

# Geotechnical approach for occupational safety risk analysis of critical slope in open pit mining as implication for earthquake hazard

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**Abstract.** Occupational safety and health (OSH) is a planned effort to prevent accidents and diseases caused by work. In conducting mining activities often occur work accidents caused by unsafe field conditions. In open mine area, there is often a slump due to unstable slopes, which can disrupt the activities and productivity of mining companies. Based on research on stability of open pit slopes conducted by Febrianti [8], the Meureubo coal mine located in Aceh Barat district, on the slope of mine was indicated unsafe slope conditions, it will be continued research on OSH for landslide which is to understand the stability of the excavation slope and the shape of the slope collapse. Plaxis software was used for this research. After analyzing the slope stability and the effect of landslide on OSH with Job Safety Analysis (JSA) method, to identify the hazard to work safety, risk management analysis will be conducted to classified hazard level and its handling technique. This research aim is to know the level of risk of work accident at the company and its prevention effort. The result of risk analysis research is very high-risk value that is  $> 350$  then the activity must be stopped until the risk can be reduced to reach the risk value limit  $< 20$  which is allowed or accepted.

## 1. Introduction

This study located in a local coal mine in Sumatera -Aceh, Meurebo District, Sumber Batu Village, of West Aceh. Coal mining activities in this area use open pit system (Open Pit). Open pit mining has entered complex mining environment in terms of high and steep, deep, surface and underground combined mining which led the geotechnical researcher to face several challenges [1]. The failure of site investigation has led to catastrophic disaster serious problem for the safety of public [2].

Ramli, [3] noted that occupational safety and health (OSH) issues in the mining industry, as well as construction projects lately, continue to grow in line with the development of technology. Such progress has resulted in the emergence of intense competition between industry and construction service providers, often associated with issues of OSH that can be used as a means to enter national and international markets. The situation has changed the society's view of the importance of seriously implementing OSH management in applying the construction project.

Therefore, the authors examine the effect of landslides on the safety of the work by using Job Safety Analysis (JSA) method, to identify the hazard of work safety which will be analyzed for risk management so that it can be grouped as hazard level and its handling technique. The purpose of this



research is to know the level of risk of work accident in the mining area of excavation of coal mining caused by the slope of unsafe slopes and prevention effort [3].

The results of this study will provide information on the level of occupational accidents, especially on the slopes of coal mines Meureubo Aceh Barat District of Aceh Province, as well as the proper implementation of OSH and Mitigation in case of Work Accidents on the slopes of a coal mine. Following figures are the condition of Meureubo coal mining in the west of Aceh Barat district in figure 1(a) and 1(b).



**Figure 1.** Unsafe Vertical slope (a) Critical Condition of the Coal Mining in Meureubo, (b) Unsafe Equipment (Bulldozer and truck) mobilization. The condition of coal harvesting place in Meurubo. [13]

## 2. Slope Stability Analysis

According to Imran [4], slope stability analysis is sufficiently made with boundary equilibrium approach to obtain the value of safety factor against the smallest collisions. Various ways are offered for this analysis, including ordinary slices, bishop, janbu, morgen stren-prize, and sarma. At least two ways must be used in this stability and safety factor used in planning is derived from the average value of the results of all the means employed [4]. A numerical model of regional scale two-dimensional finite element methods for analysis slope stability was also conducted by Faruque [5]. The result shows that there is a high prospect to cause water flow into the tension zone that eventually creates slope instability. A deep drainage system as suggested by Bomont also being considered [6]. The drained residual shear strength is also applicable for slope analysis with preexisting shear surface [7].

