is 19.0 kN/m$^3$, cohesive force is 23 kPa, internal friction angle is 25°; bulk density of spoil is 18.7 kN/m$^3$, cohesive force is 19 kPa, internal friction angle 24°; bulk density of sandstone in cross fall area 19 kN/m$^3$, cohesive force 23 kPa, internal friction angle 25°; internal cohesive force between coal 11# and floor strata 21 kPa, internal friction angle is 25°.

According to field monitor materials, the subsidence angle is about 55°. After the B902 working face is finished, the subsidence area has extended to monitor point S40-4, while the influence of horizontal displacement velocity caused by later mining will decrease. The accumulative total displacement of S40-4 is 448 mm and displacement velocity is 73mm/d. The displacement and velocity toward south increase because the increased elastic area has entered slope area. As a result, the strata angle increased, the down force increased, displacement increased, and so did the velocity.

By Analyzing AnJiaLing surface mine practice, the conclusion can be drawn as follows: when the slope angle is 42° and the height of slope is 180 m, the stability coefficient is 1.38, the length of $L_h$ is 47 m, the protecting coal pillar is no less than 308 m.
5 Conclusions

Relationship between exposure length and stability coefficient under different slope angle was obtained. Decrease proportion of exposure area under slope angle variations was also analyzed.

- Underground mining below surface mine slope will cause instability of overlying strata and influence the surface slope safety. According to related mechanical model analysis, the stress distribution mechanism of overburden layers was elicited. The outcome of numerical simulation verified the correctness of the theory.

- By the establishment of mined slope calculation model, the stability calculating method was analyzed, the judgment formulae was elicited, with the determination principle and judgment of minimum protecting coal pillar width of slope drawn.

- Aiming at reducing mining cost and reclaiming resources, surface mining and underground mining was united. In order to reduce the impact on surface mine slope caused by underground mining, various measures should be taken and the following principles should be obeyed. The subsidence area caused by underground mining should not enter the slope area; periodic weighting length can be shortened according to active releasing roof strata; the mined-out area should be backfilled properly.

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