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Study on the Shape Optimization of Composite Slope at the End of Irregular Boundary Open-Pit Mine

Haoran Li[1]*, Runcai Bai[1], Guangwei Liu[1], Han Du[2], Jing Zhang*, Jinwen Xu[3]

[1]Liaoning Technical University, Institute of Mining, Liaoning, Fuxin, China

[2]Department of Hydraulic Engineering, State Key Laboratory of Hydroscience and Engineering, Tsinghua University, Beijing, China

[3]East open-pit mine of China Coal Pingshuo group, Shuozhou, China

**Corresponding Author.*

Abstract

In order to optimize the shape of the compound slope at the end of the open-pit mine under the condition of non-irregular boundary, the compound slope composed of the stope end and the inner dump in the south of the open-pit mine in Pingshuo is studied. Due to the impact of land acquisition, the space of external dump is seriously insufficient, and with the development and change of mining engineering and the influence of geological structure, the problem of compound form optimization and the release and utilization of internal drain space in the south side is generated. Through field investigation and theoretical analysis and numerical analysis method, on the basis of investigating the ore party production status, to establish a 3 d geological model, select two battery profile typical position, using rigid body limit equilibrium method from the perspective of 2 d, in the full study south help shrink battery limit compound stope side slope and mine safety distance, flat width, and the direction of dump active line and the relationship between the stability design of multiple slope configuration scheme, through the various methods of slope stability, enforceability and comparing some important parameters such as displacement capacity, ultimately determine the technology feasible economic and reasonable boundary zone composite slope space form. Based on the above research results, FLAC3D software was used to study the stress-strain relationship inside the slope, revealing the deformation and failure mechanism and stability of the composite slope in the south bound area. The results show that the landslide mode and stability of the composite slope in the south bound area of pingshuo Andaobao open-pit coal mine are mainly controlled by the safe distance between stope and dump and the weak layer of 11 coal floor. According to the design, the economic and reasonable parameters of the composite slope in the south slope shrinkage boundary area are as follows: the safe distance between the stope end side and the dump site is 50m, the width of the dump flat plate is 60m, and the working line Angle of the dump line with the abandonment height of 255m is 125°, the total discard space was95,934,100 m^3.

***Keywords**: irregular boundary; open-pit mine; composite slope; land expropriation; shape optimization; the numerical model*

I. Introduction

With the increasing demand for energy, the production capacity and scale of open-pit mines are increasing year by year. Therefore, the optimal design of the side slope form has become an important research topic in the production and development of open-pit mines [1-5]. As the inner dumps develop continuously in various open-pit mines, the morphological optimization of the composite side slope, which is formed by the stope and the dump in open-pit mines, restricts the production of open-pit mines[6].

At present, scholars at home and abroad have conducted considerable research on the form optimization of the composite side slope in generic forms. Cao Lanzhu et al. [7-8] focused on the form design of the composite soil-rock anti-dip side slope in open-pit mines with boundaries and obtained the side slope form by using the rigid equilibrium limit method and the three-dimensional numerical simulation method. Bai Runcai et al [9] studied the stability of the composite side slope in open-pit mines by using the reverse checking algorithm of the part subdivision control. Li Rongwei et al [10] found that the composite side slope composed of the outer dump and the excavation slope might get instable under the influence of groundwater. Sun Chengliang[11] designed and calculated the reasonable boundary side slope form of open-pit mines based on the north slope project of the outer dump in Yilan open-pit mine. Crusoe et al [12] studied the deformation and failure mechanism of the composite side slope in open-pit mines and analyzed the influence of the weak floor occurrence on the stability of the composite side slope. Ruo Rui et al [13] combined the limit equilibrium method with the finite element method to calculate and analyze the stability of the side slope. Zheng Yingren et al·[14] studied the stability of rock and soil slope by using the finite element method of strength reduction, and found that the constriction of force and displacement was a reasonable criterion to judge the side slope breakage after a detailed analysis of the operation precision and influencing factors of the finite element method of strength reduction. Liu Rucheng et al. [15] analyzed the failure mechanism of the slope instability according to the optimization theory, and determined the most dangerous slip surface position of the slope failure under the influence of weak lfloors. Yao Xiangji[16], Tang Wenliang et al.[17] analyzed the stability of the composite soil-rock slope in open-pit mines and determined the safe distance between the stope and the dump.

To sum up, the optimization of the composite slope form grows increasingly prominent in the open-pit mine production, but very few studies have touched upon the problems of the composite slope with irregular boundaries on the end slope. The paper selected the composite slope of the southern boundary limit at Antaibao open-pit mine in Pingshuo mining area, Shuozhou in Shanxi Province, which is caused by land acquisition, as the engineering background, and technological means such as field research, theoretical analysis and scheme comparison were used to determine the reasonable operation line development direction for dumping and the composite slope form that has the maximum dumping volume in the slope stability conditions. The research results of this paper not only guarantee the economical, safe and efficient operation of the open-pit mine but also provide a certain basis for the design and implementation of the composite slope project in similar conditions.

II. Analysis of Geological Conditions in the Slope Project

Pingshuo Antaibao open-pit mine is located at the northern end of Ningwu coal field. As the stope is advanced eastward and gets influenced by the anticline structure of the Luzi ditch, the dip angle of the coal bed suddenly increases. The floor of the coal bed drops from the height of about +1280m to +1020m to the east of the anticline influence zone. In some parts of the zone, the maximum decline reaches over 200m, which increases the thickness of the covering layer in the upper coal layer and the mining depth. Meanwhile, the stripping materials and the corresponding stripping ratio also rise. Great changes have taken place in mining technical conditions. Influenced by the land acquisition in the dump, the space of the outer dump is insufficient. In order to guarantee safety and improve economic benefits, the boundaries are limited at the southern end of Antaibao open-pit mine, so the boundary area is formed. This provides enough space for dumping and relieves the dumping pressure. In addition, it also causes the abrupt changes in the horizontal direction (east to west) on the earth's surface, and makes the overall mining boundary irregular. The limited boundary zone rises in the air towards north. At the western slope is 11, the floor of the coal bed. Its dip angle is approximately 19°, and the length is 1000m about from east to west and 800m from south to north. The shape is an inverted triangle. At the bottom of the limited boundary zone, the depth drops to 1105 level, which is about 200m away from the earth surface. The dumping is done horizontally in the boundary zone, and the eastern slope works as the retaining structure for the dump. The positions of the limited boundary zone are shown in Fig.1.

