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High Rock Bench Landslide Mechanism with Offset Dragline Excavation

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Abstract

The dragline operates at 40 meters high rock stripping in Heidaigou Surface Mine. Geological joints and blasting vibration trigger slope failure that lead to the formation of a high bench with the absence of platform and berm, hence affecting the safety of surface mine production. This paper presents a systematic analysis on landslide mechanism at high rock bench with dragline excavation. It adopts limit equilibrium method to evaluate the stability of high rock bench. Varies bench heights, slope angles, loads, circumstances and numerical simulation are used to simulate the stability of the rock slope when the dragline operations process. Hence the key elements that affect the stability of high rock bench and the mechanism of failure are obtained which serve as a theoretical basis for landslide prevention.

Key words

High rock bench, stereographic projection method, limit equilibrium method, FLAC3D, landslide mechanism

1. Introduction

Heidaigou surface mine, is a surface coal mine with highest production capacity in China. In 2007, this mine imported the first dragline and used the side cast blasting method by throwing the overburden sideways onto blasted material on offset benches. After this new technology reform, a 38~42m rock bench above coal seams (shown in Figure 1) could use the side cast blasting method by throwing the overburden sideways onto blasted material on offset benches to mine. Some damages such as rib spalling, collapsing (shown in Figure 2) took place in dragline high rock bench, due to its complex geological structure, rock joints, fracture rock, high bench, precipitation and blasting vibration. The formation using the side cast method also concerns with regards to the equipment and the safety of workers. Based on the above conditions, this paper studies the high rock bench failure and its influence parameters with the use of theoretical analysis and laboratory numerical simulation, thus depicting the measures to be done to prevent landslide when the side cast method is used. The finding is meaningful to the landslide prevention for using side cast method.

Fig. 1a. Model of high bench slope and dragline offset

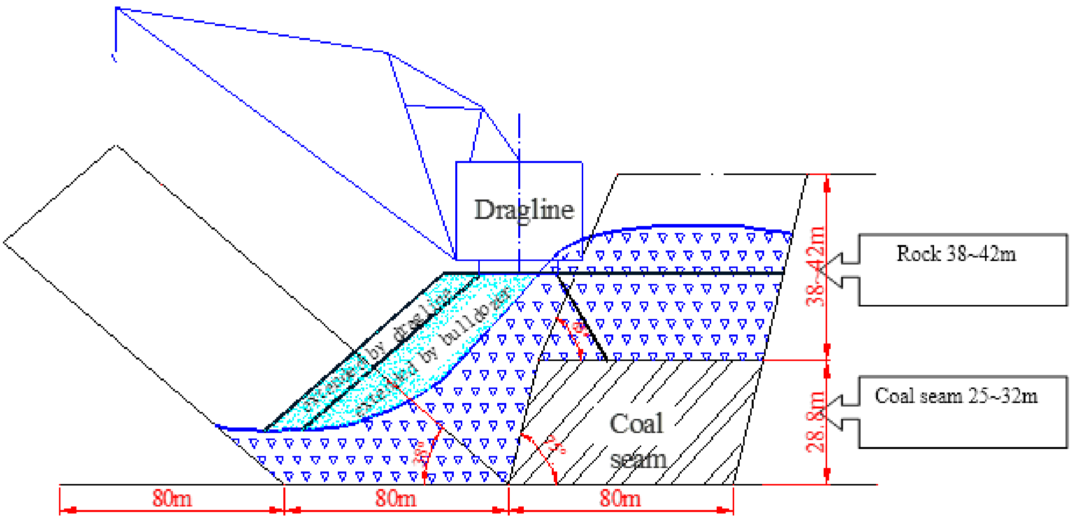

Fig. 1b. Sketch of dragline work on the high rock bench

Fig.2. Photo of rib spalling failure at high rock bench

2. Geological Conditions

The reformed technologies used in Heidaigou mining, as shown in Figure 3, include bucket-wheel-excavator, conveyor belt and dumping machine continuous mining method in upper loess; while the lower loess and upper rock layer apply single-bucket and truck mining method; the lower rock layer used casting blast and dragline overcasting mining method; the semi-continuous mining technique of single-bucket, truck, ground-breaking-station and conveyor belt was applied to the coal seam.

