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Influence of Underground Coal Mining on Surface Morphology and Soil Erosion

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Abstract. This paper uses FLAC 3D numerical simulation software to establish the model of concave slope, convex slope, mixed slope and uniform slope to simulate the influence of underground coal mining on surface morphology. The modified universal soil loss equation (RUSLE) was used to estimate the amount of soil erosion caused by underground coal mining. The results show that underground mining will cause the increase of surface slope, the decrease of slope length and the increase of soil erosion. The soil erosion is uniform slope, concave slope, mixed slope, convex slope, and uniform slope (straight slope) is the key prevention and control slope of soil erosion in underground mining.

1. Introduction

Coal mining underground will cause large-scale surrounding rock movement, resulting in changes in surface morphology (slope, slope length), providing favourable conditions for soil erosion. Soil erosion in mining area is one of the hot issues studied by researchers at home and abroad. At present, domestic and foreign scholars take the surface external force as the research object, and conduct in-depth research on the soil erosion caused by coal mining. In 2014, Chen Sixu [1] used GIS and RUSLE models to quantitatively study the soil erosion in the hilly areas of southern China, and analyzed the spatial distribution characteristics of soil erosion and its relationship with slope and altitude. In 2006, Bai Zhongke [2] used RS and GIS technology to study the changes of soil erosion and land use caused by coal mining subsidence in Tashan Mine, Datong, Shanxi Province. It was found that coal mining changed the surface morphology, soil erosion increased, reduced tillage area and reduced land use. These studies are based on the extra-surface force, but the soil erosion in the coal mining area is not only affected by the external force of the surface, but also by the underground mining. In 2016, Song Shijie et al [3-4] carried out simulation experiments on soil erosion in mining areas based on the characteristics of soil erosion in coal mining areas, combined with the influence of surface external forces and underground mining, so that the research of soil erosion in coal mining areas has taken a step forward.

Based on the research of Song Shijie, combined with the actual irregular (concave, convex, mixed, uniform slope) surface morphology, this paper uses FLAC 3D numerical simulation software to study the surface morphology and soil erosion of underground coal mining, in order to soil erosion in coal mining area. Governance provides a reference.



2. Overview of the study area

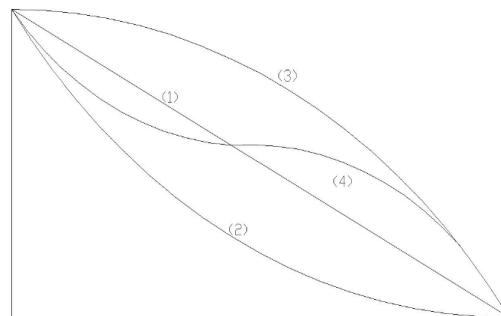
This paper selects Dafosi Coal Mine located in Binchang Mining Area in the northwest of Xianyang City, Shaanxi Province as the research object. The area of Dafosi Minefield is 86.3km². The main coal-bearing strata in the coal mine is Yan'an Formation. The 4# coal is the main coal seam of this group. The depth is 400-600m, the thickness is between 2.8~12.5, the working surface width is generally 200-220m, the annual propulsion distance is 1-2km, the mine adopts fully mechanized top coal caving method, and the roof management method used the full fall method. Dafosi Coal Mine belongs to the hilly and gully region of the Loess Plateau. The vegetation coverage rate is less than 30%, and the annual rainfall is 500-600mm. The soil erosion in the rainy season is more serious; Hydraulic Erosion is the main soil erosion type. The average soil erosion modulus is 3367t/(km² • a) and the average scour depth is 23mm. It belongs to the national key soil erosion control areas.

3. construction of numerical model for underground coal mining

Coal mining is a nonlinear large deformation problem. Therefore, this paper uses FLAC 3D numerical simulation software to simulate and simulate the surface deformation caused by coal mining. It has certain advantages in dealing with nonlinear large deformation problems. The FLAC 3D numerical model was constructed based on the information of a borehole histogram of the Dafosi Coal Mine.