The strata of the limited boundary zone on the southern slope are the abandoned material layer, sandstone, 9 coal, sand and mudstones, 11 coal, and soft mudstone from top to bottom. When the basement of the dump is at +1105m level, the lithology of the stratum is sandstone. At the bottom of No. 11 coal bed is mudstones with relatively weak physical and mechanical indexes. As the slope and the dumping load constantly increase, the composite slope with a height of more than 300m will be formed on the slope of the stope below +1105m and at the dump above +1105m after the soil is discharged in the southern limited boundary zone. Therefore, there is a great hidden danger of landslide. Physical and mechanical indexes of the rock and soil mass in various strata are shown in Table 1.

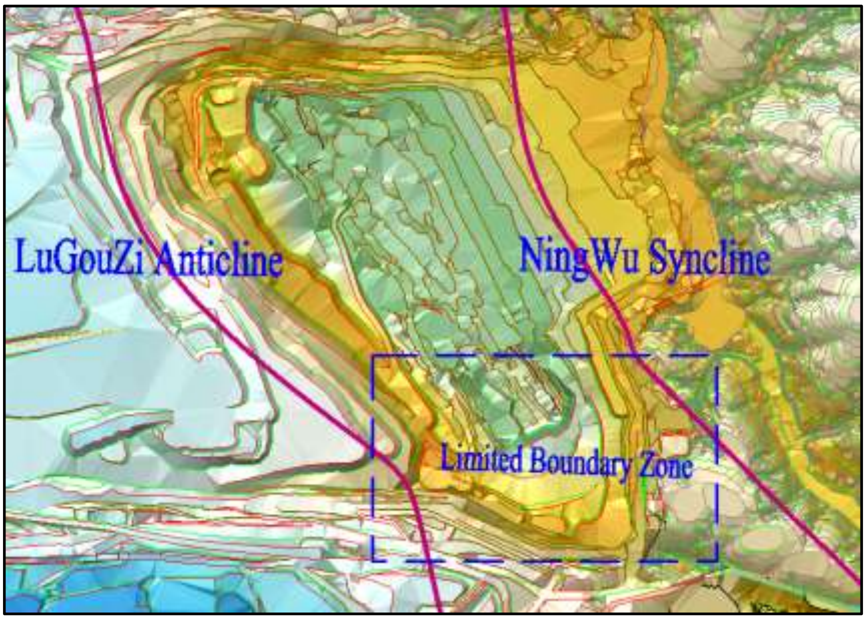

Fig.1: The positions of the limited boundary zone

Tab 1 Physical and mechanical parameters of rock and soil mass

Name	Bulk density（KN/m^3）	Cohesion（Kpa）	Interior friction An（°）
Wastes	18.7	16-18	16-18
Quaternary Loose Layer	19.5	22-25	21-22
4 Coal	14.1	160	22
9 Coal	14	160	22
11 Coal	14.2	160	22
Sandstone	24.6	272	37.7
Sand Shale Interbed	24.6	300	28
Weak Mudstone	15	43	16
Bedrock	25.2	950	30

III. Composite Slope Stability Analysis

In order to optimize the design of the composite slope forms in the southern limited boundary zone, the paper is based on the comprehensive consideration of the geological characteristics of the composite slope project in the southern limited boundary zone of Antaibao open-pit mine. Two typical sections (both perpendicular to the working line of the inner dump) are selected for analysis and calculation, namely, I-I section and II-II section.The planemetric position of the geological section is shown in Fig. 2, and the geological section of the slope project is shown in Fig. 3.

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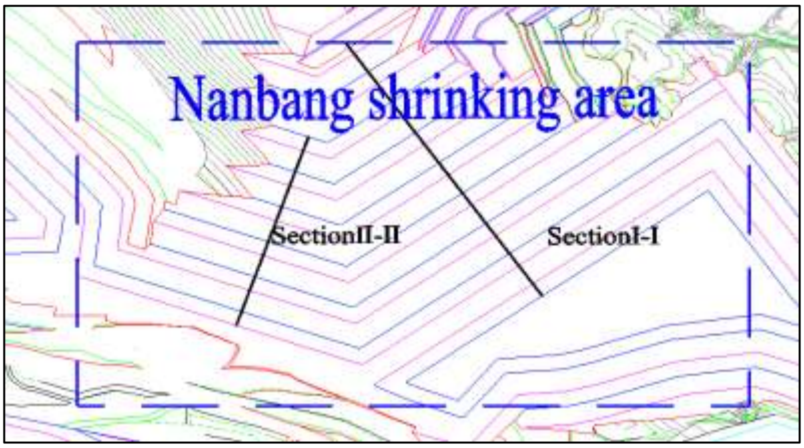