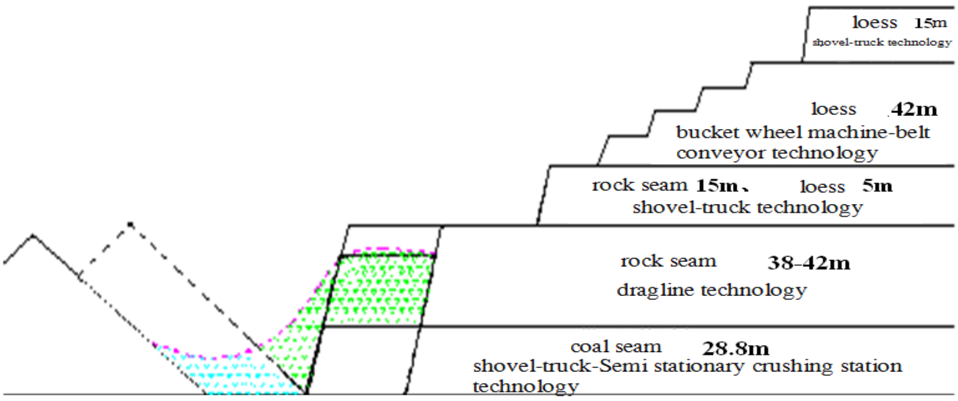

Fig. 3. Schematic diagram of mining technology section in West area

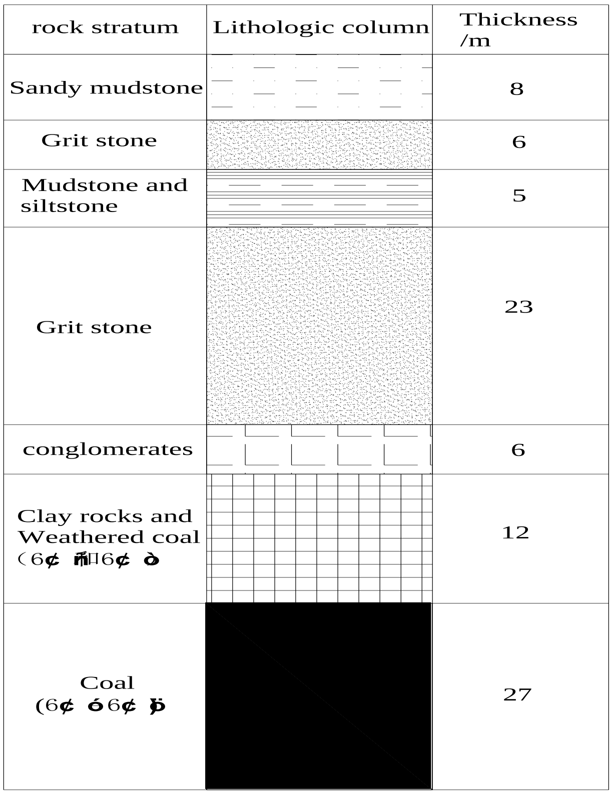

Fig. 4. Typical layers in Heidaigou Surface Mine

After blasting, failure joint sets could not be observed in the East area, only one rib spalling was found. In the West area, joint planes were well developed and rib spalling took place as a wedge failure, size range from several cubic meters to hundreds of cubic meters. Generally, the East was more stable than the West area, typical joint planes from the West area were hence chosen for research, bar graph of the section as Figure 4.

Figure 4 show that high bench is mainly comprised of sandstone, mudstone, clay-rock and weathered coal. After rock testing, the locally rock parameter of physical and mechanical properties are generated and shown in Table 1.

Table 1. Rock parameter of physical and mechanical properties at high rock bench

Name	Density ρ/kg·m^{-3}	Bulk modulus K/Pa	Cohesion C/MPa	Internal friction angle φ/ °
Mudstone	2440	8.80×10^{9}	1.28	27
Sandstone	2334	2.68×10^{10}	2.73	30
Clay-rock	1770	1.10×10^{6}	0.05	29
Weathered-coal	1400	1.30×10^{7}	0.02	32

The integrity index of mudstone is 0.88, joint sets were well developed. The integrity index for Sandstone is 0.06 ~ 0.5, sandstone integrity varies widely; there are loose structure, cataclastic structure and stratified structure for sandstone. According to the onsite observation, cataclastic structure and stratified structure are main rock structure of the rock. The safety of casted material bench is lowered because energy of multi –blasting damaged the cohesive force inside the original rock joint sets and weekend the strength of rock mass. As the rock joint sets developed and the slop of the bench material is steep, rib spalling was caused.

