CORRELATION BETWEEN OVERALL SLOPE AND SLOPE STABILITY OF HIGHWALL IN PIT TUNGGAL, BORNEO

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ABSTRACT

Slope stability is an important aspect of the mining operation. Hence, an in-depth understanding of slope stability and variable that affect it is very crucial. This research was conducted in pit tunggal, Borneo. The aim of this research is to identify the correlation between overall slope and slope stability in highwall slope at pit tunggal. Slope stability analysis was conducted with SLIDE V 6.00 software using Morgenstern-Price's limit equilibrium method. The result of this research shows that, as the highwall slope gets steeper, the slope stability represented by a factor of safety (FS) may decrease. Otherwise, when the highwall slope gets declivous, the factor of safety may increase.

Keywords: Slope Stability, Factor of Safety (FS), Highwall

INTRODUCTION

Slope stability is an important aspect of the mining operation, especially in the coal industry. To achieve a high coal production target, comprehensive slope stability analysis is necessary.

Highwall slope of a coal mine is expected to be able to stand as steep as possible. This is correlated with the stripping ratio and economics rate of a coal mining operation. Therefore, it is necessary to conduct research that correlates the overall slope and slope stability of highwall.

One method that is used in slope stability analysis is a limit equilibrium method. Basically, this method is identifying the value of safety factor (FS) by comparing the ratio between resisting forces and driving forces that act on a slip surface of a slope.

LITERATURE REVIEW

In the limit equilibrium method, slope stability is defined by a safety factor (FS) which is a ratio between resisting force and driving force of a slope. Theoretically, a slope is stable with safety factor value more than 1 (FS > 1), which means the resisting force is larger than the driving force. If the slope has less than 1 safety factor (FS < 1), it is considered that the slope is unstable because of the driving force is larger than the resisting force.

$$FS = \frac{c + \sigma \tan \varphi}{w \sin \alpha} \qquad \textbf{(Eq. 1)}$$

In slope stability analysis, a method that is used is varies depends on slope condition and type of failure that is more likely to occur. In-depth understanding of slope stability principal is important in mining operation because it can highly affect the effectiveness and efficiency of a mining operation, workers safety, and the safety of mine trucks and machinery. Aspects that need to be concerned with in keeping the stability of a slope is slope design, physical properties and mechanical properties of slope material, geological structure, and pore water pressure.

The rock mass is a volume of rock that consists of minerals, texture and composition, and also discontinuity planes, forming a material with elements that connected one to another as a unit. A rock mass that is massive without any discontinuity planes found in it is considered as an intact rock. Rock mass strength is very affected by the frequency of discontinuity planes, therefore rock mass will have less strength than intact rock.

Gabrielsen (1990) in Sihotang (2008) states that the occurrence of discontinuity plane is associated with the change of stress, temperature, strain, mineralization, and recrystallization that occurs on rock mass in a long period of time. According to Hencher (1987), geological structure and discontinuity in rocks are weak zones and paths for groundwater seepage. The existence of

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geological structure and discontinuity will decrease the shear strength of a rock mass and will increase the chance of a slope to fail. Moreover, the amount of load that is given to a rock mass will also be forwarded anisotropically to the surrounding rock mass, hence the slope stability rate will be decreased.

METHODS

This research began with a literature study of the geological condition of the research area and fundamental materials that relate to this research, as well as completing administration requirements in order to begin the research.

The next stage is to collect all data that is necessary to perform slope stability analysis. Data that is used in this research are rock core, geotechnical laboratory test, and actual slope design of highwall in the research area.

Data processing begins when all data are collected. In this research, data processing consists of overburden characterization, rock mass characterization of overburden units, recapitulation of UCS and wet density data, determination of m_i constants of each overburden units, determination of disturbance factor value, recapitulation of unit weight, cohesion, and angle of internal friction of other materials, and determination of groundwater depth of each slope design.