Fig.2: Sectional position plan

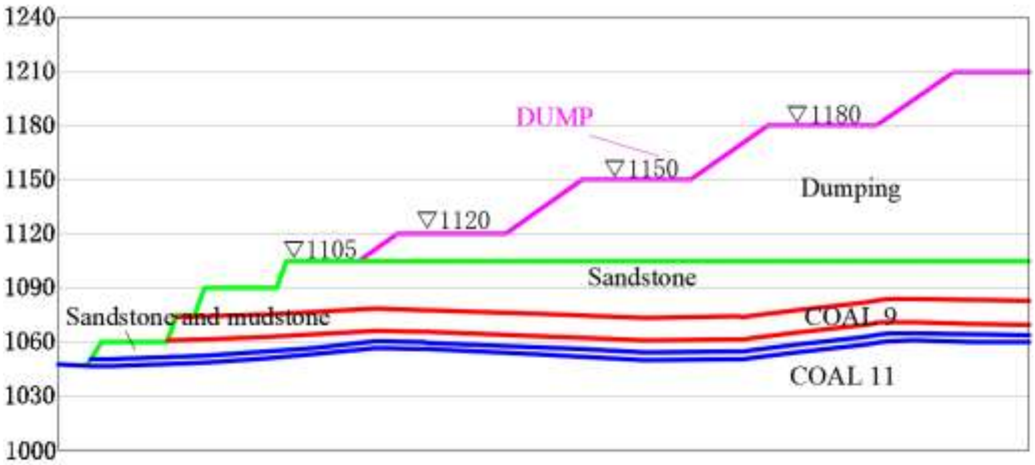


Fig.3: Slope engineering geological profile

3.1 Safety reserve coefficient selection

The limit equilibrium analysis method is used for slope safety evaluation and analysis. The safety reserve coefficient K is a quantitative parameter in the slope stability analysis and calculation, and its value is directly related to the fact whether the designed slope is economically feasible and safe and reasonable[18]. Based on the current understanding of structural conditions, regional geological conditions and the importance of slope at Antaibao open-pit mine, the following factors including the physical and mechanical indexes of rock and soil mass, service life, potential hazards, importance, etc. are taken into consideration while selecting the safety reserve coefficient for the calculation of the composite slope stability in accordance with the requirement in Codes For the Design of Open-Pit Mines in Coal Industry[19] (GB50197-2015). And it is determined that the selected safety reserve coefficient of the slope should be 1.2 in the design and calculation of the composite slope in the southern limited boundary zone.

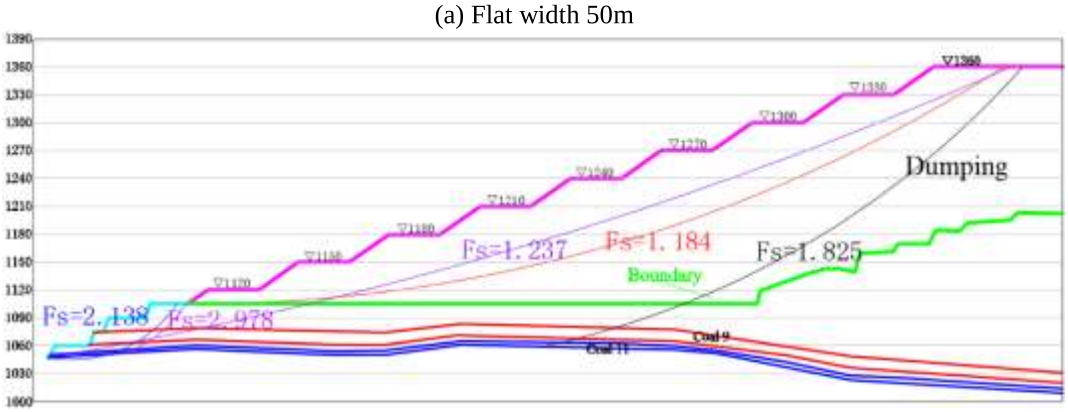
3.2 Quantitative analysis of composite slope stability

According to the field research, the dumping bench height is 30m, the bank slope is 35°, and the dumping elevation is 1,360 in the design of the southern limited boundary zone at Antaibao open-pit mine. To determine the optimum safe distance and the optimum dumped flat plate width between the dump and the stope slope of the limited boundary zone, this paper first makes a stability calculation of the composite slope of the dump when the dumping flat plate widths are different. Next, it obtains the dumping plan that satisfies the safety reserve coefficient and then compares different plans. Finally, it works out the plan of the maximum dumping quantity in the limited boundary zone on the premise of ensuring safety.

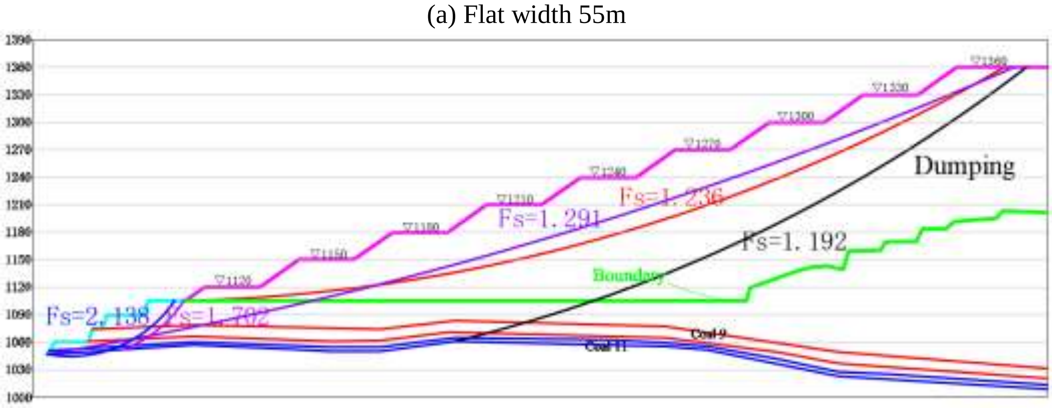
3.2.1 I-I section slope stability calculation

Regarding the slope engineering conditions of I-I section, when the safe distance between the stope lope and the dump is 40m, 50m and 60m, and the dumping flat plate width is 50m, 55m and 60m, respectively, the stability coefficient of the composite slope is designed and calculated. In all, nine composite slope forms of the limited boundary zone are obtained. The results of the stability coefficient calculation are shown in Fig. 4-6. The important indicators of each plan are shown in Table 2.