3.1 Surface morphology of the study area

According to the actual surface morphology, the simulated surface slope is divided into four types: concave slope, convex slope, mixed slope and uniform slope. The schematic diagram of the surface slope is shown in Figure 1.



(1) uniform slope (2) concave slope (3) convex slope (4) mixed slope

Figure 1. Schematic diagram of surface morphology.

3.2 4# coal seam overlying rock stratum and its mechanical parameters

Based on the information of a borehole histogram of Dafosi, the overlying strata structure of the model is constructed. For the convenience of calculation, the stratum is merged according to its mechanical properties during the modeling, and the overlying strata of the 4# coal seam are finally formed. There are 24 layers (including coal seam and bottom plate). The physical and mechanical properties of each rock layer are shown in Table 1.

Table 1. main rock strata and lithologic parameters.

Stratigraphic lithology	Bulk modulus /Mpa	Shear modulus /Mpa	Tensile strength /Mpa	Cohesion /Mpa	Internal friction angle /(°)	Density kg/cm ³
sandy	3000	2250	0.75	2.16	36	2510
coarse	4200	2900	1.5	5	34	2560
middle	3300	2500	1.2	4	37	2580
fine sandstone	2700	1600	1	2	35	2540
conglomerate	3330	2000	8.5	3	38	2300

4# coal	1000	0.46	0.6	1.2	28	1430
loess	280	0.09	0.35	0.85	25	1960

3.3 Numerical Model Framework Construction

The average depth of 4# coal seam is 460m, the thickness is 9m, the annual thrust distance is 600m, the working surface width is 200m, and the surface slope is 5° , ie $X=600\text{m}$, $Y=200\text{m}$, $Z=460$, the X-axis direction is the main observation direction. The two boundary surfaces of the model X direction and the two boundary surfaces of the Y axis are set as a single constraint boundary, the bottom boundary surface of the Z axis direction is a full constraint boundary, and the upper boundary is set as a free boundary, the above geometric parameters and the surface morphology described above are utilized. Based on the above geometric parameters and the surface morphology and the overlying strata structure of the 4# coal seam, the FLAC 3D three-dimensional geological models of concave slope, convex slope, mixed slope and uniform slope are constructed respectively, as shown in Fig. 2. In order to facilitate the analysis of the calculation results of the main section, we set up 24 monitoring points on the surface along the X direction at $Y=100\text{m}$, as shown in Figure 3.

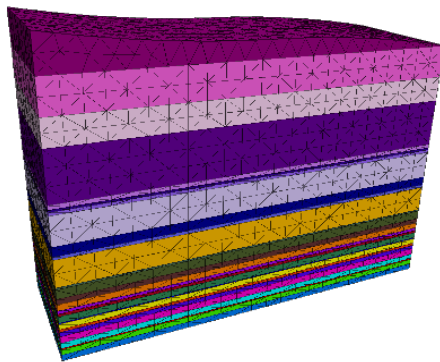


Figure 2. three-dimensional geological model.

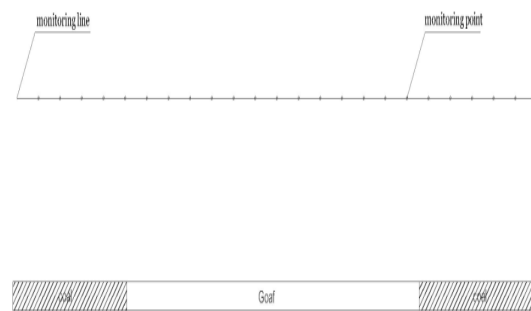


Figure 3. layout of monitoring points.

4. Influence of underground coal mining on surface slope type

In this paper, the slope is divided into three equal length sections to calculate the LS value of the non-uniform slope. C. D. Castro et al. show that the slope is divided into three sections to obtain a reasonable LS value [5].