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3. Characterisation of Landslide Structure

Blocky structure and varied sliding planes were features identified after the casting of a high strength rock [1,2]. Thus the reason for high bench damage and deformation is varies structural planes exist in side the slop. Two sets of dominant joint planes were found (Table 2 and Figure 5) by onsite investigation and revealed trace investigation, put together with investigations at exploration, revealed trace planes are likely to form a certain angle with the slop surface and crossed with each other and likely to cause wedge sliding. Typical section comprises of rock high bench and coal bench, in which the average thickness can be obtained by drilling as shown in Table 3.

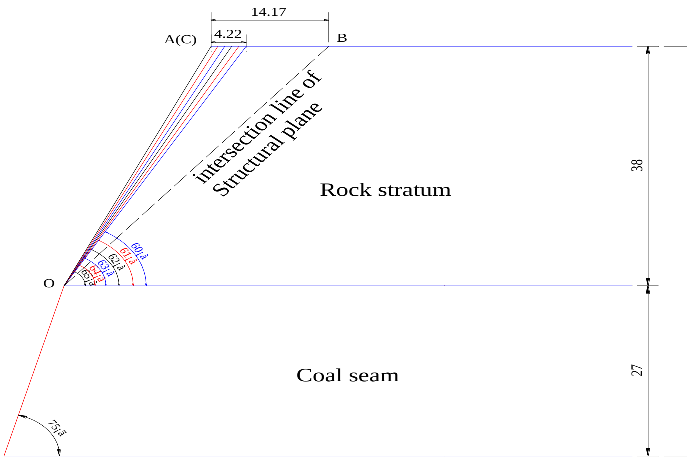


Fig. 5. Typical section of slope profile

Table 2. Slope profile and joint planes of typical section

Name	Dip Direction	Dip angle
Bench slope	N 45°E	65°
Joint plane 3	N 4.2°E	58°
Joint plane 4	N 85.8°E	58°

Table 3. Physical and mechanical properties of joint plane

Fraction angle φ/ °	Bulk modulus C/Pa
26	32000

4 Analysis of high rock bench failure model

There are two joint sets formed as "X" inside the high rock bench, one is EW direction the other is S or ES direction. Two joint sets can be observed at the after blasted high rock bench, these two joint sets are cross over each and with good connectivity and continuity. As affected the structure of join sets, dragline offset and the situation of working at high rock bench can lead to wedge failure. The wedge failure was along the joint planes. Depending on According to stress conditions, wedge failure can be classified as single-slide and dual-slide [3]. The relative position of intersection line from great circle projection, slope profile and friction cone are elements that can help distinguish and determine whether failure surface intersection line meets the two following conditions [4]:

a) single-slide failure: intersection line falls at the daylight envelope between slope projection and friction cone;

b) dual-slide failure: intersection line tends to fall between slope face and some joint planes dip direction and above a [1].

Figure 6 shown, between bench slope face and friction cone is a daylight envelope. Joint plane 3 and 4 of the great circles projection are intersection at I. O is the centre point and projection OA and OB are the joint plane of 3 and 4. OI is the wedge intersection line, which fall into daylight envelope. The above a and b conditions were fulfilled, which can hence be considered as a dual-slide wedge failure.

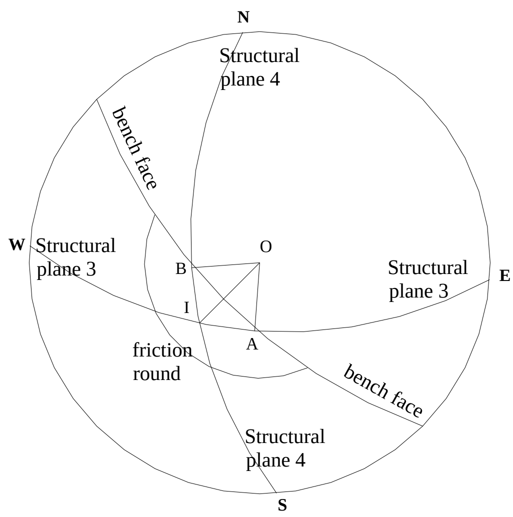


Fig. 6. Polar-radiation equatorial-plane analysis of typical section

5 Analysis of the failure mechanism of dragline at high rock bench

5.1 Analysis of factors affecting dragline high rock bench stability using limit equilibrium method

The stability of dragline high rock bench is influenced by external factors such as rig load, ground water and blasting vibration, as well as by internal factors such as bench height and slope angle. As a result, limit equilibrium method is used to calculate the factor of safety and to determine the influencing degree of each factor. By considering the influence of rig load, ground water, blasting vibration on the first place, integrated consideration of three factors influencing the dragline at high rock bench stability is done.

a) In considering the influence of rig load, consider the working load of the rig, by calculate of the weight and work impact, consider the force 1069.082KN, add the force to the top of the stick, same direction with gravity force.

b) In considering of ground water influence, based on the result of overlap shear test of the clay rock bedding plane, the cohesion force and internal friction angle should discount by 9.3%

c) In considering of blasting vibration influence, quasi-static method was implemented. According to the observed vibration speed and duration during the experiment, the maximum radial acceleration is ai=0.823, dynamic load is flash load, so its influence is much smaller than the static load, so the reduction factor 0.5 is used in this experiment.