(a) Flat width 50m



(a) Flat width 55m



(a) Flat width 60m

Fig.4: Analysis results of slope stability in section I-I when the safe distance is 40m

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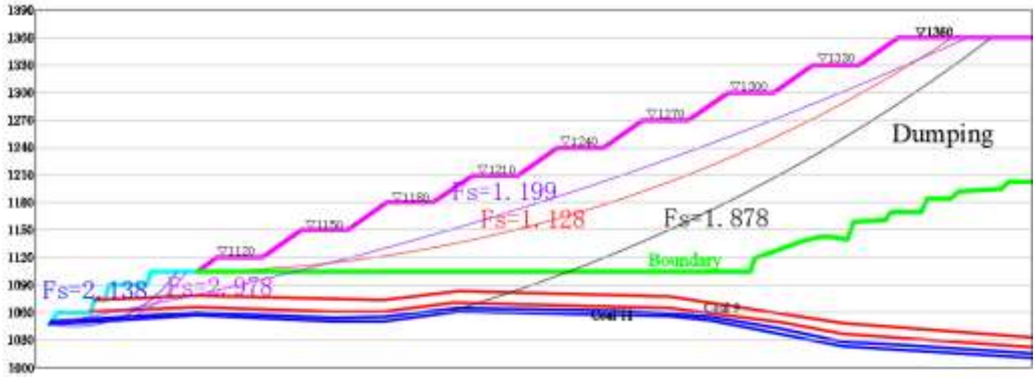
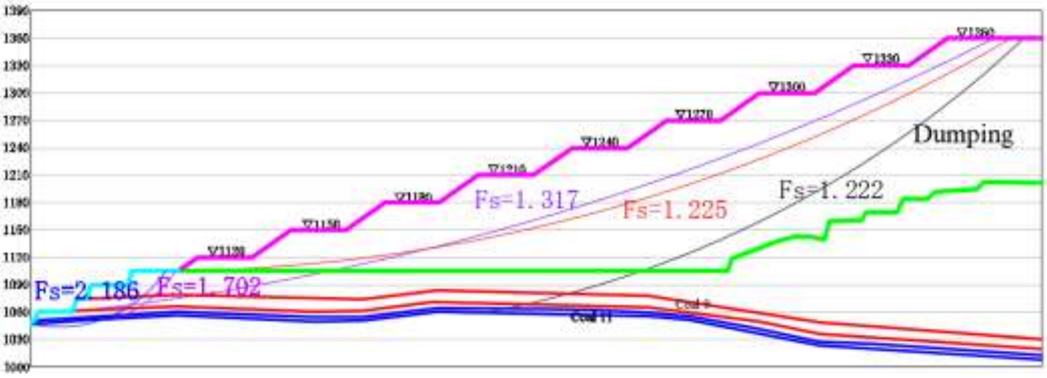


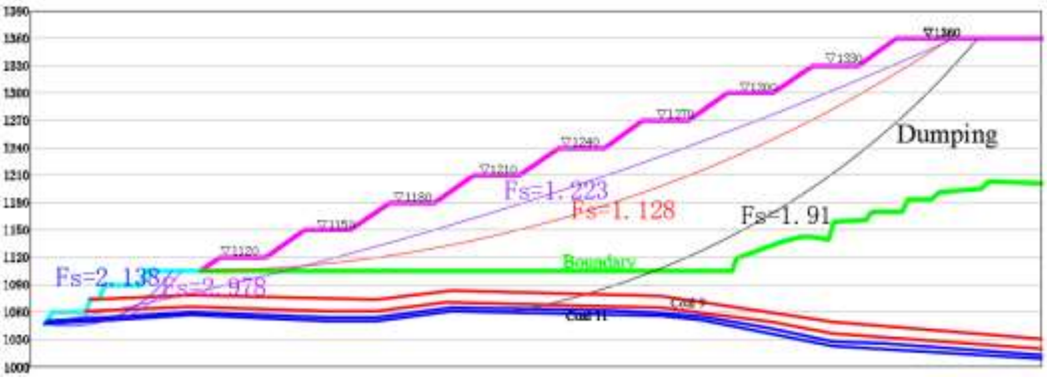
(a) Flat width 50m

(a) Flat width 55m



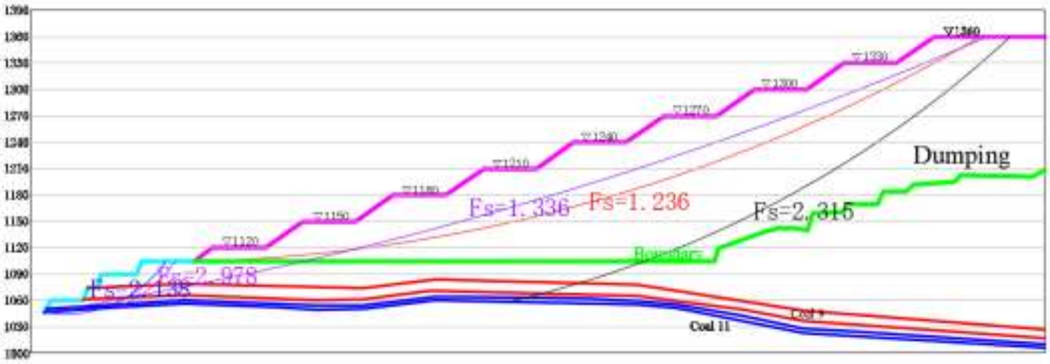
(a) Flat width 60m

Fig.5: Analysis results of slope stability in section I-I when the safe distance is 50m



(a) Flat width 50m

(a) Flat width 55m



(a) Flat width 60m

Fig.6: Analysis results of slope stability in section I-I when the safe distance is 60m

Tab 2 Calculation results of slope stability in I-I profile with different safety distances and width of plate

Scheme	Safe distance	Width /m	Slope angle of battery limit /°	Slope angle of dump /°	Fs	Rejection height/m	Discharge volume/ $10000m^3$
Scheme 1		50	18.9	18.5	1.113	75	1602.02
Scheme 2	40	55	18.2	17.6	1.155	195	7057.47
Scheme 3		60	17.5	16.8	1.192	195	6706.07
Scheme 4		50	18.7	18.5	1.116	75	1595.12
Scheme 5	50	55	18	17.6	1.175	195	6750.84
Scheme 6		60	17.3	16.8	1.228	255	9593.41
Scheme 7		50	18.5	18.5	1.128	75	1588.22
Scheme 8	60	55	17.8	17.6	1.184	195	6444.21
Scheme 9		60	17.1	16.8	1.236	255	8394.21

According to Table 2, the dumping plans that satisfy the composite slope safety coefficient 1.2 include: plan 6 and plan 9. From the established three-dimensional geological model of Pingshuo Antaibao open-pit mine and the block model operand, it can be known that: the total dumping amount of Plan 6 and Plan 9 is 95,934,100 m^3 and 83,942,100 m^3, respectively. By comparison, Plan 6 can achieve the maximum dumping volume in the southern limited boundary zone on condition that the safety and stability coefficient is satisfied, which effectively relieves the dumping pressure and makes technology workable at reasonable economic costs. Therefore, Plan 6 is chosen as the plan for dumping soil in the limited boundary zone.