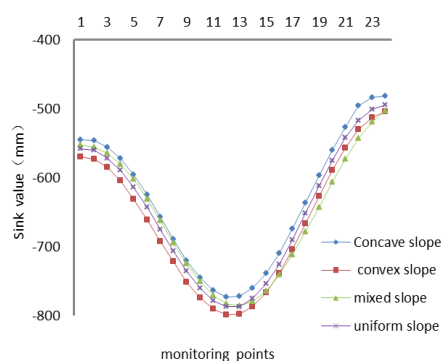


Figure 4. Sink value of different slope.

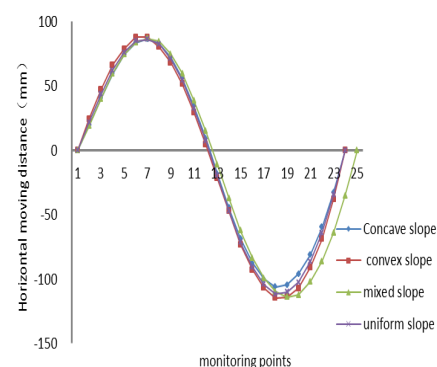


Figure 5. Change in slope length of different slope.

4.1 Influence of underground coal mining on slope

It can be seen from Figure 4 that no matter which kind of slope type, coal mining underground has increased its slope, and the slope increases of different slope types are different. The increase in slope is in order of large to small: uniform slope, convex slope, concave slope, mixed slope. The slope is increased as a whole but the slope is reduced locally. The slope of the concave slope and the uniform slope mainly appear in the slope of 200-400 m, and the slope of the slope and the mixed slope is

reduced mainly appearing in the 400-600m slope section; the part with the largest slope change occurs at the top of the slope.

4.2 Influence of underground coal mining on slope length

It can be seen from Figure 5 that no matter which kind of slope type coal mining has its slope length reduced, the slope length of different slope types is different. The slope length decreases in order from large to small: mixed slope, convex slope, uniform slope, concave slope. The slope length is first increased and then decreased, but the whole is reduced. The 400m is the turning point. The slope length of the slope is reduced 400-600m. the most variable part of the slope length occurs at the foot of the slope.

5. Influence of underground coal mining on soil erosion

In this paper, the modified soil loss formula (RUSLE) is used to calculate the amount of soil erosion caused by underground coal mining. The calculation formula is as follows:

$$A = R \times K \times L \times S \times P \times C \quad (1)$$

Type, A is the average soil loss per unit area, t/(hm².a); R is the precipitation erosivity factor, MJ.mm/(hm².ah); K is the soil erodibility factor, th/(MJ. Mm), L and S are the slope length and slope factor, respectively; and P and C are soil and water conservation factors and surface vegetation cover factors, respectively.

This study only considers the increase in soil erosion caused by surface deformation. So it is assumed that the remaining soil erosion factors are not affected by underground coal mining. After extracting the FLAC 3D simulation results, the LS variation values are in Table 2;

Table 2. LS value before and after different slope mining.

slope type	concave slope	convex slope	mixed slope	uniform slope
before	9.8214	9.8101	9.5496	8.8498
after mining	10.0051	9.8420	9.6692	9.0718
change	0.1837	0.0319	0.1196	0.2220

5.1 Calculation of LS value

Irregular slope and uniform slope LS worthy calculation method is different. The calculation formula for the uniform slope is as follows:

$$LS = (\lambda / 22.13)^m (66.41 \sin^2 \theta + 4.56 \sin \theta + 0.065) \quad (2)$$

Type: λ —slope length;

θ —The slope angle, The slope angle is the tangent value of the ratio between the slope height and the slope length.

m — slope length index, $M = 0.5$, $M = 0.4$, $M = 1.0-3.0\%$ and $M = 0.2$ when slope $< 1.0\%$ and 5.0% respectively.