Febrianty, D. [8], this slope stability analysis is calculated by plaxis 8.2 software with the assumption that the analysis is the same as the Limit Equilibrium Method (LEM) method as shown in figure. 2, by dividing the period of land bounded by the landslide into vertical slices deep in plaxis made in the shape of the triangular element as shown in Figure 3. The occurrence of the landslide can be assumed to be shaped circles of shadow (colored) and total deformation mesh in the form of the arrow (arrow direction movement) as shown in Figure 4 and Figure 5. This theory of equilibrium balance is based on the following assumptions;

- (1) Land that behaves like a material, Mohr-Coulomb,
- (2) The safety factor of the components of cohesion and the inner-angle component is as large,
- (3) The safety factor for all slices of the soil mass is the same.

Safety factor is obtained by summing forces on each slice, as well as the momentary summation of the center point of the collapsed field [8].

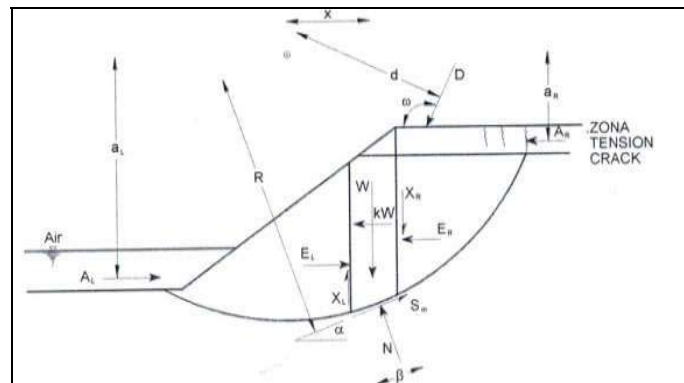


**Figure 2.** Vertical Circle Slices for Slope Analysis [8]

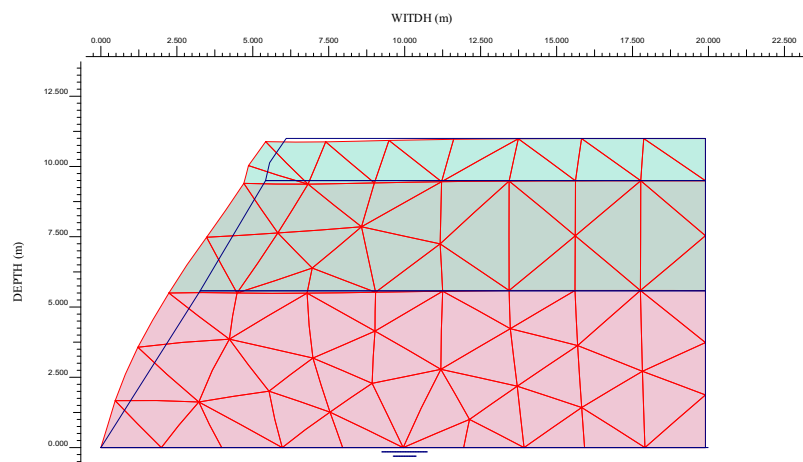


**Figure 3.** The triangular shape for the landslide field, Deformed Mesh Modeling of Plaxis 8.2 [8]

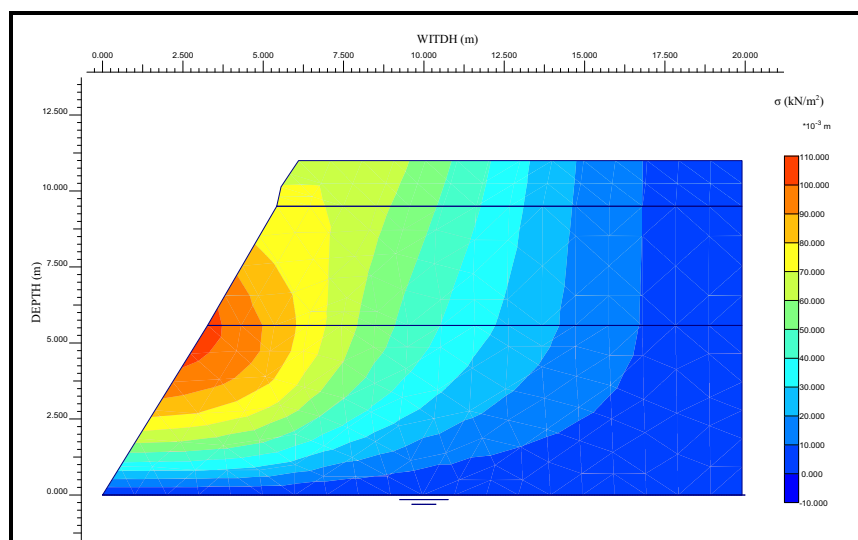


**Figure 4.** Slope failure identification of a shadow circle [8]

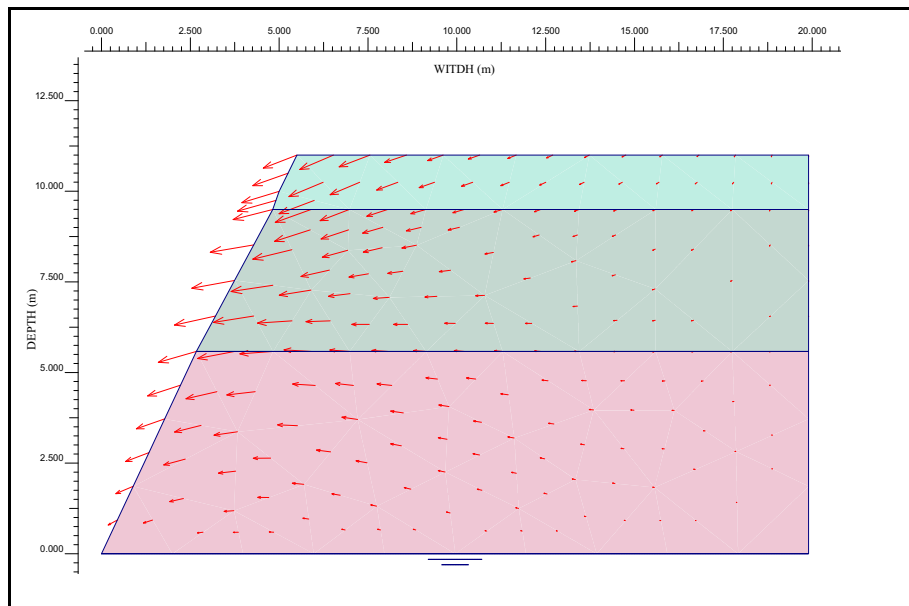


**Figure 5.** Direction of movement in the form of arrow displacement failure [8]

### 3. Job Safety Analysis (JSA)

Said [9], Job Safety Analysis or also known as Job Hazard Analysis is an effort to study/ analyze and recording each sequence of work steps of a job, followed by identification of potential hazards in it then solved by determining the best effort To reduce or eliminate/control the dangers to the work being analyzed [9].

