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Influence of depth-thickness ratio of mining on the stability of a bedding slope with its sliding surface in concave deformation

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ABSTRACT

In order to study the influence of depth-thickness ratio on bedding slope stability, whose sliding surface is flexural concave in shape under mining conditions, this paper aims to study the characteristics of deformation and damage of bedding sliding with depth-thickness ratios of 200:1, 150:1, 120:1, 100:1 and 50:1 by adopting numerical simulation analysis software combined with laboratory-made "under the influence of mining variable sliding surface slope similar simulation test bed", and to propose identification methods for slope stability under the influence of mining. The results show that mining activities under the slope reduce slope stability. With a decrease in the mining depth ratio, the influence of mining on the slope increases gradually, and the damage to the slope gradually expands, the stability of the slope gradually reduces, fracture occurs on the slope toe and the central fissure gradually develops to the surface, and reaches slide threshold when the depth-thickness ratio is 50:1.

1. Introduction

At present, China has about 38,000 underground mines, about half of which are in the Midwest. Landslides caused by mining in the mountains with landslide-prone geological conditions is one of the main forms of surface mining damage in the mountains [1,2]. According to statistics in 2005, landslides have occurred about 1200 times due to underground mining. Mining can damage the original balance of stresses in the overlying strata of the mining area. When the mining area reaches a certain scale, movement begins to expand from the stope to the surface, which can lead to surface deformation, sedimentation, landslide and other disasters, giving rise to great loss of life, property and economic construction [3,4].

The large rock mass structures that mining geological disasters are faced with are greatly different from those geological disasters triggered by natural factors and surface engineering construction is faced with. The former is mobile and unstable, while the latter is static and stable. After the underground seam is completely or partly mined out, the sliding surface turns into various curved surfaces from the original angular surface. Therefore, the stress state on the sliding surface changes considerably, and with the water effect, the stability of the sliding mass is greatly reduced.

For traditional slide slope simulation, the form of a building slope is usually adopted, in part or in the whole section for the experiment [5], but for one that is influenced by mining, we need to consider the effects of deep coal mining on the overlying rock. Therefore, in the process of experiment for the existing mining slide slope simulation, similar materials composed of bed rock, coal bed, overlying rock and slope surface are needed to apply load on the model, and the influence of mining on the side slope needs to be simulated by artificial exploitation [6]. This experiment can be used for geologically shallow depth conditions. When the condition is deep burial, the following issues arise: it is hard to simulate the exploitation range and boundary for artificial exploitation and there may be many similar materials which can be used for the desired configuration which can lead to more work. And if we place the landslide sliding surface and coal face in the same model, the sliding surface would be so small compared to the size of the whole model that it cannot simulate its migration status after mining. If the overlying rock of the coal bed is a geologically complex structure, it will not be easy to simulate the actual geological conditions. In order to solve the above problems, the laboratory has voluntarily developed an experiment table that can randomly change the dip angle, shape and bending degree of the sliding surface and is called "variable sliding surface similar simulation experiment table under mining" [7–9].

On the basis of the correspondence of a mining working surface layout and the location of a side slope bedding sliding surface, the

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sliding surface under mining would ultimately produce deformation in different degrees of flexure and shape-concave, convex, and concave-convex. This paper mainly studies the influence of the depth–thickness ratio on side slope stability under the condition of a sliding surface at 20° dip angle with concave deformation.

2. Flexure shape and damage of the side slope sliding surface with confirmed mining influence by numerical simulation

The experimental plot selected was located in the inclined mountains composed of thick limestone in the west-south such as Chongqing city, Sichuan, Hubei, Yunnan, and Guizhou provinces which have a wide distribution of limestone [10,11,1,13]. The local terrain is very complicated with dense vegetation, and the condition of the landslide formation is concealed and complex, and is similar to the instability mode of structures in inclined thick limestone [14,15].

As the first mining work surface of a certain mine, the working surface is arranged by the trend, its trend length $L = 140$ m, $1.2 < H_0/L < 1.4$ (H_0 is the average mining depth), its tendency is in full mining status. The mountain profile is chosen as the study object.

