



Slope stability of increasing height and expanding capacity of south dumping site of Hesgoula coal mine: a case study

Weidong Pan¹ · Weiliang Pan¹ · Jianyang Luo¹ · Long Fan² · Shaocheng Li³ · Ulziikhutag Erdenebileg⁴

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Abstract This paper is devoted to improve the containment capacity of the Hesgoula south dumping site. The general geology of the dumping site was obtained through geological surveys. Physico-mechanical properties of silty clay and bedrock layers that have a large impact on the stability of the dump were measured by direct shear tests and triaxial tests in laboratory. Then ultimate bearing capacity of the substrate were analyzed and calculated. This paper proposed three capacity expansion and increase plans and used GeoStudio software for comparison. Through computation of the stability of the dump site slope after capacity expansion and increase for each plan, the capacity expansion plan was determined. The capacity expansion and increase plan will solve the problem of the current insufficient containment capacity of the Hesgoula south dumping site, which is of great significance for saving mine transportation costs, improving work efficiency, and reducing grassland occupation.

Keywords Dump slope · Increasing height and expanding capacity · Soft base · Ultimate bearing capacity

1 Introduction

In recent years, open-pit mining technology has developed rapidly (Nolan and Kecojevic 2014; Long et al. 2018; Ozdemir and Kumral 2019). The Hesgoula Open-pit Coal Mine is located in the Wulagai Management Zone of Xilin Gol League in Inner Mongolia Autonomous Region. It is invested and developed by Inner Mongolia Xilinha Coal Chemical Industry Co., Ltd. The production of the first-stage of the mine is 3.0 Mt/a, which reached production in

2008; the production of the second-stage is 15.0 Mt/a, which reached production in 2012. At present, there are two pits for the production of Hesgoula Open-pit Coal Mine, and the mining depth is between 70 and 100 m. There are three outer dumps, the east dump, the south dump, and the north dump, and the loading height is about 60 m. Among them, the north dump and the east dump have reached the containment capacity and the south dump has a limited containment capacity. At present, the maximum design elevation of the south dump is + 970 m, and the maximum loading height is about 60 m. With the mining of the second mining area, the stripped material is mainly discharged to the south dump. It is expected that there will be a lack of containment capacity of about 1.5 Mt.

In 2011, due to the severe impact of rain in the rainy season, the large groundwater in the mining area resulted in a large volume local landslide in the northeast of the south dumping site during the dumping process. Due to insufficient base bearing capacity in the south of the south dumping site, the soil at the bottom of dumping site bulged, and the height of the bulge was about 15 m. Moreover, the

✉ Weidong Pan
pwd@cumtb.edu.cn

¹ School of Energy and Mining Engineering, China University of Mining and Technology, Beijing 100083, China

² College of Earth and Mineral Sciences, Pennsylvania State University, State College 16802, USA

³ Beijing China Mine Reliance Coal Science and Technology Research Institute, Beijing 100083, China

⁴ Geoscience, Geoengineering and Mining Faculty, TU Bergakademie Freiberg, 09599 Freiberg, Germany

south dumping site is close to the southwest side of the second mining area. Once a large-scale landslide is caused, it is very likely to cause serious damage to the end side of the second mining area and form a secondary disaster. In addition, there are a large number of buildings and highways in the southeast of the Hesgoula dumping site, whose stability not only affects normal dumping operations, but also seriously threatens people's property safety. Therefore, in the case that it is temporarily impossible to achieve all internal soil drainage and land acquisition, the soil dump needs to be further expanded and increased, thereby solving the problems of the increasingly prominent production stripping of the Hesgoula surface coal mine and the serious lack of soil dumping capacity. Researchers have done a lot of research in these areas.

The limit equilibrium method is a common method for analyzing slope stability, which has the advantages of simple principle, simple calculation, and practical results (Pan et al. 2019). In 1916, Petersson concluded that the shape of the soil when it was damaged was approximately arc-shaped based on a large number of experiments, and proposed the original Swedish arc method (Wu 2017). Lu and Liu (2016) used two kinds of limit equilibrium methods to compare and analyze the ultimate bearing capacity of the dump site base. It is shown that Sakarowski's theory is based on the theory of loose media, which is more suitable for analyzing the ultimate bearing capacity of the dump site. Li et al. (2011) elaborated the problems that seven different limit equilibrium methods should pay attention to in the stability analysis of dump sites, and compared and analyzed the calculation accuracy of these limit equilibrium methods. Poulsen et al. (2014) analyzed the stability of the dumping site based on the limit equilibrium method and continuous media and found that when the strength of the basement is weak, the basement plays a leading role in the stability of the dumping site. At this time, the failure mode of the dump is double wedge failure, and the slip surface of the failure is straight. Tanja and Chrysothemis (2019) used SRF from two oak quarries in England to perform slope stability analysis. The characteristics of the extremely weak Sherwood sandstone were studied, and the stability evaluation was performed using finite element analysis and limit equilibrium method, and a geometry suitable for the slope was proposed (Zhao et al. 2019; Cao et al. 2019; Wang et al. 2019; Li et al. 2018).

Numerical simulation and similarity simulation experiments are also important methods to study the slope stability of dumping sites. Zhang et al. (2017) carried out a study on the stability of the dumping capacity of the Hunchun open-pit mine in consideration of particle size classification. The stability of the original dump and the expanded dump was analyzed using FLAC3D. Based on the establishment of a three-tiered step model, the stability

of the entire dump slope and each layer were analyzed. Sun et al. (2010) numerically simulated the change of the stress field during the dumping process of the dumping site with thick and soft silty clay with low water content. The research determined the change of the main stress vector of the dump site with the increase of the stacking. It is considered that the combination of the middle silty clay layer and the upper rejects or the silty clay layer and the lower bedrock is the dominant weak layer in the dump. Guan (2013) used FLAC3D to analyze the landslide mechanism of the internal dump site in the soft loess substrate of the open-pit mine. The results show that the strength of the rejects and the soft base layer, the height of the rejects, and the slope angle are the main external causes of the destruction of the internal dump. The landslide of the internal dump is mainly due to the tensile and shear damage of the rejects. Shear failure, followed by plastic deformation of the base, eventually causes the internal dump to slip along the base. Ogbonnaya and Chidinma (2019) studied the stability of the slopes of the Enigma tailings reservoir in southeastern Nigeria. They studied the geotechnical parameters of the slope and used GeoStudio for stability analysis to calculate the safety factor of slope stability. Ji (2013) used similar simulation experiments to perform rheological simulation on the loess substrate dump site, and monitored the relationship between the shear stress and normal stress of the soft silty clay layer at different times during the experiment. The bottom friction experiment was conducted to study the landslide mechanism of the inclined soft base dump site and concluded that the soft base of the dump site is a controlling factor in the deformation and failure of the dump site and affects its failure mode. GeoStudio is widely used in the slope stability analysis (Nakamura et al. 2013; Yu 2017; Xu et al. 2014; Lu 2016; Yang et al. 2016a, b).