The next stage is data analysis. After all physical and mechanical properties data of each overburden units and materials are collected, the next step is to make a cross-section of the highwall slope then draw the slope design with software AutoCAD 2017. The slope design consists of three boundaries which are an external boundary, material boundary, and water table. When all slope designs are finished, slope stability analysis can be performed with software Slide V6 by importing the slope design to the software.

The final stage is to determine how stable is highwall in the research area with variations of overall slope based on the results of slope stability analysis with reference to the threshold criterion for slope stability of Stacey (2009).

RESULTS AND DISCUSSION

Data Processing Results

- **Overburden Characterization**

  Based on observation of subsurface seam condition and availability of material properties data, highwall slope in this research is represented by five overburden unit, that is OB A12, OB A10, OB A9, OB A8, and OB Below A8.

- **Rock Mass Characterization of Overburden Units**

  Rock mass classification used in this research to characterize overburden units is geological strength index (GSI). This classification considers RQD (Deere, 1968) and joint discontinuities (Bieniawski, 1989).

Table 1. GSI value of overburden units

Unit *Overburden*	RQD rata - rata (%)	*Joint Conditions* rata - rata	GSI rata - rata
A12	65.74	12.14	51.07
A10	69.27	12.03	52.68
A9	84.23	12	60.12
A8	83.89	12.27	60.36
Below A8	82.44	13.7	61.77

- **UCS and Wet Density of Overburden Units**

  Based on data selection and validation, a statistical parameter such as average and standard deviation of UCS and Wet Density can be determined.

Table 2. UCS value of overburden units

UNIT OVERBURDEN	PROPERTY	MEAN	STD.DEV
A12	UCS	0.975	0.624
A10	UCS	1.105	0.140
A9	UCS	1.362	0.907
A8	UCS	1.272	0.830
BELOW A8	UCS	1.474	0.953

Table 3. Wet Density value of overburden units

OB	WD		
	AVERAGE	MEDIAN	STDEV
A12	2.15	2.14	0.07
A10	2.12	2.15	0.12
A9	2.13	2.14	0.08
A8	2.17	2.17	0.08
BELOW A8	2.21	2.21	0.06

- **M_i Constants of Overburden Units**

  Mi constants value of overburden units determined by calculating the thickness percentage of each lithology type in overburden units and multiply each percentage to mi value of the lithology according to

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Marinos and Hoek (2001) classification.

Table 4. M_i constants of overburden units

OVERBURDEN UNIT	Mi Constants
A12	7.4
A10	7.5
A9	6.5
A8	7.5
BELOW A8	9.9

- **Disturbance Factor Value**

  Lithology found in the research area are sedimentary rocks with UCS value ranges 0.512 – 4.330 (soft rock). The mining operation was conducted with the help of blasting procedure (PPA max = 0.012 g, a max = 0.0078 g) and excavation. Hence, based on the disturbance factor constants table of Hoek (2002), proper D value to be used in this research is 0.7. With consideration of blasting procedure was carried out to the bench face, disturbance factor coverage is 15 m from slope face. It refers to disturbance factor coverage classification from Hoek and Karzulovic (2000) based on bench height in the research area, which is 10 m.

- **Unit Weight, Cohesion, and Angle of Internal Friction of Other Materials**

  Some materials in this research use mohr – coulomb failure criterion. Those materials are coal, weathered layer, weak layer, weak sand, and soft material. Triaxial test and direct shear were conducted to determine the cohesion and angle of internal friction. Basic physical property test also conducted to determine the unit weight of the materials.

Table 5. Unit Weight, Cohesion, and Angle of Internal Friction of Other Materials

Material	Unit Weight (kN/m³)	Cohesion (kN/m²)	Angle of Internal Friction (°)
Coal	12	146	22
Weathered Layer	18	16	5
Weak Layer	18	7	14
Weak Sand	25.2	25	26.2
Soft Material	18.5	7.84	23.66

Slope Stability Simulation

- **Highwall_22**

  Simulation on slope design Highwall_22 with overall slope 22^0 shows that slope is unstable according to the threshold criterion for slope stability in open pit mine with FS_{det} 1.186.