3.2.2 II-II section slope stability calculation

The direction of the dumping working line is mainly determined by the angle of the working line. The reasonable angle of the working line is obtained by calculating the safety and stability coefficient of the slope with different

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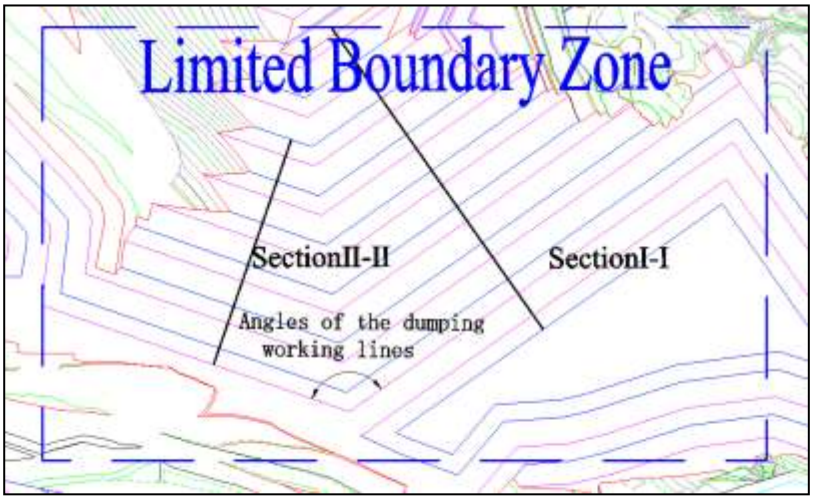
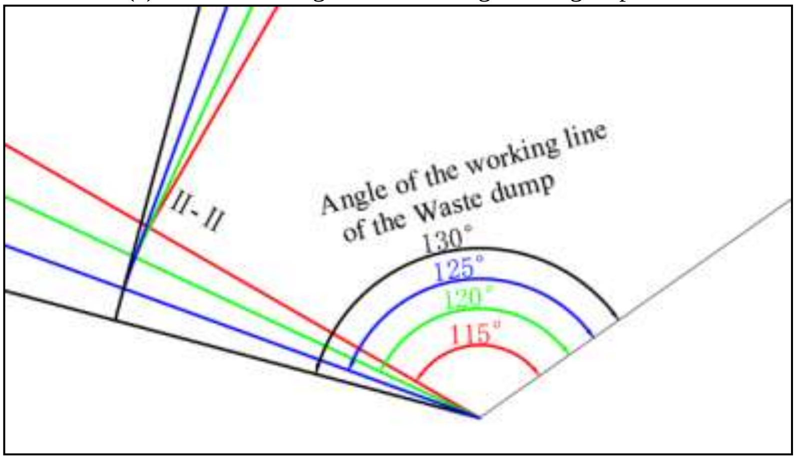
working line directions in the II-II section. Finally, the parameters of the composite slope on the southern slope of the limited boundary zone are obtained by combining the calculation results of the sections I-I and II-II. The working line angle diagram of section II-II is shown in Fig 7. Fig. 7 (a) is the spatial sketch map of the working line angle. When the profile is selected, the profile line should be perpendicular to the direction of the working line on the dumping step. Therefore, the dumping working line angles are different, so the directions of the II-II profile lines are also different. Fig. 7 (b) is the plane sketch map of the working line angle. The left II-II profile line is the profile position corresponding to different working line directions.



(a) Schematic diagram of working line angle space

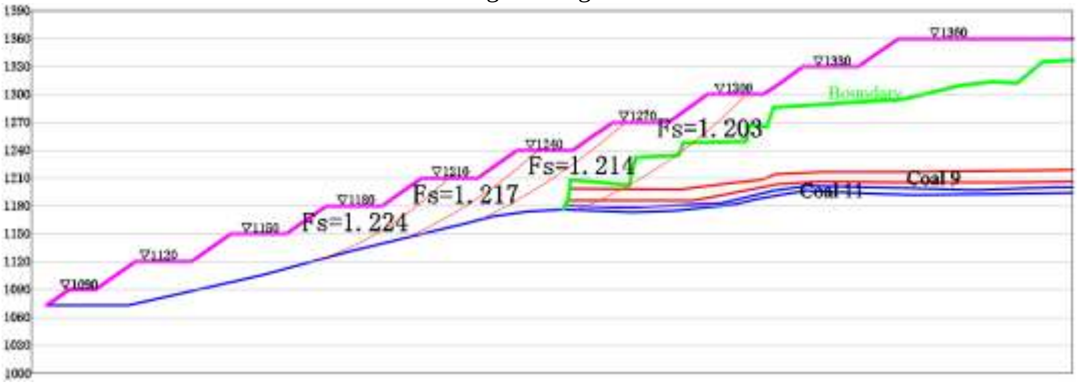


(b) Schematic diagram of working line angle plane

Fig.7: Section II-II position and working sketch line Angle

By changing the angle of the dumping working line on the southern slope of the limited boundary zone, the safety and stability coefficient of II-II section is first calculated when the dumping flat plate width is 60m, the dumping elevation is 1,360m, and the angles of the dumping working lines are different. Finally, the optimum working line angle of dumping is determined. Regarding the slope engineering conditions of II-II section, the slope stability coefficient is calculated when the dumping flat plate width is 60m, the dumping elevation is 1,360m, and the angles of the dumping working lines are 120°, 125°and 130°. The calculation results are shown in Fig. 8. Through calculation and analysis, the slope stability results of II-II section is shown in Table 3.