In addition, there are many studies on the expansion and increase of dumping sites. Li (2017) analyzed the stability of the Xiaowangzhuang dumping site to increase the capacity and increase the slope. The relevant physical and mechanical parameters of the rock and soil were obtained through experiments and the current stable state of the dump site slope was calculated and analyzed. Ding (2017) optimized the slope parameters of the Antaibao open-pit mine dump to increase capacity, proposed an expansion and increase plan for the impact of anticline structures, and analyzed the method of bearing capacity and limit equilibrium of the basement. Zhou (2016), based on the theoretical analysis of the stability of the internal slope of the dumping site of the Harwusu open-pit mine at different stages, used the limit equilibrium theory to obtain the stability coefficients of the four main positions, and analyzed the increase plan. Yang et al. (2016a, b) analyzed the factors affecting the slope stability of the Nansigou

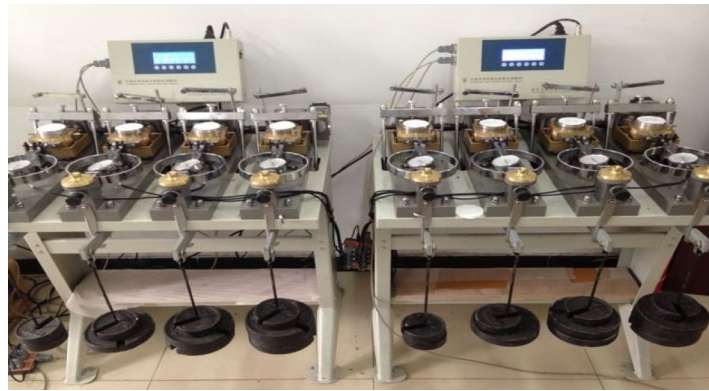


Fig. 1 Quadruple stepless variable-speed strain-controlled direct shear

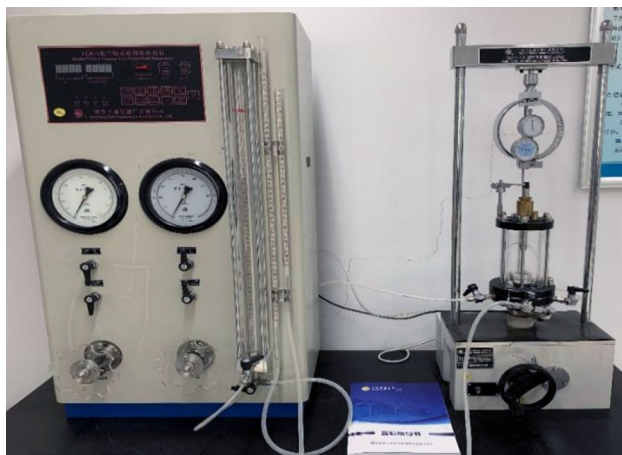


Fig. 2 Triaxial test measurement controller

dumping site, and verified the landslide model using computer numerical simulation software. At the same time, based on the calculation results of the ultimate bearing capacity of the basement, the soil discharge parameters were determined. Li et al. (2015) studied the stability and expansibility of the dump site of the Qidashan Iron Mine, set the parameters of the dump site slope model, and used the limit equilibrium method to calculate the slope safety factor.

At present, most of the research on the stability of dumping sites in surface mines has focused on the safety factor of slope stability, factors affecting the deformation and failure of dump sites, and limit equilibrium analysis, mostly theoretical analysis. GeoStudio software is rarely used to analyze the stability and safety factor of slopes in existing studies that combine the specific engineering background to expand and increase the dumping site. This paper will use GeoStudio software to analyze the Heshgoula dumping site for capacity expansion and increase plans.

2 Geology condition of the study area

The Heshgoula Open-pit Coal Mine is part of the Heshgoula Pasture Coalfield. It is located 67 km southwest of Bayan Husuo Town, Xilin Gol League, Inner Mongolia, in the Uragai jurisdiction. The mining area has a continental climate, with cold winters and hot summers, and drought and little rain. The swamp terrain of the mining area is low-lying and densely swamped. The surrounding area is low-mountain terrain, and the altitude is generally around 1100 m. The Heshgoula Coal Mine is located in the ridge of the southern section of the Greater Xing'an Mountains and is a mountain basin spreading from north to north. The basin is 45 km long with an average width of about 5 km. The terrain in the basin is generally high in the north (about 960 m above sea level) and low in the south (about 910 m above sea level). Strata exposed around coal-bearing basins are: Lower Permian light metamorphic rocks and Upper Jurassic volcanic rocks. The basin contains the Lower Cretaceous coal-bearing rock series, Tertiary, and Quaternary. According to drilling data, the south dump site layer is mainly composed of discarded material, base silt, and clay in the second mining area, and the fault is not developed.

To obtain the geotechnical physics suitable for this study, laboratory tests on a large number of physical and mechanical parameters of rock and soil were performed. The direct shear test was performed on soil samples by using a quadruple stepless variable-speed strain-controlled direct shear instrument, as shown in Fig. 1. The triaxial compression test of soil samples was also conducted using TCK-1 triaxial test measurement controller and TSZ10-1.0 strain-controlled triaxial instrument, as shown in Fig. 2. The results of laboratory tests were combined with the previous geological survey report of the area to comprehensively analyze various parameter indicators (Wang et al. 2005). The physical and mechanical properties of rock and soil are shown in Table 1.

