

[JESTEC] Undercutting Mining

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UNDERCUTTING MINING METHOD, WHY NOT? A GEOTECHNICAL CONSIDERATION FOR COAL OPTIMIZATION

Abstract

To reduce the stripping ratio, mining with undercutting method can be an alternative even though it has high geotechnical risk. The method is carried out by cutting the low-wall slope so that the dip of rock bedding at low-wall is smaller than the slope angle. This study describes geotechnical consideration for undercutting design of coal mine in order that mining activity can be carried out with minimum risk. The analysis used finite element method by taking into account the aspect of mining sequence. The variables included the conditions of geological structure, rock structure, bedding, and geohydrology. Material properties used for the analysis were based on laboratory tests. The result shows that the slope resulted from undercutting method was stable even though with critical safety factor. The values of safety factor for undercutting design with and without buttress were 1.03 and 1.08, respectively. By considering the short mining sequence, undercutting method can still be implemented by preventing the potential for degradation of physical and mechanical properties of material from occurring. This method was successfully carried out, so mining activity was able to be done properly without any instability issues.

Keywords: Undercutting, Lowwall, Coal Mine, Slope Stability, Daylight

1. Introduction

Coal deposits, especially in back-arc basin and fore-arc basin, usually form successive layers with specific bedding position. The dip of coal bedding varies from gently sloping to perpendicular forming a vertical bedding. In several locations of the study area, folding structures were found in either micro or macro scales. Based on the geological condition, mining activity will form high-wall and low-wall sections. High-wall is part of mine slope that is perpendicular to the dip of rock bedding, while low-wall is the dip of mine slope that is in the same direction as the dip of rock bedding (Fig. 1). Undercutting mining is defined as mining activity that cuts low-wall slope so that the angle of mine slope is greater than the angle of rock bedding or discontinuous plane (daylight).

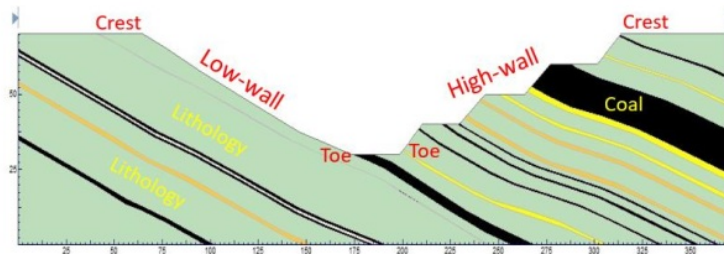


Fig. 1. Low-wall and high-wall of coal open-pit mine [1].

Contact between beds is a weak zone, and at the contact of rock bedding, it is usually found a thin layer that can trigger instability of slope. Slope stability of low-wall is affected by bedding contact between two rocks [2]. Bedding contact is usually in the form of clay which has high plasticity, thus it will separate two different beds. Because it separates two different parts, the cohesion value becomes zero and the internal friction angle becomes 13° , which were obtained based on back analysis result [2]. When a weak plane is formed at contact of two rocks, it is assumed that the upper bed only relies on the bed below it, so, with the concept of stress, the smaller the lower part, the greater the stress received, leading to potential for overstress at the toe. Overstress occurs due to difference in bedding ratio between the top and the bottom. The smaller the bedding ratio, the smaller the safety factor produced (Fig. 2) [1]. Since the rock bedding has a weak zone, it may cause failure at the toe. The toe failure is one of the contributing factors that leads to landslide at low-wall (Fig. 3) [3].

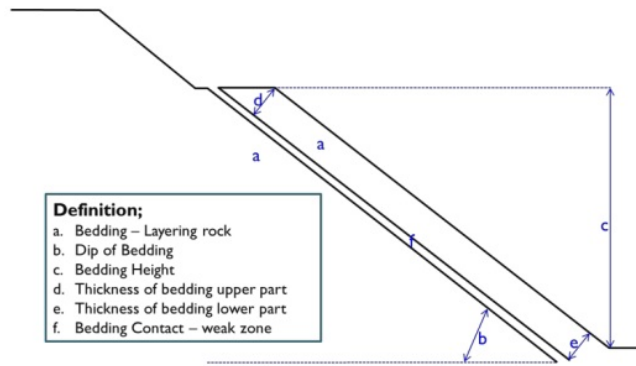


Fig. 2. Bedding ratio at low-wall [1].