Working line angle 120 °



Working line angle 125 °

Working line angle 130 °

Fig.8: Calculation results of slope stability of II-II section under different working line angles

Tab 3 Section II-II slope stability calculation results table

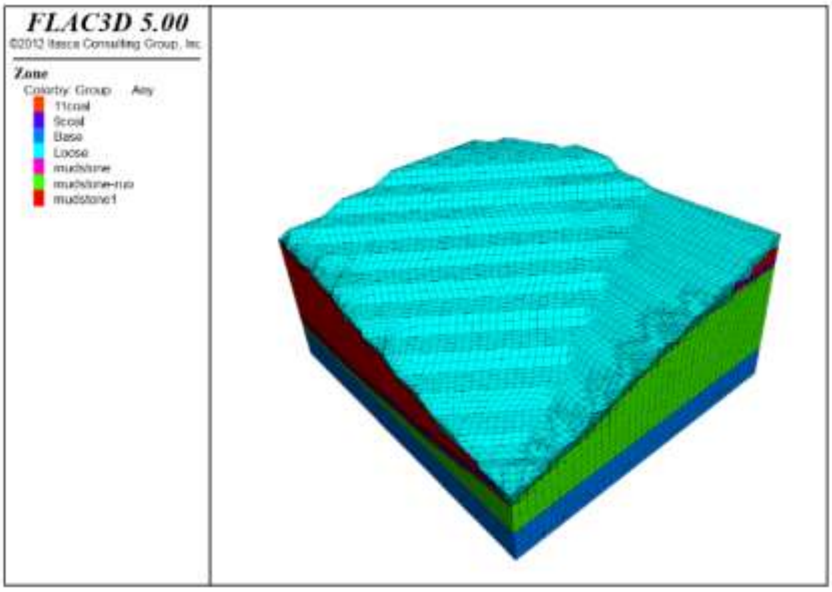
Working line angle /°	Width of dumping pan /m	Rejection height /m	Fs
120	60	1360	1.154
125	60	1360	1.203
130	60	1360	1.248

When the included angle of the dumping working line is 125°and the slope stability coefficient is 1.203, the safety reserve coefficient is satisfied. Meanwhile, the landslide pattern of the slope is a combination of tangent sliding and translational sliding.

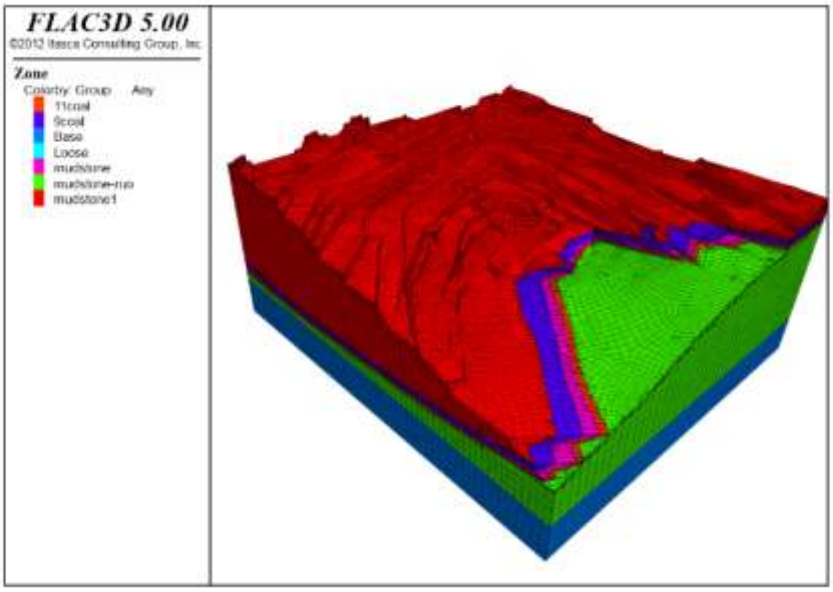
The calculation results of I-I section and II-II section are combined to obtain the reasonable economic parameters of the composite slope on the southern slope of the limited boundary zone. They are as follows: the safe distance between the stope slope and the dump is 50m, the dumping flat plate width is 60m, and the angle of the dumping working line is 125°.

IV. Numerical Simulation

The traditional two-dimensional limit equilibrium method fails to study the complex stress analysis and constitutive relationship within the rock and soil materials. Moreover, it also can't accurately describe the process of slope instability caused by changes in the internal structure of the slope. FLAC^{3D} is a method to simulate and analyze the geometry based on Lagrange difference method, and it is widely used in the analysis of discontinuity and nonlinearity in the rock mass structure. To a certain extent, it can avoid the difference that sliding body is regarded as rigid body in the two-dimensional analysis process. Therefore, numerical simulation should be used as a supplement in studying the stress-strain relationship and stress distribution of the slope rock mass. Therefore, FLAC^{3D} software is used in this section to simulate the composite slope on the southern slope of the limited boundary zone at Antaibao open-pit mine. The three-dimensional slope calculation model should be close to the engineering practice, so that the calculation model and calculation results are more accurate. Due to the complexity of FLAC^{3D} modeling, 3DMine and Rhinoceros software are used for modeling pre-processing, and then mesh is divided for the 3D geological model. Based on the data collected on the composite southern slope of the limited boundary zone at Antaibao open-pit mine, the safe distance between the stope slope and the dump is 50m and the dumping flat plate width is 60m and the angle of the dumping working line is 125°. And then FLAC^{3D} model for the southern slope of the limited boundary zone is established through stratification, as shown in Fig. 9(a). The stratified model diagram of numerical simulation is shown in Fig. 9 (b).