Table 1 Recommended physical and mechanical indexes of rock and soil

Lithology	Density ρ (g/cm ³)	Moisture content w (%)	Saturation, S_r (%)	Cohesion C (kPa)	Inner friction angle φ (°)
Southern discarded materials	1.82–1.87	22.6–27.1	74–82	31.5–42.0	11.8–14.2
Southern silty clay	1.77–1.95	21.0–34.0	69–99	22.1–69.4	10.9–18.7
Southern clay	1.69–2.01	20.8–41.5	84–99	38.9–169.9	9.9–42.0
Western discarded material	1.88–1.95	22.8–36.9	79–87	29.7–55.9	13.7–21.0
Western silty clay	1.96–2.01	21.5–23.4	58.2–92.5	32.8–56.1	16.0–29.9
Western clay	1.78–1.99	21.8–39.5	82–97	35.7–133.2	10.2–40.0
Northern discarded material	17.9–1.94	24.9–27.6	65.8–92.3	28.6–48.8	15.8–22.4
Northern silty clay	1.85–2.03	22.2–25.8	76–99	29.3–57.9	17.2–18.0
Northern clay	1.74–2.01	23.8–39.5	79–97	36.7–121.2	10.8–42.2
Eastern discarded material	1.80–1.88	22.5–32.0	79–87	42.3–50.4	7.3–15.4
Eastern silty clay	1.73–2.02	22.8–40.4	84–97	34.8–169.4	11.1–21.3
Eastern clay	1.76–1.98	23.9–39.2	81–95	35.7–101.2	10.2–32.2

The waste with high moisture content at the bottom of the dump is of low strength, which is the key layer that leads to internal destruction of the waste. The Tertiary clay layer with high water content is a weak basement layer, which is the main stratum in which the basement undergoes shear failure. This clay layer has large occurrence thickness and high water content. Mudstone is a relatively stable supporting layer in the basement.

A dozen of geological survey boreholes were obtained through exploration geological drill on the dumping site. According to the geological data of the boreholes ZK1,ZK2,ZK5,ZK6,ZK7,ZK8,ZK9 and the field measured parameters, the profile coordinates of south dumping site are recorded in Table 2. The typical engineering geological profiles are shown in Fig. 3.

As shown in Table 2 and Fig. 3, 8 profile coordinates are recorded, from PM1 to PM8, and 4 typical engineering geological profiles are presented, which are PM1, PM3, PM4, and PM6.

3 Calculation of ultimate bearing capacity of dump substrate

3.1 Bearing mode

There are two main failure modes of the open-pit mine dumping site instability. One is the undercutting instability of the dump site caused by insufficient load capacity of the basement of the dump site. The other is sliding instability controlled by the properties of the rejected material and the strength of the weak base layer (He and Yan 1999). This chapter mainly studies the ultimate bearing capacity p_u of the basement in the dump site undercutting. Using the formula of Taisha foundation ultimate bearing capacity, the stability of the dump is evaluated from the perspective of the bearing capacity of the substrate

$$p_u = \frac{1}{2} \gamma_0 b N_\gamma + c N_c + q N_q \quad (1)$$

Table 2 Coordinates of engineering geological profile of the south dumping site

Profile name	Profile coordinates
PM1	Starting coordinates (428,788.5, 5,086,176) End coordinates (428,286.6, 5,085,957)
PM2	Starting coordinates (429,286.1, 5,086,131) End coordinates (429,405.0, 5,085,735)
PM3	Starting coordinates (429,816.6, 5,086,635) End coordinates (430,166.0, 5,085,999)
PM4	Starting coordinates (429,710.9, 5,086,843) End coordinates (430,190.3, 5,087,338)
PM5	Starting coordinates (429,668.3, 5,087,043) End coordinates (430,194.1, 5,087,545)
PM6	Starting coordinates (428,990.6, 5,086,762) End coordinates (428,711.0, 5,087,068)
PM7	Starting coordinates (429,288.8, 5,088,345) End coordinates (428,688.9, 5,087,673)
PM8	Starting coordinates (429,447.8, 5,088,977) End coordinates (430,124.3, 5,088,690)

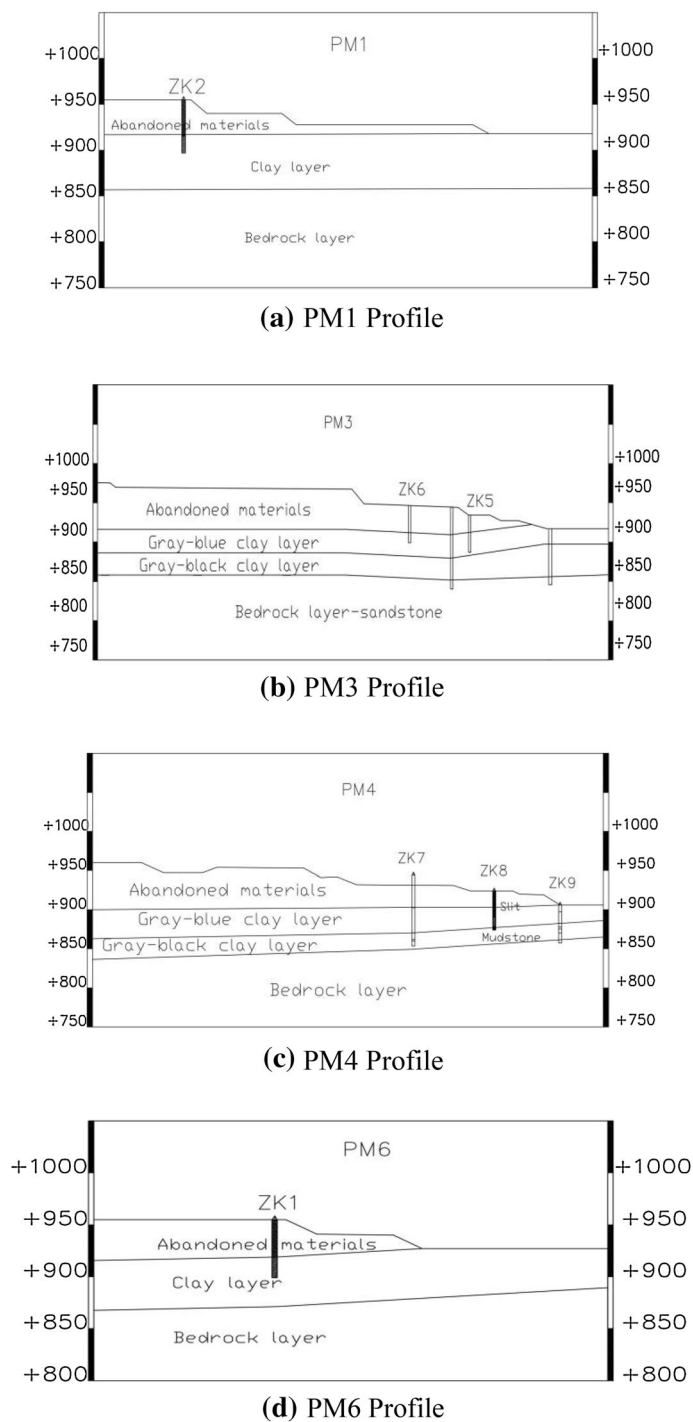


Fig. 3 Engineering geological profile

where γ_0 represents the specific weight of base soil, b is the base width, c is the cohesion of base soil, q is evenly distributed gravity of the upper soil layer. N_γ , N_c , N_q are bearing capacity coefficients related to the internal friction angle φ of the soil.