### 4. Risk Analysis

According to the Australian Standard [10], the risk is the possibility or probability of occurrence of something that can lead to an impact on a goal. The risk is measured based on the possibility of a case or consequences that can be caused. While an understanding of Occupational Health and Safety Australian Standard (OHSAS) 18001 risk as cited from Ramli [3], is a combination of the possible happening of dangerous event or exposure with the severity of injury or health problem caused by the event or exposure [10]. The effect of drill vibration from mining site has also given an impact to the surface as [11] which lead to accelerate the landslide possibility surrounding the pit site. This circumstance is also part of risk analysis.

According to Australian Standard [12], risk analysis is a systematic activity using existing information to determine the extent and consequence of frequency of an event. This analysis should consider the range of potential consequences and how risks can occur. The purpose of the risk analysis is to distinguish between small risk and large risk and provide data to assist evaluation and risk management. The semi-quantitative analysis yields more detailed priorities than qualitative analysis, since risk is divided into categories. This method is similar to qualitative analysis, the difference lies in the description or description of the parameters that exist in the semi-quantitative analysis is expressed with a certain value or score. According to Australian standard 4360: 1999, the semi-quantitative analysis considers the possibility of combining two elements, namely probability (likelihood) and exposure (exposure) as frequency. There is a strong relationship between the frequency of exposure and the probability of occurrence of risk [12].