2.1. Modeling

Based on the characteristics of mining rock mass mechanics, this paper applies the Mohr-Coulomb elastic-plastic model criterion. The model is 281.91 m in length, 330.89 m in height, its sliding surface is 300 m in inclined length, the slope body is 240 m in total length and the dip angle of the model is 20°. Its bottom boundary is fixed, so the bottom horizontal and vertical displacement is zero; its left and right boundary is horizontally fixed; its top surface is the free boundary; the sliding surface is 120 m away from the mining coal with different depths of 0.6 m, 0.8 m, 1.0 m, 1.2 m, 2.4 m. According to these five depth ranges, this paper simulates five depth-thickness ratios: 200:1, 150:1, 120:1, 100:1 and 50:1, so as to study the influence of underground mining with these five depth-thickness ratios on sliding surface stability. The numerical analysis model is shown in Fig. 1.

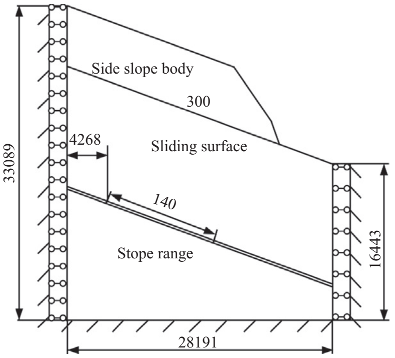

Fig. 1. Numerical analysis model.

2.2. Analysis of calculation results

Since the vertical stress is normally much greater than the horizontal stress, and the distribution of the vertical stress alone adequately reflects the distribution of the primary stress, the distribution of vertical stress is analyzed in this paper [16–18]. Before mining begins, the top, middle and bottom of the side slope are under the influence of vertical stress imposed by the overlying strata. The stress and fracture distribution after mining are shown in Fig. 2:

The stope roof forms a stress-induced broken rock zone caused by mining. As mining continues, the baseboard under the goaf vertically bears less pressure stress, but the baseboard on the top and bottom of the goaf that does not go through the orebody will result in a pressure stress concentration phenomenon. With deeper mining and a decreasing depth-thickness ratio, this phenomenon will become more and more obvious, and the value will become increasingly larger at the same time.

At the same time, as mining continues, in the top goaf roof the inner stress redistributes tending to a new equilibrium, which leads to the formation of a mobile top goaf stress-relaxed area and a supporting pressure area along the goaf that moves forward as mining progresses. When the tension stress zone arrives on the top of the goaf, this zone becomes larger and more focused and the tension stress value increases as mining becomes deeper. When the depth-thickness ratio is 50:1, the tension stress value becomes the largest. When it is 100:1 and 50:1, the goaf top will undergo tension stress yield, which indicates that the rock in the goaf top is damaged, which manifests as fully developed fractures in the fracture figure.

The development of fractures under different depth-thickness ratios can be seen from the fracture figure. The top goaf appears as a trapezoidal shaped fracture and, with deeper mining, the direct roof of the coal bed caves over a larger area. The indirect roof and the main roof also appear as a separation layer and a curve. Later, the direct roof mining fracture develops a cut-through, which leads to a large area break-off on the main roof and more fractures in the fracture area involving a larger area with more intensive distribution. This indicates that smaller mining depth-thickness ratios result in more destructive damage of the overlying strata. At the same time, fracture of the slope body gradually develops with thicker mining: when the depth-thickness ratio is 200:1, mining has little influence on the slope body, thus no obvious fracture appears; when the depth-thickness ratio is 150:1, small fractures appear on the middle and middle-low parts of the slope body. It is clear that the mining influence increases as the depth-thickness ratio decreases; when the depth-thickness ratio is 120:1, the mining impact increases further with intensive fracture areas appearing in the middle-low part of the slope body, and the tensile stress concentration area occurs at the same time because of the ground depression, and small fractures appear on the slope body surface. When the depth-thickness ratio is 100:1, besides the slope body surface fracture and the middle-low concentrated fracture, fracture also appears on the slope toe and mining will have a great influence on the stability of the slope body by this time. When the depth-thickness ratio is 50:1, more fractures develop on the slope body, and result in a larger fracture concentrated area. With increasing numbers of fractures on the slope surface and body, mining now shows the greatest influence on the slope body and this indicates that, as the depth-thickness ratio decreases, stability of the slope body also gradually decreases. However, the simulation slope body is still in a relatively stable state and no landslides occur.

The data from displacement observations of the sliding surface, as shown in Fig. 3, are used with a similar ratio for similar simulation application.

From the analysis of above simulation results, we can see that: when mining makes the sliding surface follow a concave deformation, the deflection curve of the sliding surface has the same overall tendency of low in the middle and high at both ends. The deflection curve is small at the boundary of both sides, large in the middle-low section, and is largest when it is 147 m from the left margin. This is consistent with the concentrated fracture in the middle-low side slope in the fracture distribution figure.

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