3.2 Calculation of ultimate bearing capacity and safety factor of the substrate

The ultimate bearing capacity of the saturated gray-blue clay layer in the basement of the south dumping site is calculated using the formula for calculating the ultimate bearing capacity when the base soil mass undergoes overall

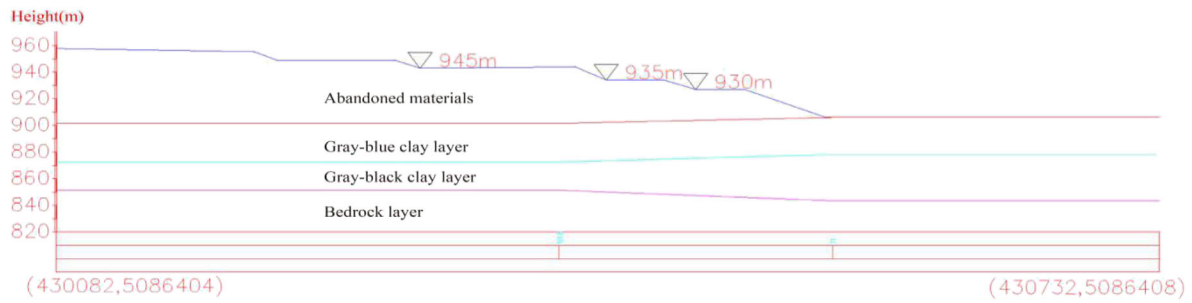


Fig. 4 Schematic diagram of the bearing capacity of the south dump site

Table 3 Calculation for safety factor of bearing capacity of the south dump site

Calculate location		935 m elevation	945 m elevation
Slope parameter	Slope height (m)	28	37.76
	Slope angle (°)	17	15
	Average base dip angle (°)	0	0
	Depth of foundation (m)	0	0
Calculation result	Ultimate bearing capacity (kN)	714.99	1011.04
	Overburden load (kN)	554.68	748.03
	Safety factor	1.29	1.35

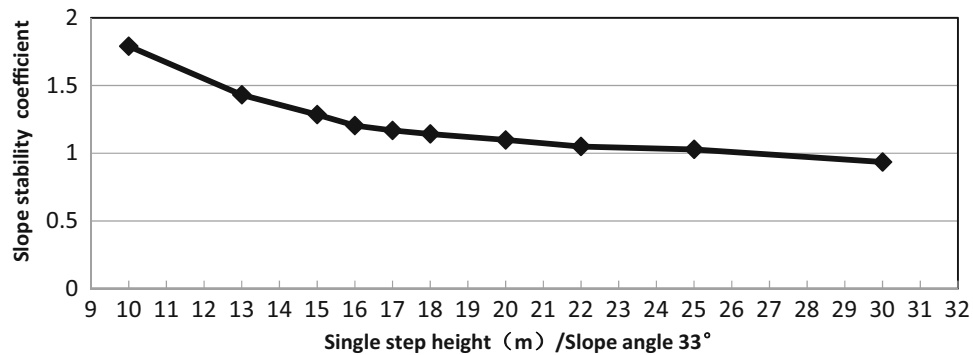


Fig. 5 Relationship between single step height and stability coefficient

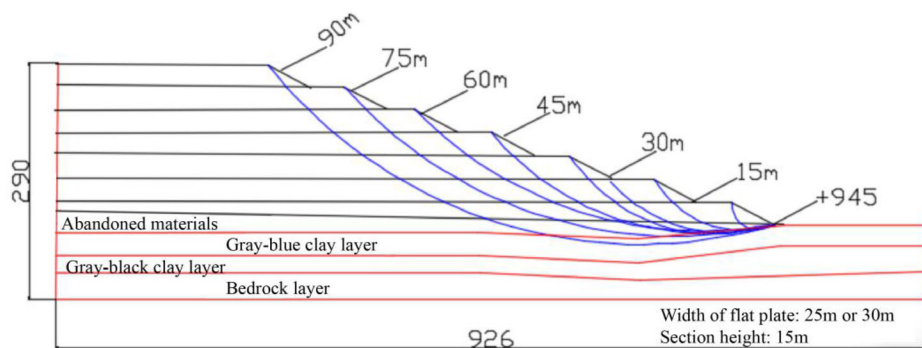


Fig. 6 Slope stability calculation section

Table 4 Physical and mechanical properties of rock and soil

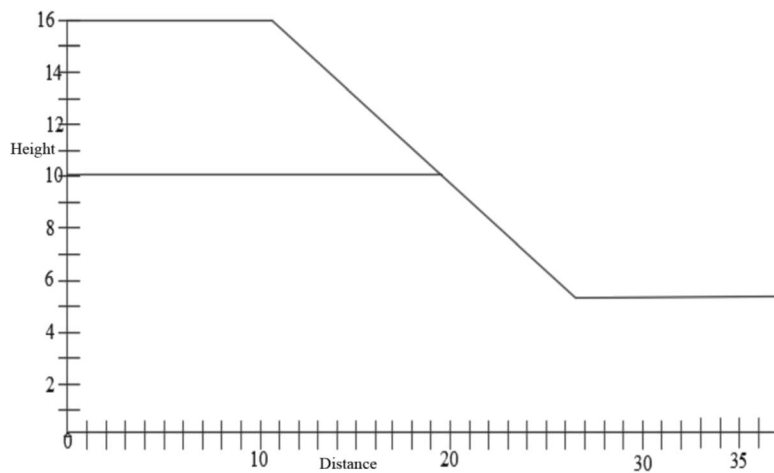
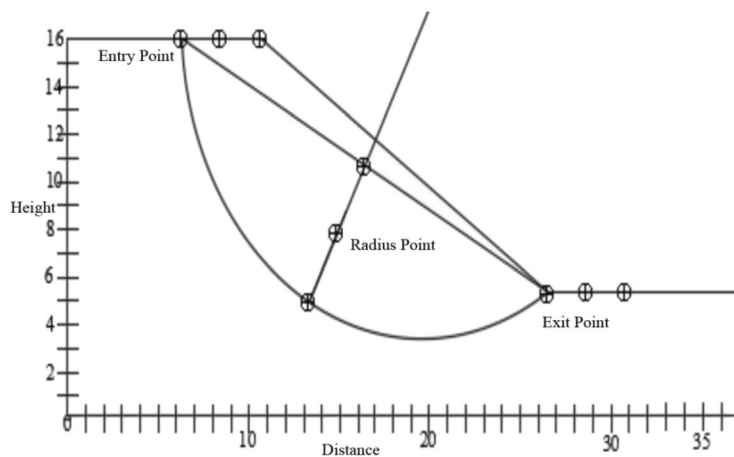
Lithology	Specific weight (kN/m ³)	Cohesion (kPa)	Inner friction angle (°)	Elastic modulus (GPa)	Poisson's ratio
Discard material	19.0	18.3	26.7	0.246	0.6
Gray-blue clay	20.0	23.1	28.4	0.426	0.46
Grey-black clay	20.0	28.4	30.6	0.542	0.4
Bedrock	22.0	50.7	32.7	0.787	0.309