- **Highwall_20**

  Simulation on slope design Highwall_20 with overall slope 20^0 shows that slope is stable according to the threshold criterion for slope stability in open pit mine with FS_{det} 1.322.

- **Highwall_18**

  Simulation on slope design Highwall_18 with overall slope 18^0 shows that slope is stable according to the threshold criterion for slope stability in open pit mine with FS_{det} 1.396.

- **Highwall_16**

  Simulation on slope design Highwall_16 with overall slope 16^0 shows that slope is stable according to the threshold criterion for slope stability in open pit mine with FS_{det} 1.561.

Slope Stability Analysis

Highwall slope stability analysis is conducted with variations of the overall slope. Highwall slope with overall slope 22^0 is unstable. Otherwise, highwall slopes with overall slope 20^0, 18^0, and 16^0 are stable. The explanation of the unstable results is because the driving forces acting on the slip surface are more dominants than the resisting forces acting on the slip surface. Otherwise, the stable slope has more dominants resisting forces than driving forces that acting on the slip surface. Based on the results of this research, as the overall slope gets declivous, the safety factor will rise. Otherwise, as the overall slope gets steeper, the safety factor will decrease.

As shown by equation 1, the declivous overall slope's angle will reduce the α. Hence, the declivous slope has a smaller driving force that acts on the slip surface.

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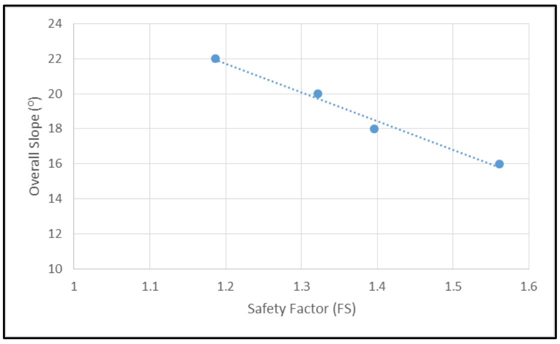

Figure 1. Graph of correlations between safety factor and overall slope

CONCLUSIONS

Based on the results of research on the correlation between overall slope and slope stability of highwall, we can conclude that as the overall slope gets declivous, the safety factor of the slope will rise. Otherwise, as the overall slope gets steeper, the safety factor will decrease. It is shown by the increasing value of safety factor as the highwall overall slope design in research area gets declivous. Redesigning the slope geometry by lengthening the berm of highwall slope will declivous overall slope and increase slope stability.

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Appendix I. Slope Stability Simulation by SLIDE V.6.0