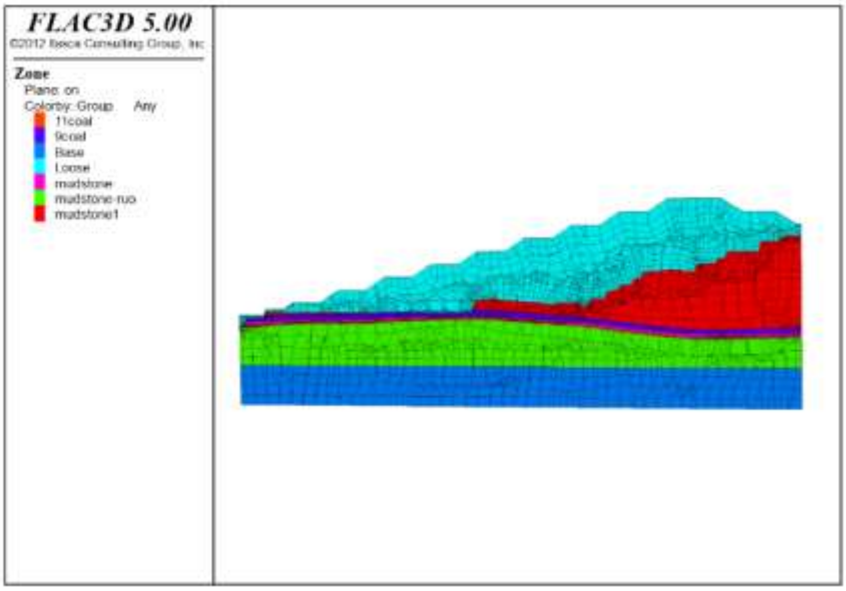


(a) Three dimensional numerical simulation model diagram



(b) Layered model of Three dimensional numerical simulation

Fig.9: Three-dimensional numerical simulation layered modelIn the diagram of numeric simulation, 290,998 units and 128, 638 nodes are divided, respectively. According to the geological conditions on the southern slope of the limited boundary zone at Antaibao open-pit mine. The corresponding three-dimensional slope model is made up of dumped materials, sandstones, 9 coal, sand-mudstone, 11 coal, soft mudstones and basements from top to bottom. The numeric simulation results of the slope stability in I-I and II-II sections are shown in Fig. 10.



(a) Three dimensional numerical simulation model of section I-I

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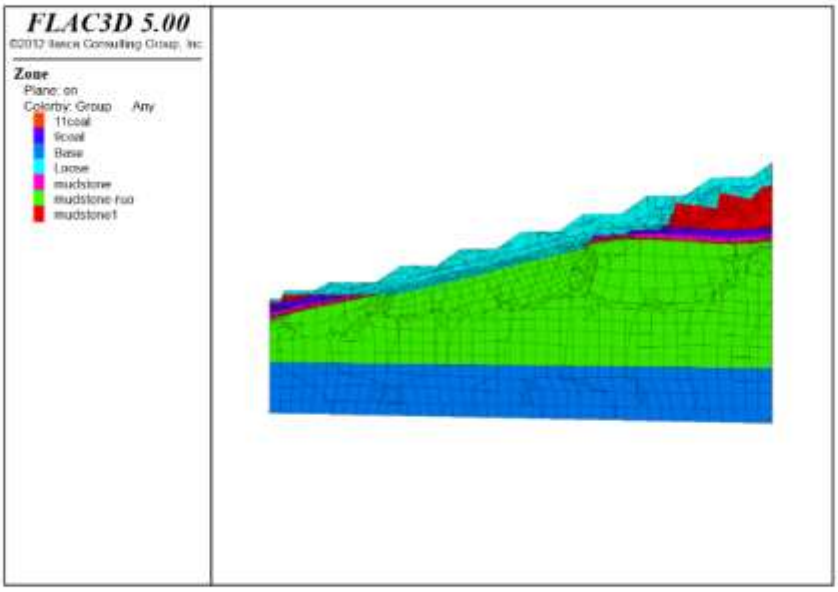
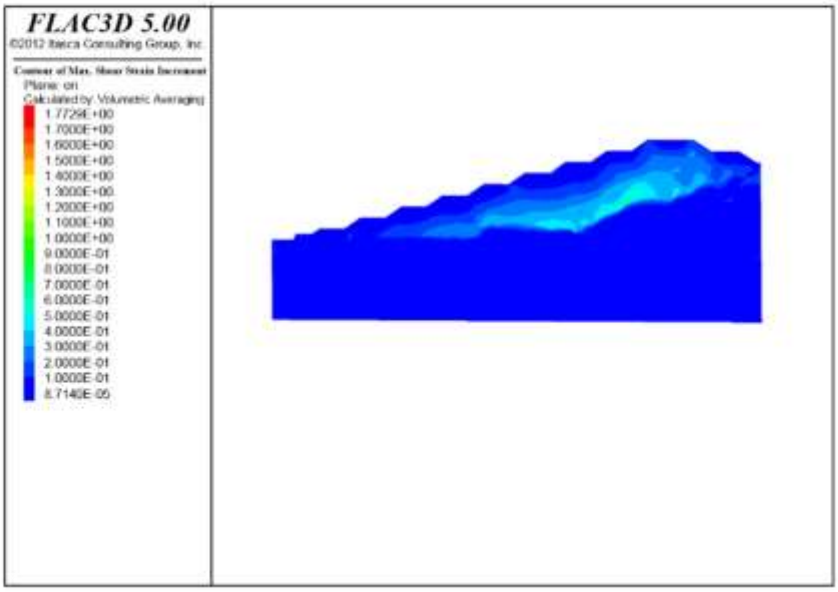