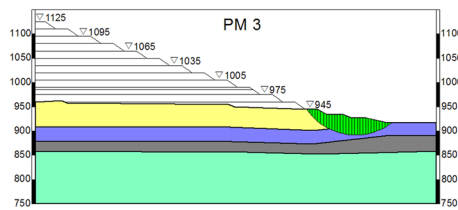
shear failure. The ratio of the ultimate load capacity of the dump site to the overburden load (p) of the base is the base load safety factor (K_s). The value of K_s is between 1.2 and 1.5, depending on the length of the service life of the dump and the hazard of the landslide.

$$K_s = \frac{p_u}{p} \quad (2)$$

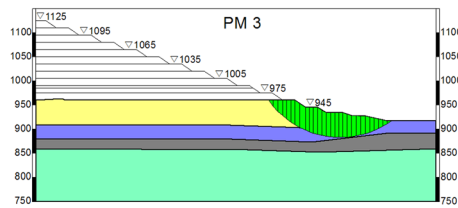
The calculated base bearing capacity and safety factor of the PM3 profile at + 935 m and + 945 m levels are shown in Fig. 4, and the parameters and calculation results are shown in Table 3.

As shown in Table 3 and Fig. 4, the calculation results show that the safety factor of the base bearing capacity of the + 935 m level and the + 945 m level are greater than 1.2, which indicate that the south dump site can be

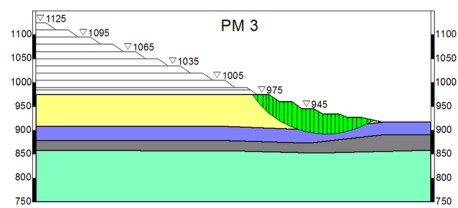
**(a)** Model**(b)** Slip surface analysis**Fig. 7** GeoStudio modeling analysis diagram



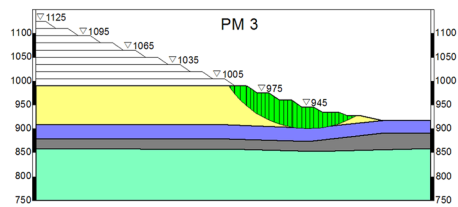
(a) Slope stability factor $F_s = 2.363$ when height increasing by 0 m



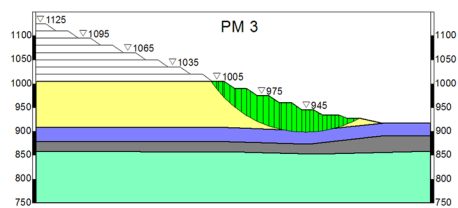
(b) Slope stability factor $F_s = 1.836$ when height increasing by 15 m



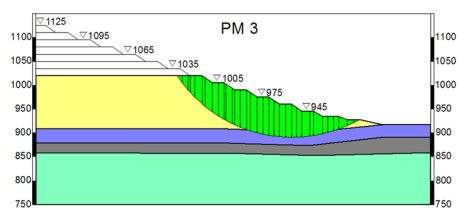
(c) Slope stability factor $F_s = 1.522$ when height increasing by 30 m



(d) Slope stability factor $F_s = 1.336$ when height increasing by 45 m



(e) Slope stability factor $F_s = 1.231$ when height increasing by 60 m



(f) Slope stability factor $F_s = 1.157$ when height increasing by 75 m

Table 5 Slope stability coefficients after the slope is gradually increased (Scheme 1)

Height increase (m)	0	15	30	45	60	75
Slope stability coefficient	2.363	1.836	1.522	1.336	1.231	1.157

expanded and increased to increase the containment capacity of the dump.

4 South dumping site increase and capacity expansion design

Due to the mining conditions, the waste materials of Heshgoula open-pit coal mine cannot be discharged in a short period of time. All the discarded materials have been stripped to the outside dump. At present, three external dumps have been formed, of which the south dumping site has an area of 7.445 km², designed height of 75 m, and height of a single stage of 15 m. The waste materials are mainly clay, sandstone, and mudstone produced by stripping in the second mining area. With the improvement of the open-pit mining capacity, a large number of stripped materials need to be discarded. Therefore, a plan for increasing and expanding the south dump is needed.

4.1 Determination of the maximum step height in the south dumping site

According to field measurements, the natural repose angle of the initial steps of the south dump site is between 24° and 26°. The natural repose angle of the upper steps varies with the nature of the discarded materials, ranging from 28° to 38°. The median value of 33° is used in this study. After the analysis of the limit equilibrium theory and the actual engineering geological conditions, the relationship between the height of the abandoned step and the stability factor in the south dump is determined, as shown in Fig. 5 (Chen et al. 2016). From Fig. 5, when the stability factor of the step is 1.2, the limit step height is 16 m, and the original designed dump section is stable at 15 m in height. In addition, the maximum discharge height of the first step is 15.2 m based on the calculation of the bearing capacity of the foundation. Based on the current construction situation of the south dumping site, the height of the dumping section is still 15 m.