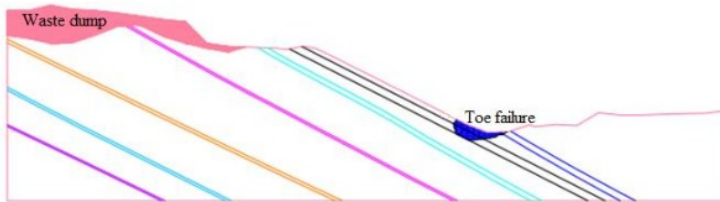


Fig. 3. Landslide at low-wall due to toe failure [3].

Slope stability analysis is closely related to the existing structure pattern, especially discontinuous plane. In this analysis, rock was assumed to be a rigid plane separated by weak plane that is cut by joints making the bed look like being cut into pieces; thus, the movement is purely due to frictional force at the bottom of the slope. When driving force gets bigger, buckling will potentially occur (Fig. 4).

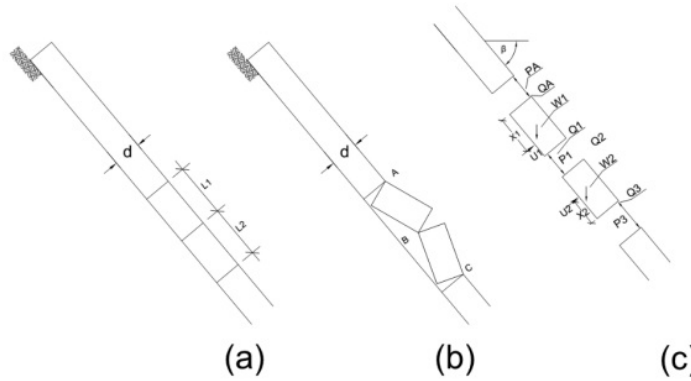


Fig. 4. Inaccurate application of rigid-and-jointed bed for low-wall stability [4].

Analysis of landslide **due to** buckling is carried out with assumption that at the toe of slope there are joints receiving pressure along the slope, and additional assumption of Young's modulus (Fig. 5). As a result of the pressure, buckling occurs. The shorter buckling (L), the greater the force required for the buckling process to occur. Water flowing in sandstone pore and impermeable mudstone cause a decrease in values of cohesion and internal friction angle.

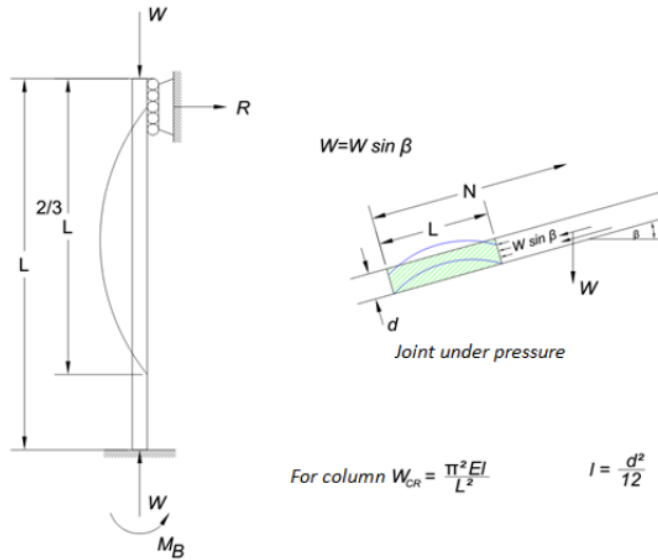


Fig. 5. Buckling concept at low-wall [4].

Analysis of low-wall stability uses concept of toe failure that occurs very quickly without showing any indication of instability. This type of landslide is triggered by low angle joint at the base of excavation. The low angle joint often cannot be detected from drilling, so field observation is very important in determining the possibility of low angle joint.

Landslide at low-wall is affected by pile load at the top of slope, which is considered to provide a significant burden to the low-wall slope. Loose pile material will put the load fully at the base which is passed on to the slope. Placement of overburden must be spaced from the slope to reduce load on the slope surface [3]. Landslide at low-wall can also be triggered by weathered rock on the slope surface. This type of landslide usually occurs in tropics which have very high weathering rate, and the surface is influenced by rill erosion.