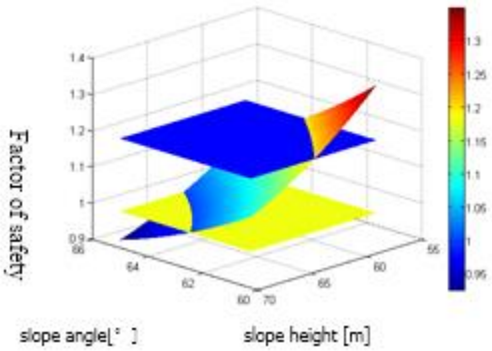


Fig.7. 3D curve graphic showing the relationship between factor of safety, slope heights and angles without loading

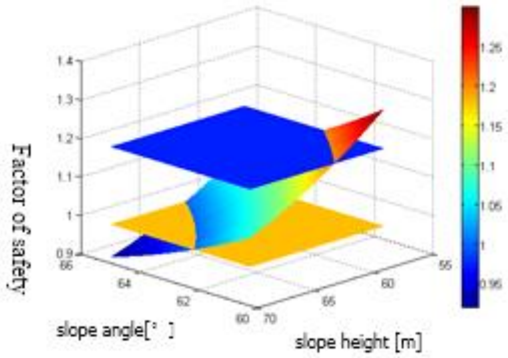


Fig.8. 3D curve graphic indicating the relationship between factor of safety, slope heights and angles with loading

As shown in Figure 7 and Figure 8, comparing the scenario under the influence of rig load, with the one with no loading, the factor of safety reducing rate is smaller with slope angle increases under the condition of constant slope height, from 2.5% at 60° down to 1.1% at 65°. If the condition of slope angle is constant, the factor of safety reducing rate presents a less significant increase as the height increases.

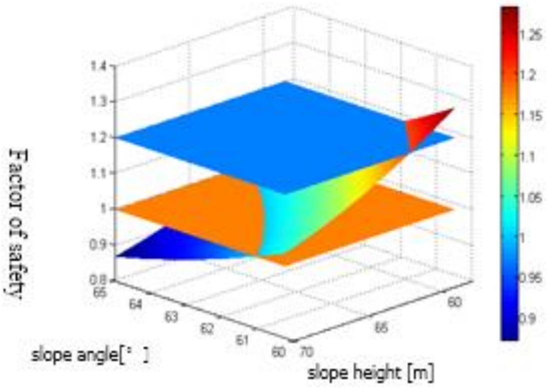


Fig.9. 3D curve graphic spitting the relationship between factor of safety, slope heights and angles with influence of blasting

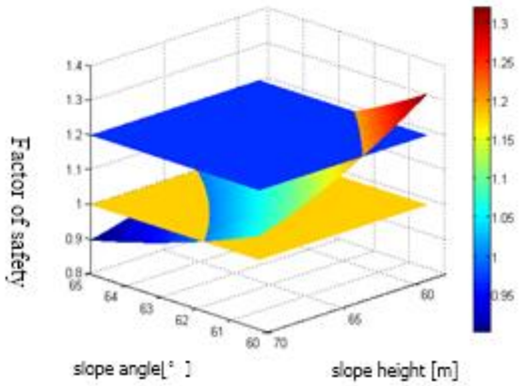


Fig.10. 3D curve graphic signifying the relationship between factor of safety, slope heights and angles with influence of ground water

Figure 9, compares the condition without loading and under the influence of blasting vibration, of which the bench factor of safety decreases by 4.9%~5.7% in combinations of all heights and angles. While Figure 10 compares the condition without loading and under the influence of ground water in which the bench factor of safety decreases by 2.3%~2.5% in combinations of all heights and slope angles.