(b) Three dimensional numerical simulation model of section II-II



(c) Shear strain increment diagram of section I-I

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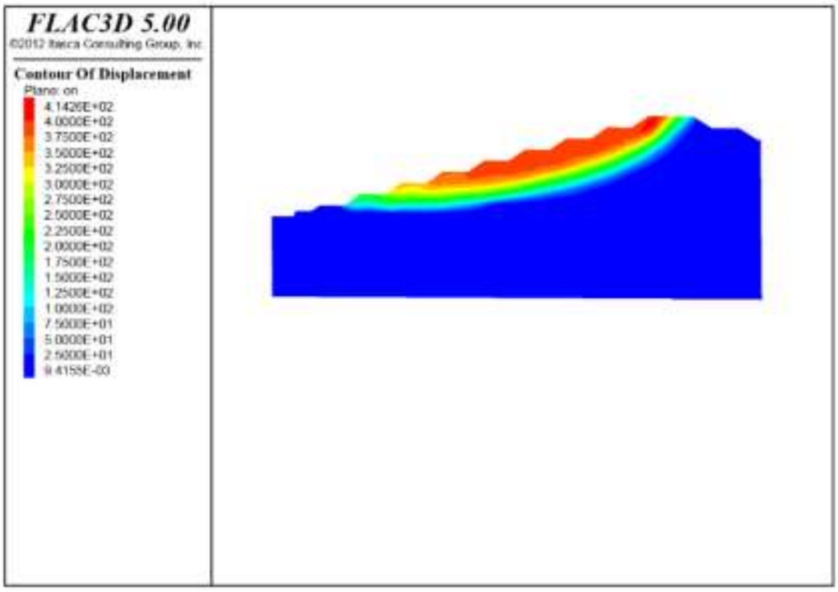
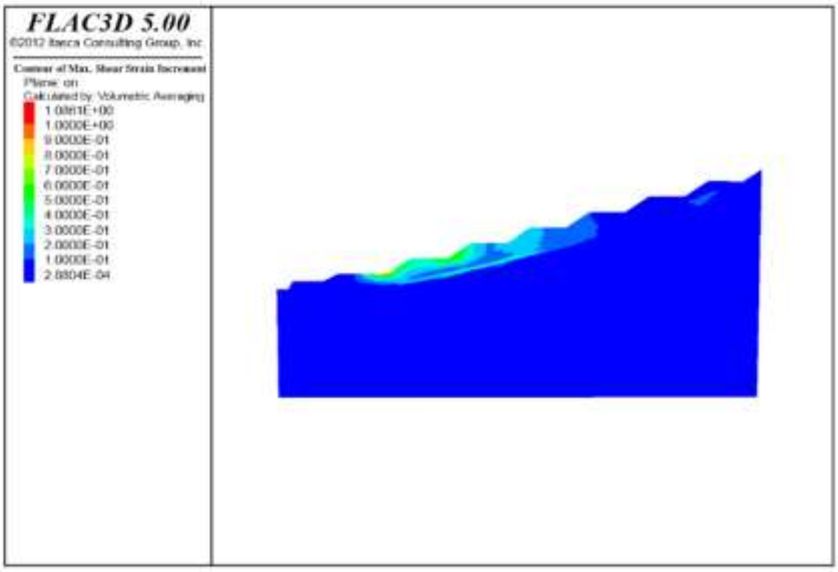
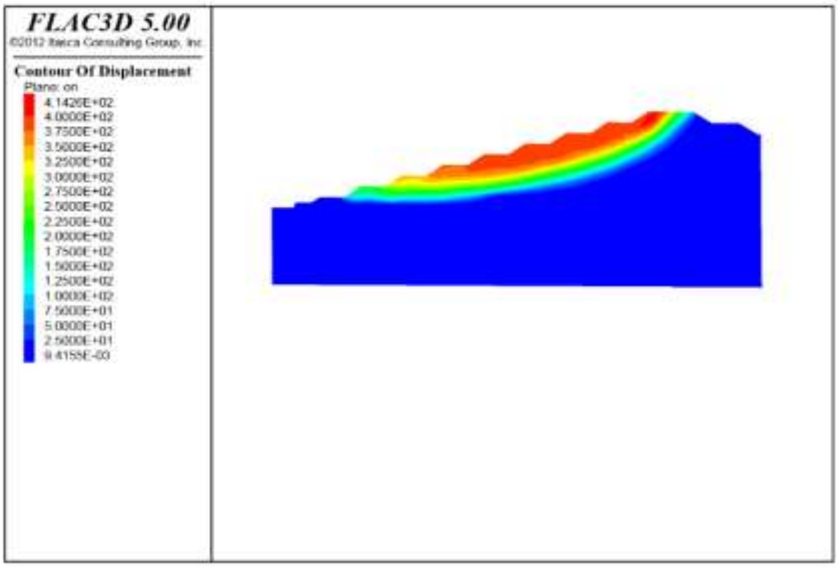


(d) Maximum displacement map of section I-I



(e) Shear strain increment nephogram of section II-II



(f) Maximum displacement nephogram of section II-II

Fig.10: Slope numerical simulation

(1) Fig. 10 (c) is the shearing stress increment figure when the I-I section slope is at critical failure, and Fig. 4.4 (e) is the shearing stress increment graph when the I-I section slope is at critical failure. It could be known from the simulation results that the rock mass damage of the slope is mainly caused by shearing strain. The positions of the stress concentration, the potential positions of the failure surface and the obvious stress changes can be clearly seen in the Fig.

(2) Fig. 10 (d) is the maximum displacement figure when the I-I section slope is at critical failure. It can be clearly seen from the figure that the slope makes circular slide easily along the dumped materials under the impact of dead load and crustal stress. Fig. 4.4 (f) is the maximum displacement figure when the II-II section slope is at critical failure. It can be clearly seen from the figure that the displacement changes appear along the shear failure of 11 coal floor. When the slope is under the impact of dead load and crustal stress, the combined failure of tangent sliding and translational sliding easily happen along 11 coal floor.

The paper aimed at the composite slope forms on the southern slope of the limited boundary zone at Antaibao open-pit mine. Based on the results achieved through the quantiative method of the two-dimensional slope stability and the strength reduction theory, FLAC^{3D} finite difference calculation software was used for the three-dimensional numeric simulation calculation of the composite slope. The simulated result is consistent with the analyzed result of the two-dimensional limit equilibrium method. Meanwhile, they verified the sliding pattern.

V. Conclusions

(1) When the slope is under the combined action of dead load and crustal stress, the shear failure happens inside the slope. The sliding pattern is a combination of circular sliding and the tangent-translational sliding.

(2) Through the integration of I-I section and II-II section, the rigid limit equilibrium method was used to obtain the reasonable economic parameters of the composite slope on the southern slope of the limited boundary zone. They are as follows: the safe distance between the stope slope and the dump is 50m, the dumping flat plate width is 60m, the dumping elevation is 255m, the angle of the dumping working line is 125°and the total dumping space is 95,934,100 m^3.

(3) FLAC^{3D} numeric simulation software was used for the simulated calculation of the southern composite slope in the limited boundary zone. It could be known that the sliding pattern and the stability of the composite slope are

mainly controlled by the safe distance between the stope slope and the dump together with the soft layers of 11 coal bed. In addition, the simulated result was consistent with the analyzed result of the two-dimensional limit equilibrium method. It proved that the sliding pattern is a combination of circular sliding and tangent-translational sliding.

Acknowledgements

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