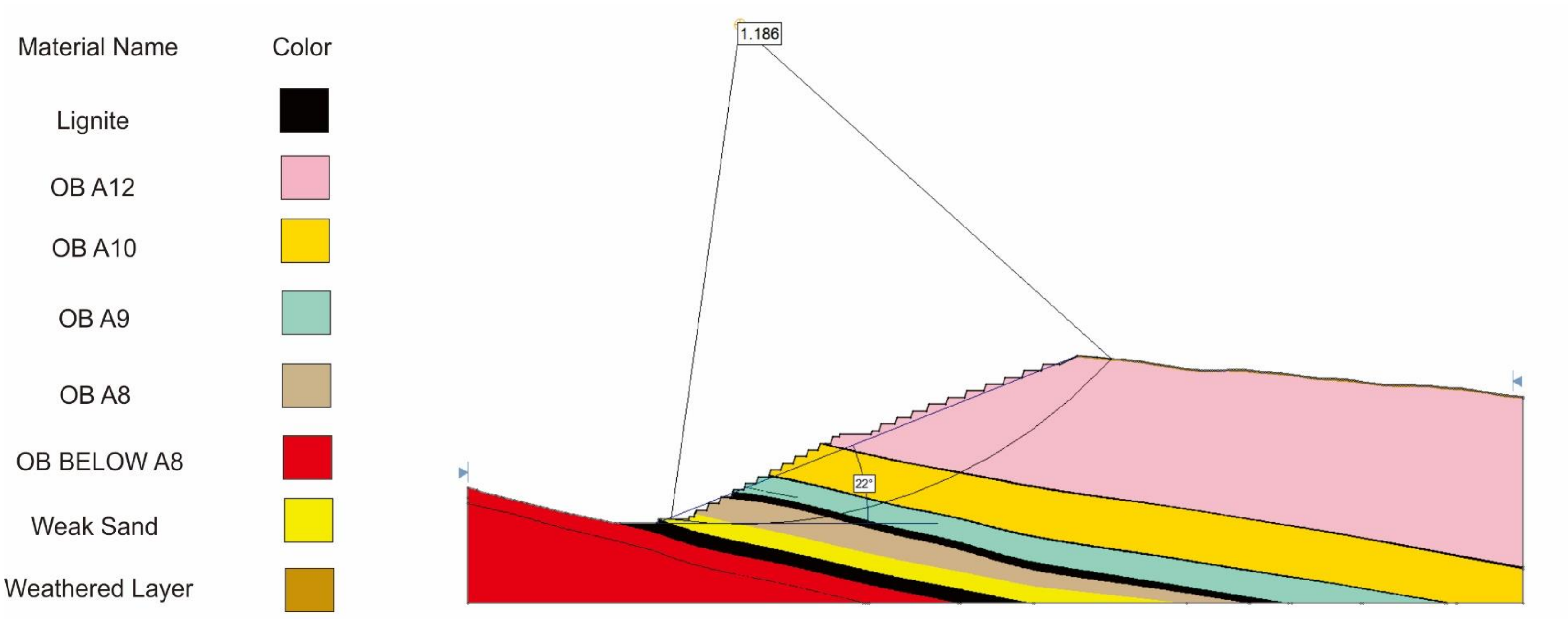

Figure 1 Simulation of highwall slope with overall slope 22°

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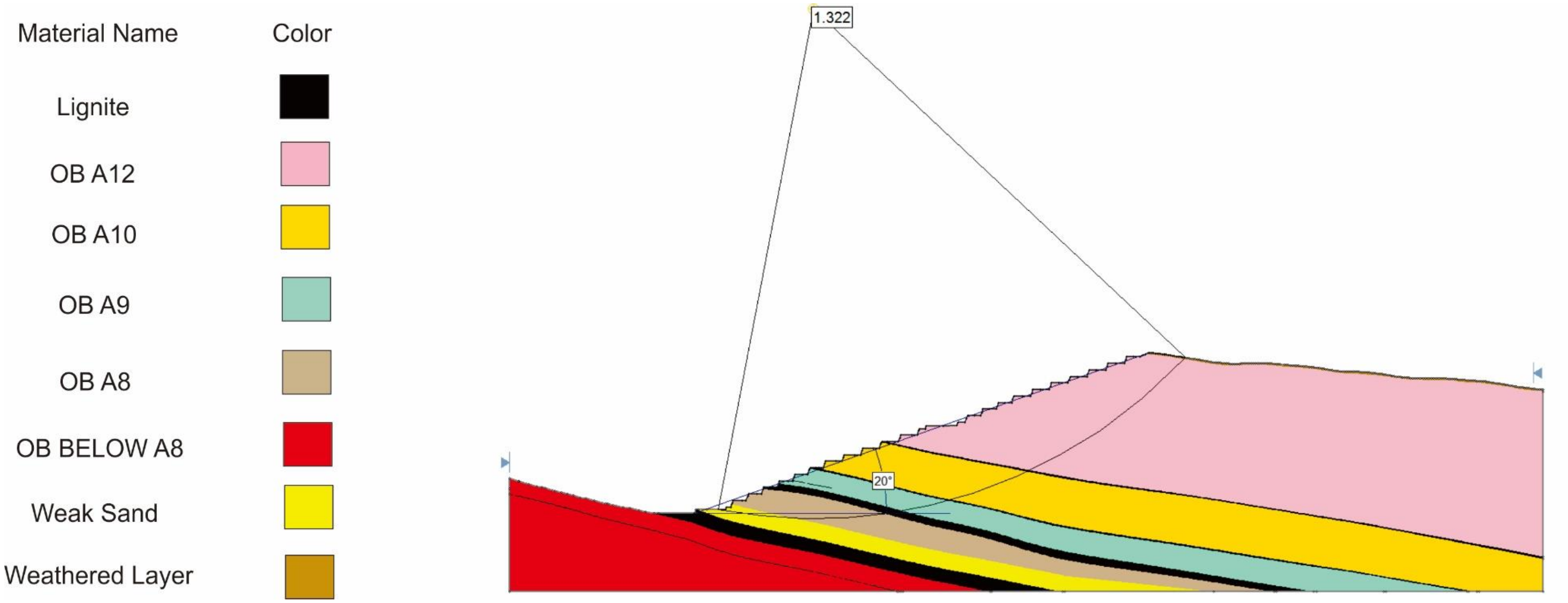