Fig. 8 Slope stability factor of section PM3 (Scheme 1)

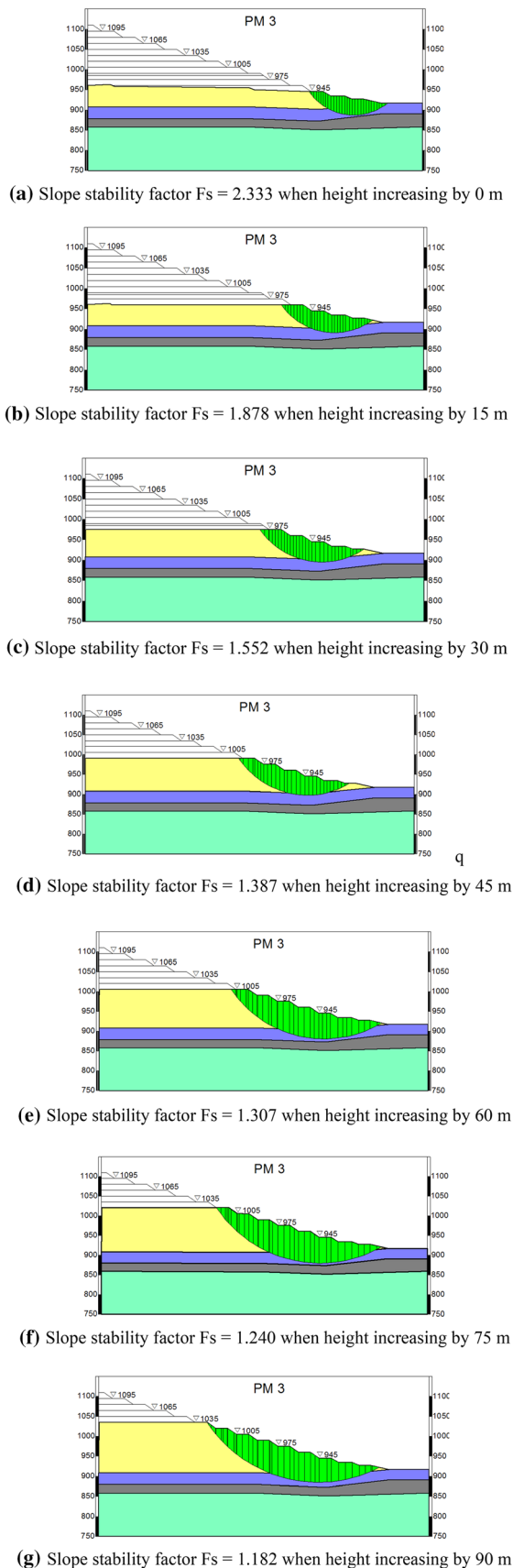


Fig. 9 Slope stability factor of section PM3 (Scheme 2)

Table 6 Slope stability coefficients after the slope is gradually increased (Scheme 2)

Height increase (m)	0	15	30	45	60	75	90
Slope stability coefficient	2.333	1.878	1.552	1.387	1.307	1.240	1.182

4.2 Drainage scheme design of the south dumping site

4.2.1 Soil disposal scheme

The height of the dump section is determined to be 15 m, according to the actual situation of the site, three schemes for the width of dump site are proposed:

Scheme 1: The slope below the + 945 m bench is boundary, and the bench of + 945 m and above are designed with a width of 25 m and a section height of 15 m.

Scheme 2: The slope below the + 945 m bench is boundary, and the bench of + 945 m and above are designed with a width of 30 m and a section height of 15 m.

Scheme 3: The slope below the + 945 m bench is boundary, and the bench of + 945 m and above are designed with a width of 30 m and a section height of 35 m.

4.2.2 Model establishment

According to the plan for the expansion and increase of soil discharge capacity, a typical PM3 profile of the south dumping site is taken as an example for stability analysis. The yellow filling layer in the model is the waste materials, below which is the base of the dump. The steps above the waste are virtually increased soil discharge steps. This paper uses GeoStudio software to simulate the inherent characteristics of soil slopes. Theoretical analysis of slope stability was conducted and PM3 profile analysis was performed using GeoStudio software (SLOPE/W) module. The different loading height models of the PM3 profile are plotted as shown in Fig. 6. The model length is 926 m, the model height is 290 m, the slope height is 132 m, and the slope rate is 0.288. When the boundary conditions are fixed in the horizontal and vertical directions, there will be no relative displacement in the X and Y directions. Table 4 lists the physical and mechanical parameters of rock and soil required for calculation according to the actual conditions of the project.

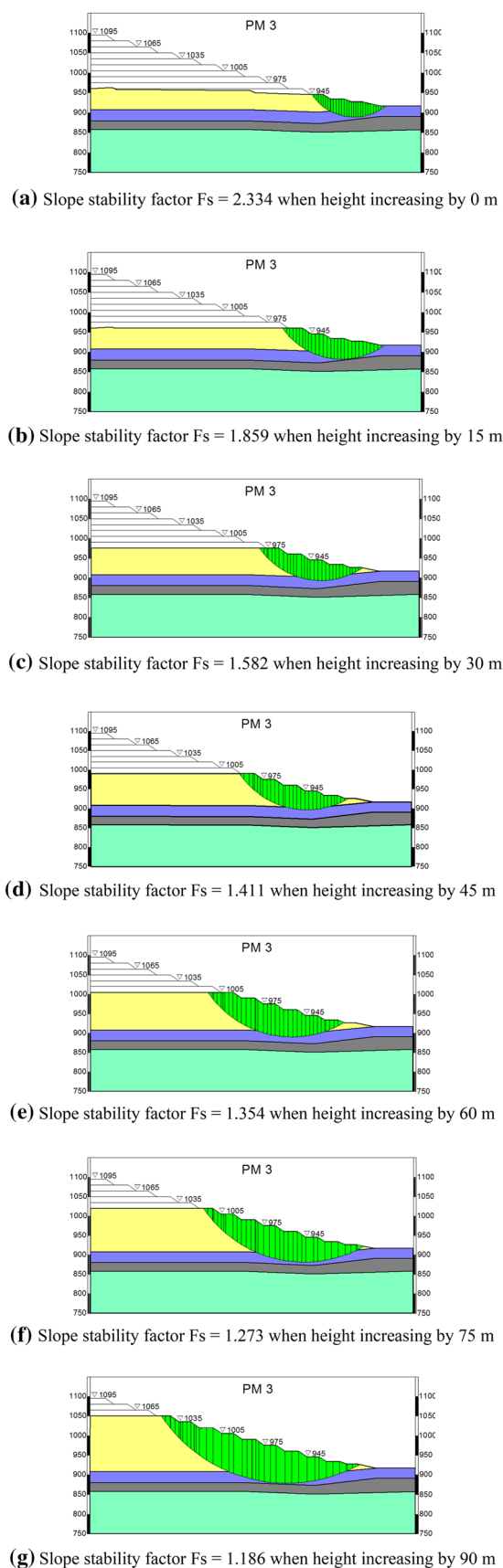


Fig. 10 Slope stability factor of section PM3 (Scheme 3)

4.2.3 GeoStudio modeling analysis

We firstly imported the model profile created in AutoCAD into GeoStudio software and set the relevant parameters and the range of the entrance and exit of the sliding surface in the software (SLOPE/W) module, as shown in Fig. 7a, b. Then, the adjacent slip surfaces with different loading heights were checked and calculated. Finally, the simulation results were analyzed.