Joint pattern plays a very important role **for instability** because there are some joints that are key to all joint systems. This type of instability is triggered by joint or fracture that cuts each other forming a shape of "X". Under normal condition, instability of natural slope is generally in stable condition. However, if a part of the "X" formation is taken due to slope forming, then instability may occur due to

reduced horizontal force and increased groundwater level in joint area that results in increased hydrostatic pressure either vertically or horizontally (Fig. 6). Instability will occur when resisting force is smaller than driving force. If this mechanism can be known from the beginning, then instability can be anticipated early.

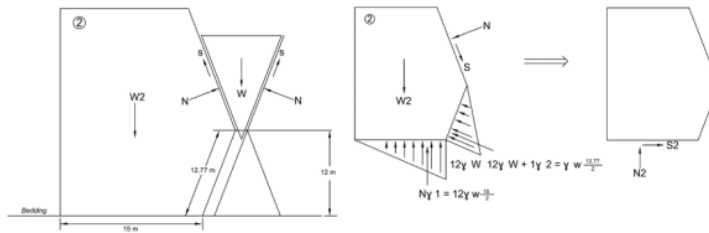


Fig. 6. Unfavorable joint mechanism [4].

2 The increased factor of safety for 'closed' joint ends cases over their 'open' counterparts for small scale slopes confirms the effectiveness of support measures such as bolting and wire meshes that essentially force exposed joint ends to move together. The modelling in the paper also confirms the loss in efficiency of such support with increasing slope height and suggests that other stabilization methods be considered for large slope [5]. The consideration of this variability was essential to reproduce buckling failure. Back analyses of failure mechanism were done, leading to representative values of the in-situ stress state and the normal and shear stiffness modulus of the foliation discontinuities [6].

Clastic sedimentary rocks in the Warukin Formation have low hardness [7] and the rocks will degrade when exposed to the surface [8]. With this condition, clastic sedimentary rocks, especially claystone, have limited engineering properties, and type of clay mineral must be considered before choosing construction material [9-10]. Large scale low-wall failures cause considerable disruptions to mining associated with a loss of production, damaged infrastructure, and the potential loss of life [11]. Depressurization is indispensable in pit optimization and pit design [12]. Numerical modeling in slope stability analysis for optimizing mine slope is more convincing in the result of slope stability analysis [13]. Theoretical aspects of resonant and chaotic dynamics to practical applications, and lays an essential logical foundation for future developments [14].

2.Methods

The method used in this study is back analysis on landslide at low-wall. Back analysis was carried out by exploring all geological and geohydrological conditions as well as physical and mechanical properties of slope rock, then evaluating slope stability analysis that had been carried out before the landslide occurred. Geological condition was explored by detailing slope material, identifying contact zone, calculating bedding ratio, and mapping structure seen after the landslide; while geohydrological component was explored by identifying slope bedding to obtain the type of aquifer.

Structure was mapped to determine the orientation of joint pattern found on the slope and identify the existence of low angle joint. Field observation includes identification of failure zone found in the landslide area as an indication of release point of force from rock bedding. Physical and mechanical properties were evaluated by comparing sampling position to the results of laboratory tests that have been carried out. Additional number of samples required for further analysis was added for detailing back analysis later. Laboratory tests such as hardness test, 7 axial test, and uniaxial test were carried out by following the ASTM standards. Material properties used for analysis are in Table 1.

Table 1. Material properties.

Material	Properties					
	Unit weight (kN/m ³)	Cohesion (kPa)	Friction angle (°)	Tensile strength (kPa)	Young mod. (kPa)	Poisson ratio
Disposal and buttress	17	75	20	75	125000	0.4
Mudstone	18	160	35	160	125000	0.4
Weak zone	14	10	30	5	50000	0.4
Coal seam	14	189	35	189	50000	0.4

3. Results and Discussion

The research area was located at one of the coal mines in the Warukin Formation with low-wall dip of about 9°. The area consists of sandstone, claystone, and coal with hardness below 1 MPa. The groundwater level was relatively high, about 10 m from the surface. Undercutting was planned to be carried out to the toe of landslide that had occurred before. The landslide caused mining activity to stop, leaving the pit neglected, so 1/3 toe of the landslide was submerged in water. Mining was carried out again after 5 years the pit had been abandoned and the mining process began with dewatering of the water in the pit.