Figure 2 Simulation of highwall slope with overall slope 20^o

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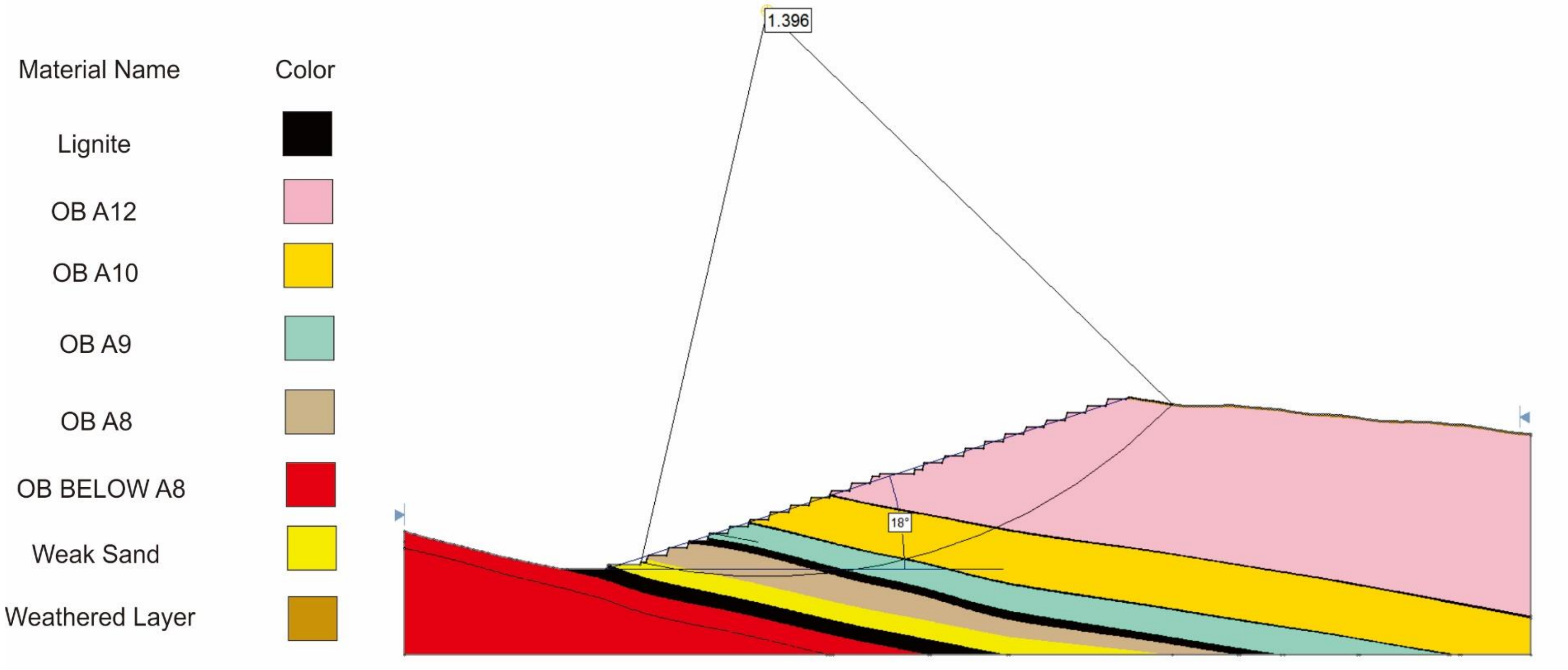