For irregular slopes, this paper divides the slopes into three equal-length sections, and calculates the slopes as uniform slopes. Each section has a different LS value. Each section has a different component of the total LS value.

$$M = \frac{i^{m+1} - (i-1)^{m+1}}{N^{m+1}} \quad (3)$$

Type: i —the ordinal number of slope section; m —the index of slope length; N —the number of equal slope length divided by slope.

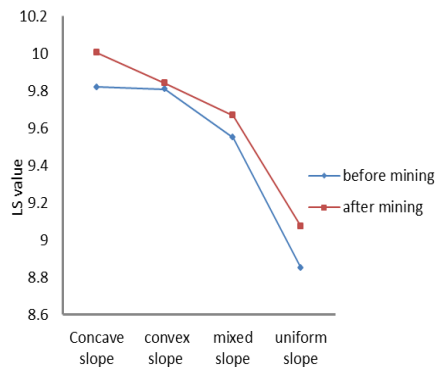


Figure 6. LS value of different slope types before and after coal mining.

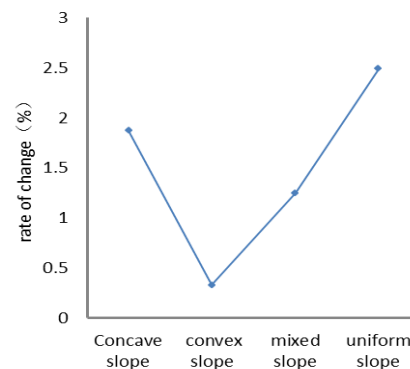


Figure 7. change rate of LS value before and after coal mining

Combining table 2 and figure 6, 7, it can be concluded that no matter what kind of slope mining will cause the increase of slope type factor (LS value). The order of LS value before and after mining is concave slope ,convex slope, mixed slope , uniform slope. The increasing rate of LS value of different slope types is different, and the order from big to small is: uniform slope , concave slope , mixed slope , convex slope. Although the increase rate of uniform slope is higher than other slope types, its LS value is still smaller than other slope types, which shows that underground mining has the most serious impact on the straight slope topography, and has less impact on other slopes.

Table 3. calculation results of erosion facto.

erosion factor	rainfall factor MJ·mm/(hm ² ·h·a)	Soil erodibility factor t·h/(MJ·mm)	soil and water conservation factor	vegetation cover factor
value	404.42	0.046	1	0.32

5.2 increase of soil erosion in underground coal mining

The data in Table2, as well as the remaining erosion factor values obtained by the traditional method (see Table 3), can be used to obtain the new soil loss caused by underground coal mining. The calculation results are shown in Table 4.

Table 4. new soil erosion in different slope types.

slope type	concave slope	convex slope	mixed slope	uniform slope
new soil erosion	1.0934	0.1901	0.7119	1.3217

It can be concluded from Table 4 that no matter what slope type, coal mining will increase soil erosion, of which the largest increase in uniform slope, followed by concave slope, mixed slope, convex slope. Coal mining advances 400 m (i.e. mining 1 t coal) soil erosion increment, uniform slope: 1.32 T / (hm².a), concave slope: 1.09 T / (hm².a), convex slope: 0.190 T / (hm².a), mixed slope: 0.712 T / (hm².a).

6. Conclusion

(1) No matter what type of slope, the underground mining will increase the slope and reduce the slope length, but different slope types increase and decrease in different degrees; the most variable parts of slope gradient and slope length are the top and foot of the slope respectively;

(2) No matter what type of slope, coal mining will increase the LS value. The LS values before and after mining are: concave slope, convex slope, mixed slope, uniform slope. The increase rate of LS values of different slope types is: uniform slope , concave slope , mixed slope , convex slope.

(3) Regardless of the slope type, underground coal mining will increase the amount of soil erosion, and the degree of soil erosion will increase. The amount of soil erosion increase per 1t of coal mining is from large to small: uniform slope ,concave slope, mixed slope, convex slope.

Acknowledgments

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