The stratigraphic unit of research area in the form of landslide material was on slope surface with a dip of about 14° and a material thickness of about 30 m. In-situ materials were beddings of claystone, mudstone, and coal with dips of about 7-9°. Counterweight was put on the toe of landslide material by back filling up the overburden material layer by layer, so that optimal buttress was obtained. Undercutting was carried out about 15 m from the buttress toe with an undercut depth of about 35 m, calculated from the elevation of buttress toe. The dip of undercutting slope was about 38°, therefore there was daylight due to the bedding dip of 9° (Fig. 7).

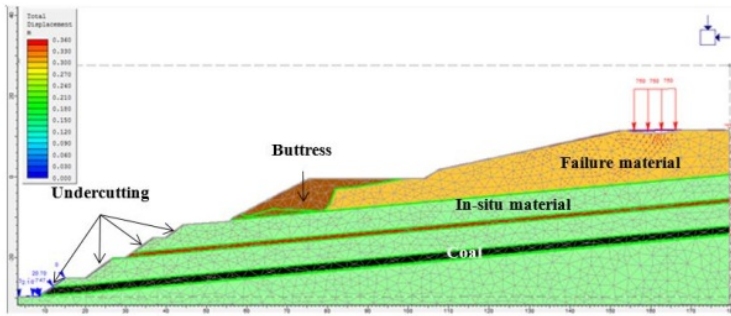


Fig. 7. Distribution of in-situ and failure materials.

Soft material at the toe of landslide material had been cleaned before the buttress construction. Removal of the landslide toe caused creeping on 1/3 part of the slope (after being submerged) but did not cause major failure (Fig. 8). Counterweight was formed at the toe of slope with a height of 15 m and a width of 25 m, and buttress dip of 17°. Undercutting formed a slope by cutting the bedding plane of in-situ rock on the low-wall side, causing daylight. Slope formation in the undercutting position was adjusted to the overall slope for undercutting.



Fig. 8. Excavation using box cut method at low-wall.

Analysis was performed to determine the stability of landslide material before the undercutting began. Stabilization of landslide material is required to know the impact on stability of undercutting that will be carried out. In general, the analysis was performed on:

1. Stability of landslide material with and without buttress.
2. Slope stability of landslide material and undercutting with and without buttress.

The analysis shows that the landslide material had safety factor of 1.01 which indicated repose condition, and this was in accordance with the real condition where the slope dip of landslide material was formed naturally when landslide occurred (Fig. 9). Stress accumulation was found at the toe of slope with slip surface in the contact area between the in-situ material and the landslide material above it. This was in line with the characteristics of the location. Buttress construction increased the stability of landslide material to 1.08, but when undercutting was carried out, the slope stability changed to 1.03 (Figs. 10 and 11).

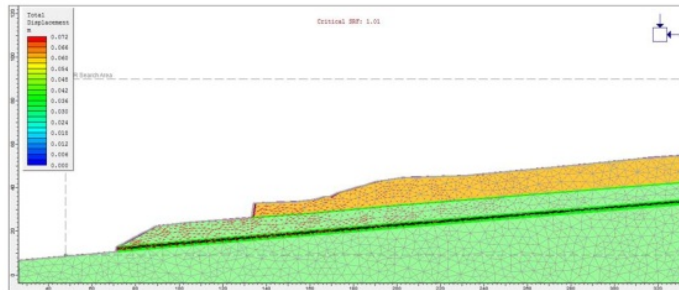


Fig. 9. Single step of in-situ and failure materials without buttress.

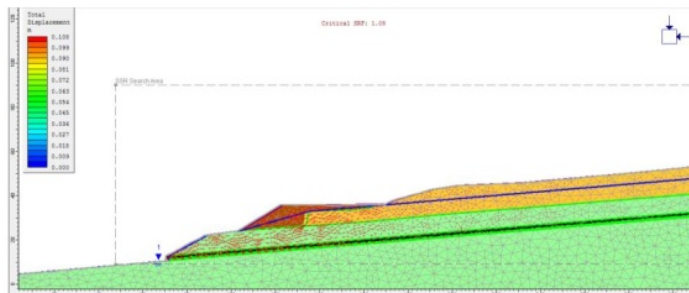


Fig. 10. Single step of in-situ and failure materials with buttress showing groundwater level to buttress.