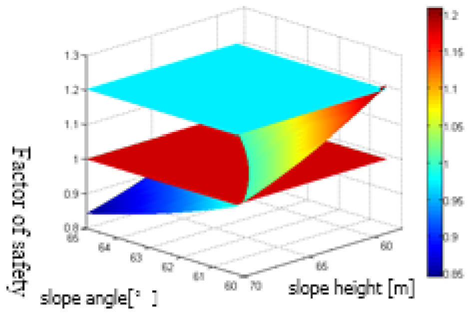


Fig. 11. 3D curve graphic revealing the relationship between factor of safety and slope heights and angles of typical section under the influence of three factors

Equation of curve graphic:

$$z = -0.0000019861x^2y^2 + 0.0002070556x^2y - 0.0019959444x^2 + 0.0002386111xy^2 - 0.0237880556xy + 0.1135594444x - 0.0067916667y^2 + 0.6160125000y + 4.1708416667 \quad (1)$$

In the formula, x is slope height, y is slope angle, z is high bench factor of safety.

Compare with the 0 load situation, the factor of safety is 10.8%~9.5% lower under the influence of these three factors. As the factor of safety significantly reduced, the slop stability is weakened. Based on the decrease percentage of factor of safety the influence of these three factors on stability is blasting vibration > rig load > ground water, so the possibility of blasting vibration caused landslide is greatest. The influence of internal factor that caused landslide can be decided by orthogonal experimental analysis method.

Table 4. Analysis of variance of orthogonal experiment

Factor	Square of deviance	Degree of freedom	F Ration	Significance
Bench height	0.012	2	2.000	No
Slope angle	**0.086**	**2**	**14.333**	**Significant**
Bulk modulus	0.004	2	0.667	No
Internal friction angle	0.002	2	0.333	No
Error	0.02	6	---	No

Table 4, it concludes the influence on the stability of the 4 factors that:

slope angle ＞ slope height ＞ bulk modulus ＞ internal friction angle

The influence of slope angle is very significant, suggesting is a sensitive factor influencing the dragline rock high bench stability. Therefore, when designing bench slope parameter, slope angle should be enhanced, decreasing slope angle would be considered first on the bass of enough casting blasting efficiency.

5.2 Numerical analysis of high rock bench failure

Surface mining is a dynamic excavating process in which a three-dimensional finite difference software FLAC3D is applied to simulate the deforming process during the dragline working, so as to provide basis for analyzing the failure mechanism of landslide. Simulating and calculating process is as below:

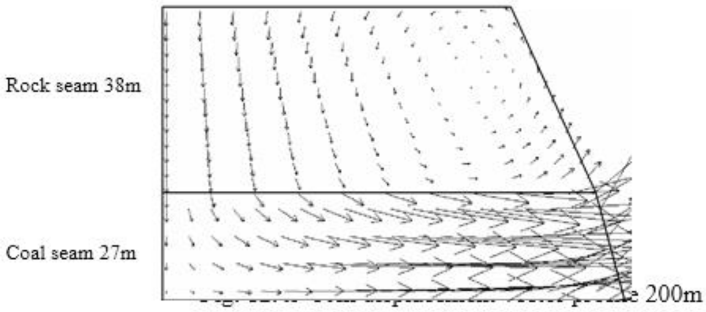
(1) Building numerical simulation model.

(2) Forming initial stress field based on original landform.

(3) Excavating the overlying strata.

(4) The mining coal seam advance is 20m, based on the combination of on site coal bench advance and model size.

At present, the height of bench is 40m, the working width is 80m, the slope angle of overcasting bench and coal bench is 75° and 65°. Discharge space is not less than 80m (coal seam floor), so model building parameter is set as 75°coal seam slope angle and 65° rock stratum slope angle. Model building range is the dragline rock high bench, where wedge blocks are preset in the model, length, width and height are 400m, 200m and 65m respectively (coal seam 27m, rock stratum 38m). The model is hence divided into 39688 units and 43441 nodes.



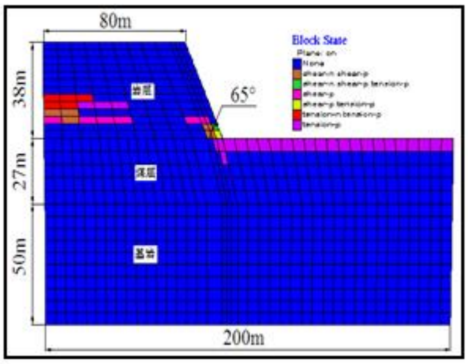


Fig. 13. x=165m failure graph digged

Mining the 38m overlying rock stratum is simulating the working process of casting blasting and dragline overcasting. The upper bench displacement vector is vertically downward, performing “settlement”. The middle displacement vector is almost parallel to slope, indicating “shearing” whereas the lower displacement vector suggests “shearing out” around the slope corner. The presence of displacement distribution on section is a closed state in the middle of slope intersecting with slope. In Figure 13, shearing failure occurs in some spots of the lower wedge, while tensile failure occurs in the coal seam. The deeper rock stratum is mainly forced by compressive stress from vertical direction, hence performing compressed yielding, due to the soft stratum (weathered coal and clay rock). All the phenomenon above show that the slope is stable.