**Table 1.** Risk Level Semi Quantitative Analysis Method (Risk Management) [12]

| Risk Level | Category    | Action |
|------------|-------------|--------|
| > 350      | Very High   | 3.1cm  |
| 180 – 350  | Priority I  | 1.8 cm |
| 70 - 180   | Substantial | 2.8 cm |
| 20 – 70    | Priority 3  | 2.8 cm |
| < 20       | Acceptable  | 0 cm   |

### 5. Analysis qualitative and quantitative

Analysis of data obtained from the Plaxis program is completed qualitatively and quantitatively to obtain results in order to be in further analysis in submitting suggestions. Plaxis program analysis has three stages as below.

**Table 2.** Material Set in Plaxis

|                                          |  | Parameter               | Name           | Yellowish<br>Light Clay<br>1-4 m | Darkys<br>Black Soil<br>4-7 m | Sandy<br>Silt<br>>7 m | Unit              |
|------------------------------------------|--|-------------------------|----------------|----------------------------------|-------------------------------|-----------------------|-------------------|
| Natural<br>Soil<br>Undisturbed<br>Sample |  | Material Model          | Model          | MC                               | MC                            | MC                    | -                 |
|                                          |  | Type of Behaviour       | Type           | Undrained                        | Undrained                     | Undrained             | -                 |
|                                          |  | Dry Soil Weight         | dry            | 16.0                             | 18.2                          | 18.52                 | kN/m <sup>3</sup> |
|                                          |  | Wet Soil Weight         | wet            | 12.5                             | 12.5                          | 20.53                 | kN/m <sup>3</sup> |
|                                          |  | Horizontal Permeability | K <sub>H</sub> | 8.64 x 10 <sup>-5</sup>          | 0.0864                        | 2.80 E-7              | m/day             |
|                                          |  | Vertical Permeability   | K <sub>P</sub> | 8.64 x 10 <sup>-5</sup>          | 0.0864                        | 2.80 E-7              | m/day             |
|                                          |  | Young's Modulus         | E              | 2000                             | 4500                          | 980.7                 | kN/m <sup>2</sup> |
|                                          |  | Poisson's Ratio         | C              | 0.3                              | 0.4                           | 0.2                   | -                 |
|                                          |  | Cohesion                |                | 0.5                              | 2.1                           | 17.75                 | kN/m <sup>2</sup> |
|                                          |  | Friction Angel          |                | 6.2                              | 8.8                           | 1.45                  | 0                 |
|                                          |  | Dilatancy Angel         |                | 0                                | 0                             | 0                     | 0                 |

#### 5.1 Data input

The stages in data input, as follow;

- Entry of geometry of the slopes reviewed,
- Selection of analysis type and element type.
- Inclusion of material properties and soil coating, which corresponds to the Table. 2,
- Preparation of mesh as a whole,
- Run from the initial stresses of the analysis, and
- Run the calculation phase.

#### 5.2 Data Output Stage

The data output stage is the stage of the results obtained from the calculation stage with the Plaxis program. The results obtained at the data output stage are:

- Calculate the safety factors obtained from the relationship graph  $\Sigma M_{sf}$  and displacement; and
- Deformation of the slope shown from total displacement.

Analysis the stability of slope by means of trial and error against slopes by using Plaxis program which requires appropriate slope angle modeling. This modeling is completed to obtain slope stability from the actual condition in the field so that the result obtained from the slope is safe from the sliding.