Figure 3 Simulation of highwall slope with overall slope 18°

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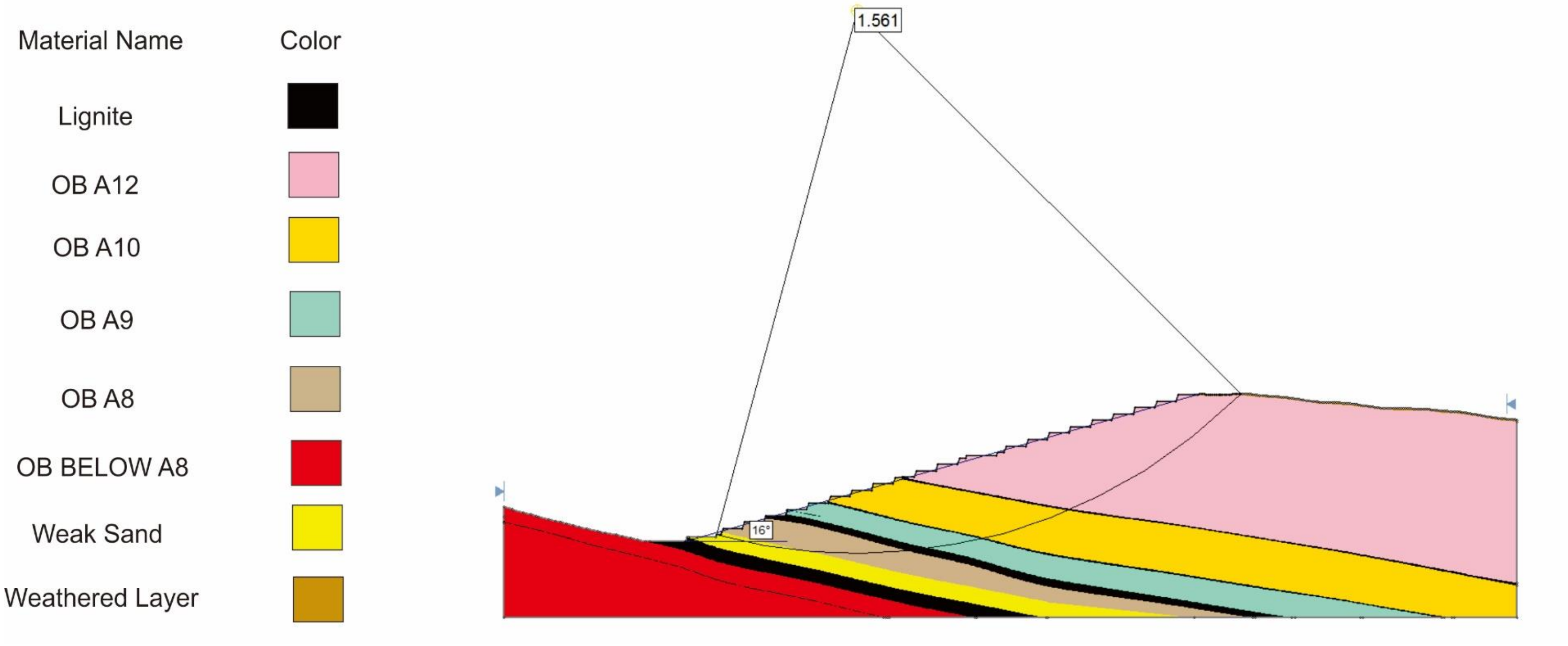

Figure 3 Simulation of highwall slope with overall slope 16°

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