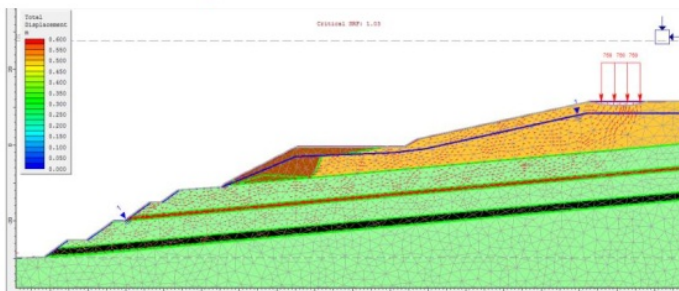


Fig. 11. Undercutting final design and showing distribution displacement.

Potential for landslide was found in the landslide material and in the discontinuous plane along the rock bedding which was a weak zone that controlled instability (Fig. 12). Material deformation occurred more in the landslide material and in the upper in-situ bed. Undercutting mining can be carried out with strict control to maintain the material properties at the top and in the in-situ material. The safety factor of 1.03 is a critical number, therefore, this should be utilized in undercutting mining. Surface water must also be managed to avoid either surface water flow into the landslide zone or infiltration to the contact zone between the in-situ and the landslide materials. If water gets into the contact zone, it will trigger slip surface along the contact zone. Heavy equipment in the landslide zone must also be restricted to keep the load stable. Heavy equipment activity in the landslide area can increase the material load, so the driving force becomes greater.

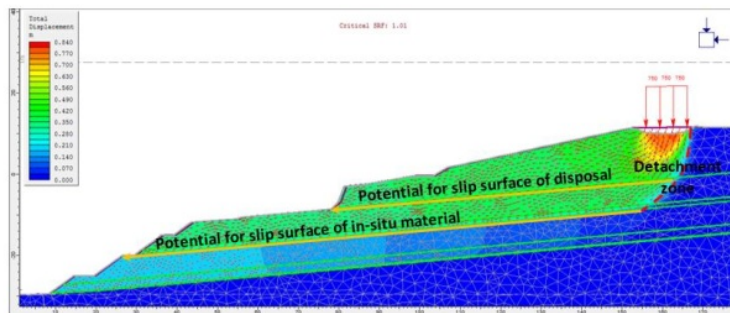


Fig. 12. Distribution of total displacement showing semi-circular pattern.

Slope monitoring system is also mandatory to obtain real condition of slope stability. The monitoring can use simple tool, considering the material has a high plasticity, so that the potential for sudden failure is quite small. Visual observation on drainage condition and buttress stability should also be regularly carried out during undercutting. With strict control, undercutting can be carried out safely and coal can be mined out properly. Coal reserves increased significantly based on the result of this analysis. When the mining is completed, the stability of undercutting and buttress were maintained (Fig. 13).



Fig. 13. Mining was completed using undercutting method without any instability issue.

Based on the analysis result, undercutting can be carried out by considering detailed geological aspects of the area, and the analysis should pay attention to the aspects. Although the safety factor is quite critical, with efforts to maintain the physical and mechanical properties, stability can be maintained.

4. Conclusions

Undercutting mining can be carried out by paying attention to the detailed aspects of geological condition. The analysis result using finite element method shows a critical safety factor, but with strict control of slope stability variables, undercutting activity can still be carried out. The analysis identified details of geological condition such as lithology, stratigraphy, aquifer, and weak zone between beds. Identification of discontinuous plane pattern must be done to ensure the kinematics of a bedding. In high stress zone, the condition of discontinuous plane has a significant role in stability of low-wall slope. Calculation of bedding ratio after modelling weak plane is highly recommended so that at the time of analysis, it will be close to the real field condition. Finite element method is recommended for low-wall stability analysis even though limit equilibrium method is still possible if circular pattern only occurs in one bedding. Depressurization is required to reduce aquifer stress due to the presence of distressed aquifer.

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