**Table 3.** Modeling of Slope Stability

| Modeling      | Varian $\theta$       |               |                       | Varian C                 |                 |                          | Hasil/<br>Output |
|---------------|-----------------------|---------------|-----------------------|--------------------------|-----------------|--------------------------|------------------|
|               | $\theta_{nt+}$<br>10% | $\theta_{nt}$ | $\theta_{nt-}$<br>10% | C <sub>nt</sub> +<br>10% | C <sub>nt</sub> | C <sub>nt</sub> -<br>10% |                  |
| $df_n + 10\%$ | +                     | OSH           | OSH                   | OSH                      | OSH             | OSH                      |                  |
| $df_n$        | +                     | +             | OSH                   | +                        | +               | +                        |                  |
| $df_n - 10\%$ | +                     | +             | OSH                   | +                        | +               | +                        |                  |

Inform: (+) Good Results, (OSH) Out Put Less Good

## 6. OSH Issues Analysis

Analysis of the data obtained from the Plaxis program is completed qualitatively and quantitatively to obtain results in order to be in further analysis in submitting suggestions.

## 7. Stages of Effect of Landslide on Occupational Safety

Analyze the impact of a landslide on work safety using JSA method. The steps in preparing the JSA (Job Safety Analysis) include:

### Determining Job Type

- Jobs that have a history of occupational accidents are the most severe or often a top priority for analyzed safety. Factors to consider in determining the work to be analyzed are as follows;
  - Occupational accident rate,
  - The level of accidents that caused the defect,
  - Potential severity of work accidents,
  - New work,
  - Jobs that have a history of near misses.
- Detailing the sequence/work steps from start to work until completion of work.
- Identify the hazards and potential of work accidents on each work sequence performed.
- Determine the control measures against the dangers of each work sequence performed.

## 8. Stages of Analyzing Hazards with Risk Analysis Methods

There are 3 ways in the risk assessment: Qualitative, Semiquantitative and Quantitative. These methods are in principle almost equal to qualitative analysis, the difference in this method description of the existing parameters expressed with a certain value/score.

- Risk analysis,
- Risk handling,
- Risk received.

## 9. Results and Discussion

### 9.1 Field observation results

Based on field observations and soil sampling on the slopes of excavated tested in the laboratory, it is found that the surface soil which is the slope of the excavation can be categorized as vulnerable to stability, the soil is quite hollow, less dense composed of yellowish light clay with cohesion values and low shear angle values respectively,  $c = 0.5 \text{ kN/m}^2$ ,  $\phi = 6.2^\circ$ ,  $\sigma = 0.3 \text{ kN/m}^2$  and darkys black soil with cohesion values and the shear angle values are also low respectively  $c = 2.1 \text{ kN/m}$  and  $\phi = 8.8^\circ$ ,  $\sigma = 0.4 \text{ kN/m}^2$ .

### 9.2 Results of Slope Stability Analysis

Based on the calculation of slope stability using Plaxis program on cross-section of excavation that has the height and slope of the slope that has been determined, the results presented by the Plaxis program is safe and meets the standards of the predetermined slope safety factor. Which is shown on natural conditions, while the conditions under which the modeling shows the condition of safe and unsafe conditions.

### 9.3 Results of Plaxis Analysis

Based on the calculation of slope stability using the Plaxis program, the results displayed by the Plaxis program are partly safe, and some do not meet the criteria of the safety factor. This can be seen in the table below.

**Table 4.** Plaxis calculation results

| Modeling             | Safety Factor<br>Varian $\theta$ |               |                      | Safety Factor<br>Varian C |          |                 |
|----------------------|----------------------------------|---------------|----------------------|---------------------------|----------|-----------------|
|                      | $\theta_{nt}$<br>+10%            | $\theta_{nt}$ | $\theta_{nt} - 10\%$ | $C_{nt}$<br>+10%          | $C_{nt}$ | $C_{nt} - 10\%$ |
| $\alpha_{fn} + 10\%$ | 1,18                             | 0,94          | 0,78                 | 0,97                      | 0,94     | 0,92            |
| $\alpha_{fn}$        | 1,42                             | 1,03          | 0,82                 | 1,04                      | 1,03     | 1,02            |
| $\alpha_{fn} - 10\%$ | 1,56                             | 1,05          | 0,87                 | 1,12                      | 1,05     | 1,06            |

In table 4 shows the lower the degree of slope ( $\alpha$ ) then the Safety Factor (SF) is getting bigger. Based on the results of the stability slip analysis with Plaxis program on the natural conditions ( $\alpha_{fn}$  and  $\theta_{nt}$ ) indicates stable slope conditions because of SF (1.03) > 1, as shown in Figure 6 and Figure 7.