4.2.4 Scheme comparison

(1) Scheme 1: slope stability analysis at 25 m dumping bench width Due to the actual soil discharge technology and equipment used in the mine, the final plate width of the designed dump site should not be less than 20 m and the height of a single step is 15 m. The slope stability calculation is based on the plate width of 25 m. The calculation results are shown in Fig. 8.

When the slope section of the south dumping site is 15 m high and the width of the plate is 25 m, the slope stability coefficients after the slope is gradually increased are summarized in Table 5. As the slope gradually increases, the green area (slip surface) also increases, that is, the stability of the slope gradually decreases. When the slope section of the south dump site is 15 m high and the width of the dumping bench is 25 m, the slope stability coefficient is 1.231 when the height is increased by 60 m, and the slope is in a stable state.

(2) Scheme 2: slope stability analysis at 30 m dumping bench width When the slope section of the south dumping site is 15 m high and the width of the pan is 30 m, the calculation result of the slope stability coefficient after the slope is gradually increased is shown in Fig. 9.

When the slope of the south dumping site is 15 m high and the width of the dumping bench is 30 m, the slope stability coefficients after the slope is gradually increased are summarized in Table 6. Figure 9 shows that, as the slope gradually increases, the green area (slip surface) also increases, that is, the stability of the slope gradually decreases. When the slope section of the south dump site is 15 m high and the width of the dumping bench is 30 m, the slope stability coefficient is 1.240 when the height is increased by 75 m, and the slope is in a stable state.

(3) Scheme 3: slope stability analysis at 30 m and 35 m dumping bench width The discharge steps below the + 945 m dumping bench are processed according to the boundary. The + 945 m dumping bench is 30 m wide, and the dumping benches above it are 35 m wide. The slope stability calculation results are shown in Fig. 10.

When the slope of the south dumping site is 15 m high and the width of the dumping bench is 30 m and 35 m combination, the slope stability coefficients after the slope is gradually increased are summarized in Table 7. Figure 10 shows that as the slope gradually increases, the green area (slip surface) also increases, that is, the stability of the slope gradually decreases. When the slope section of the south dump site is 15 m high and the width of the dumping bench is a combination of 30 m and 35 m, the

slope stability coefficient is 1.273 when the height is increased by 75 m, and the slope is in a stable state.

4.2.5 Comparison and selection of soil disposal schemes

By checking the stability of the slopes after the capacity increase and expansion of the south dumping site in Schemes 1, 2, and 3, it can be known that when the section is 15 m high and the safety reserve factor of the slope is 1.2, the width of the pan is at 25 m, the slope can be

Table 7 Slope stability coefficients after the slope is gradually increased (Scheme 3)

Height increase (m)	0	15	30	45	60	75	90
Slope stability coefficient	2.334	1.859	1.582	1.411	1.354	1.273	1.186

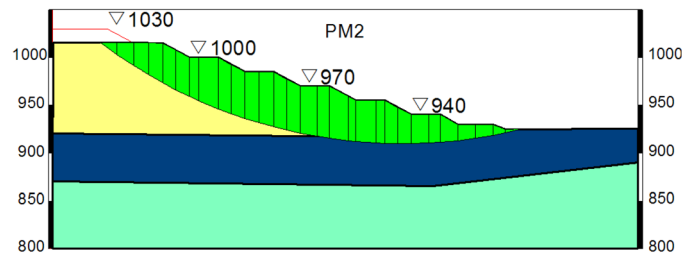


Fig. 11 Slope stability of PM2 section $F_s = 1.268$ (to the design level)

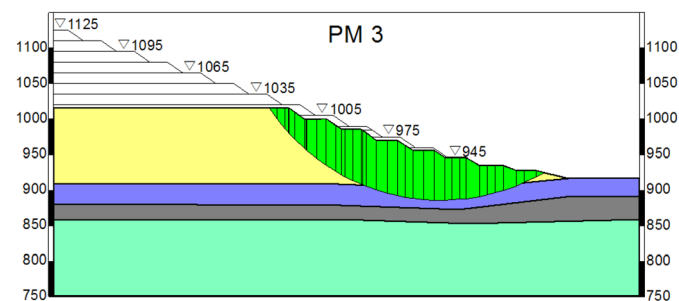


Fig. 12 Slope stability of PM3 section $F_s = 1.286$ (to the design level)

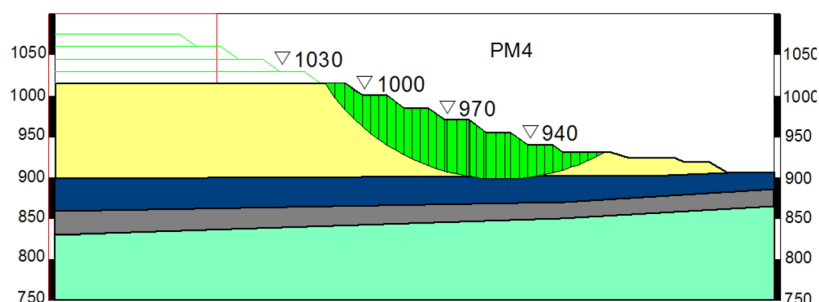


Fig. 13 Slope stability of PM4 section $F_s = 1.265$ (to the design level)