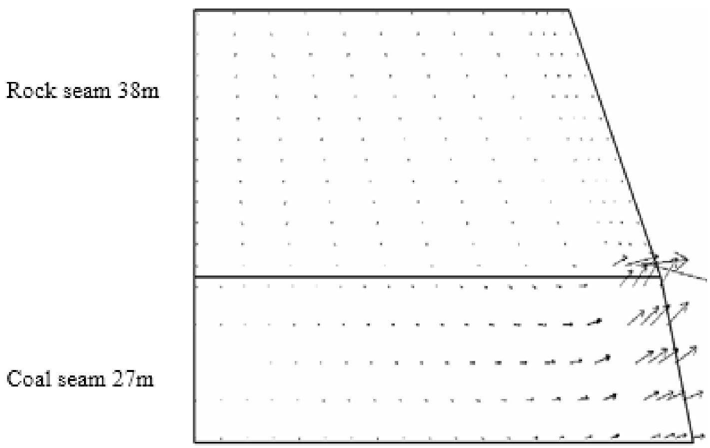


Fig. 14. Excavation to the 200m peak, the wedge changes in displacement plans

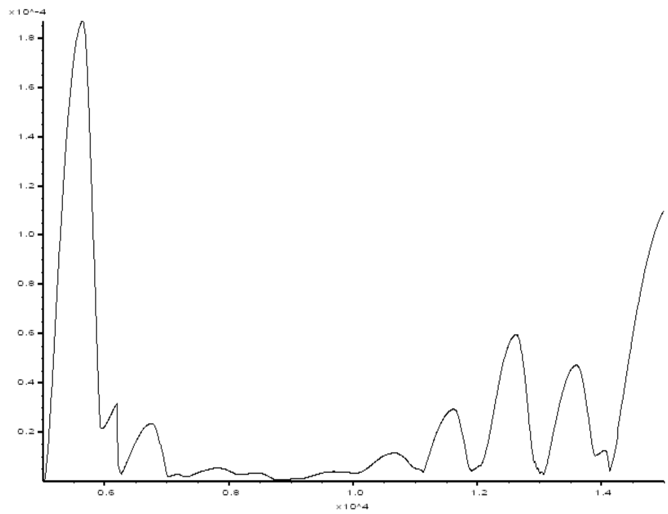


Fig. 15. Excavation to the 200m peak, the wedge changes in speed plans

As shown in Figure 14, the wedge displacement is very large, with some individual points mutated which indicating the wedge block is unstable. As shown in Figure 15, the velocity of the intersection line vertex of the wedge block mutates when the model operates to its 14200th steps and peaked at the 15000th steps. Integrated with the extended conditions of above failure zone, it can be deduced that the wedge block has deformed and rib spalling takes place in bench when coal seam is mining to 180m. The simulating result is equal to the factor of safety 0.969 (the bench is unstable when it is 1.2) calculated by limit equilibrium method.

6. Conclusion

(1) High rock bench of Heidaigou surface mine, its stability was controlled by dual or multiple sets of plane. The cause of slope failure was wedge block instability.

(2) Wedge failure occurred model through stereplot and kinematic analysis.

(3) Based on limit equilibrium method and Heidaigou surface mine working facts, the factor of safety was calculated in all states (without loading, rig load, ground water, blasting vibration and combination state). The order of effects are blasting vibration > rig load > ground water. Through carrying out the orthogonal test, the internal order of effects are slope angle > slope height > bulk modulus > internal friction angle.

(4) The result of simulating the dragline dynamic operation process through numerical simulation method indicate that the failure takes place mainly in the lower coal seam excavating process. The failure character hence settlement-shearing out, with shearing failure generated from the bottom and expands upwards to the top of the wedge block. This landslide performs obvious timeliness character. The analysis of this paper has certain reference significance to the similar mine applying cast blasting and dragline overcastting.

Acknowledgments

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