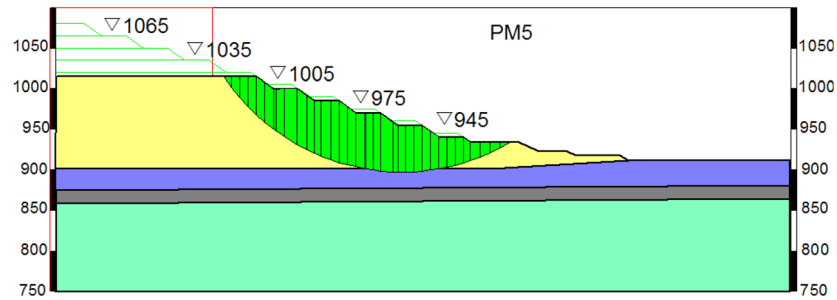


Fig. 14 Slope stability of PM5 section $F_s = 1.292$ (to the design level)

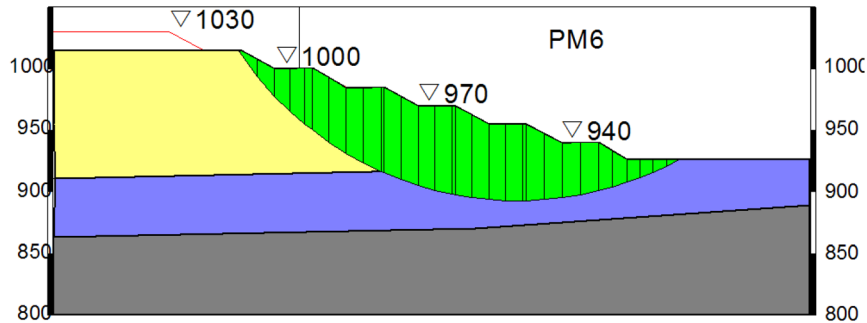


Fig. 15 Slope stability of PM6 section $F_s = 1.296$ (to the design level)

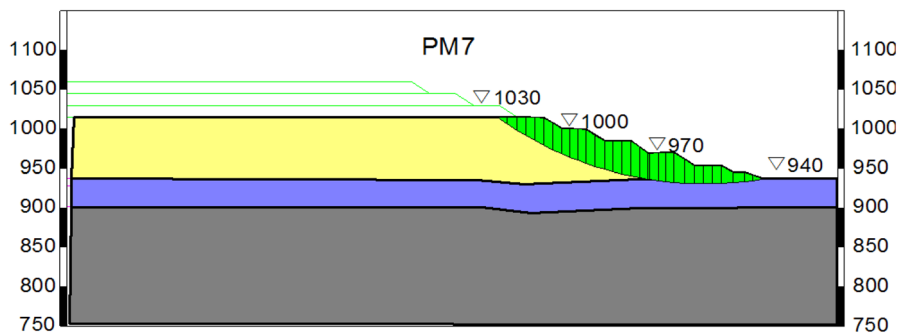


Fig. 16 Slope stability of PM7 section $F_s = 1.287$ (to the design level)

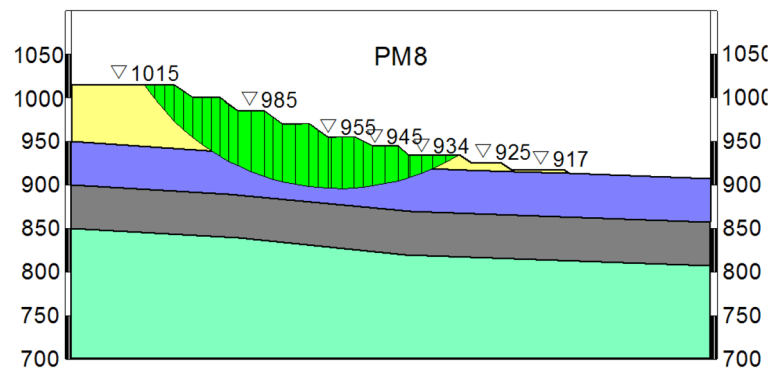


Fig. 17 Slope stability of PM8 section $F_s = 1.242$ (to the design level)

increased by 60 m; when the width of the dumping bench is 30 m, the height of the slope can be increased by 75 m; when the width of the dumping bench is a combination of

30 m and 35 m, the height of the slope can be increased by 75 m. Considering that the width of the stepped plate will increase after the dump system is arranged in the

Table 8 Summary of slope stability coefficients

Height increase (m)	PM2	PM3	PM4	PM5	PM6	PM7	PM8
Slope stability coefficient	1.268	1.286	1.265	1.292	1.296	1.287	1.242

transportation system, to ensure that it can meet the needs of slope stability and maximize the capacity of dumping, the second scheme is recommended as the final scheme.

4.2.6 Slope stability calculation after increasing and expanding the south dumping site

GeoStudio software was used for checking calculations. Based on the analysis of the stability of the width of the soil dumping bench (Wang 2007), the stability of the PM2–PM8 sections of the south dumping site slope was checked according to the design elevation. According to scheme 2, the stability of the south dumping site slope is calculated and shown in from Figs. 11, 12, 13, 14, 15, 16 and 17.

The slope stability coefficients for the seven sections are summarized in Table 8. It shows that applying the minimum dumping bench width determined by the soil discharge scheme 2, the stability coefficients of each side slope are greater than 1.20, which meets the design requirements.

4.3 Discussion

- (1) The safety factor of the bearing capacity of the basement is greater than 1.2, which indicates that the south dumping site can be expanded and increased.
- (2) In scheme 2, the slope below +945 m dumping bench is in the final state, and the dumping bench with +945 m dumping bench and above is designed as a slope with a width of 30 m and a section height of 15 m.
- (3) The feasibility of scheme 2 was validated by checking the slope stability of seven profiles after increasing and expanding the south dumping site.

5 Conclusion

Through laboratory tests of physical and mechanical parameters of rock and soil and analysis of data from previous geological survey reports, the recommended values of physical and mechanical properties of rock and soil for this study were provided. The ultimate bearing capacity of the basement of the Hesgoula south dumping site is analyzed. After comparing the three proposed schemes of dumping site design, scheme 2 was selected as the optimal

design. This research can solve the problem of the storage of a large amount of discarded materials generated by the mine stripping with the increase in the mining scale of the Hesgoula open-pit coal mine in recent years. It is of great significance for saving mine transportation costs, improving work efficiency, and reducing grassland occupation. It is a complex problem for slope engineering to study the slope stability under the condition of soft foundation. Although the conclusion of this paper is not applicable to all soft foundation slopes, it provides a solution to the problem. In the future research, a large number of physical experiments and field tests can be used to further study different soft foundation problems, and different influencing factors can also be used for further analysis and research.

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