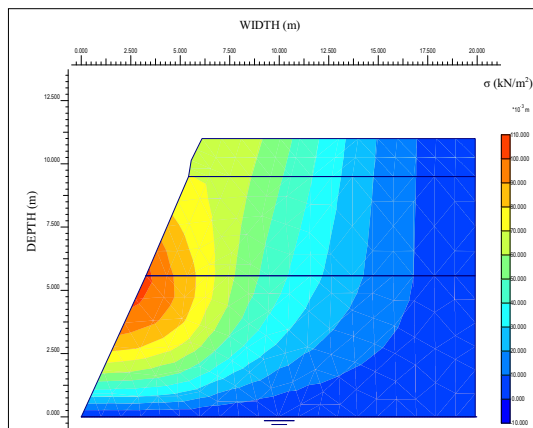


**Figure 6.** Plaxis Total Displacement Results Modeling of Cohesion Variants ( $\alpha_{fn}$ ) dan ( $\theta_{nt}$ )

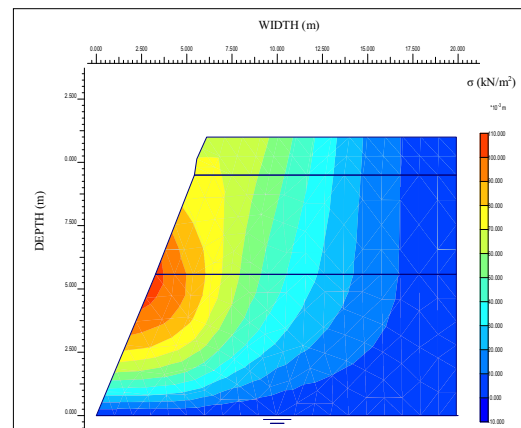


**Figure 7.** Plaxis Total Displacement Results Modeling of Cohesion Variants ( $\alpha_{fn}$ ) and ( $C_{nt}$ )

The geometry of slope stability analysis with Plaxis program under natural conditions ( $\alpha_{fn}$  and  $c_{nt}$ ) shows stable slope conditions because SF (1.03) > 1 is shown in figure 8.

In table 3. it can be seen that the highest security factor number reaches 1.56 at the time of modeling of shear variant which gains 10% ( $\pm 0 + 10\%$ ) and slope angle 54 degrees ( $\alpha_{fn}-10\%$ ). Plaxis results show safe conditions as shown in figure 9.

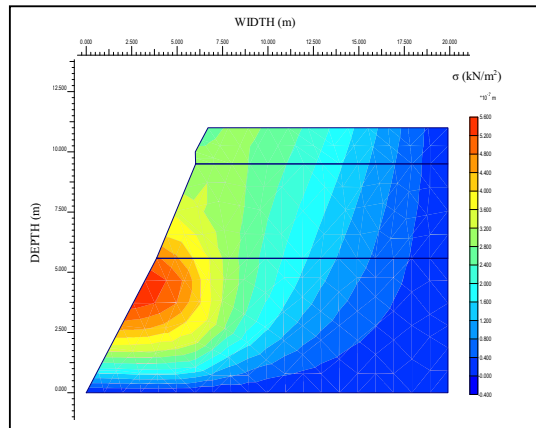


**Figure 8.** Results Plaxis Total Displacement Sliding Angle Variant ( $\alpha_n - 10\%$ ). ( $\theta$ ) and ( $\theta_{nt} + 10\%$ ).

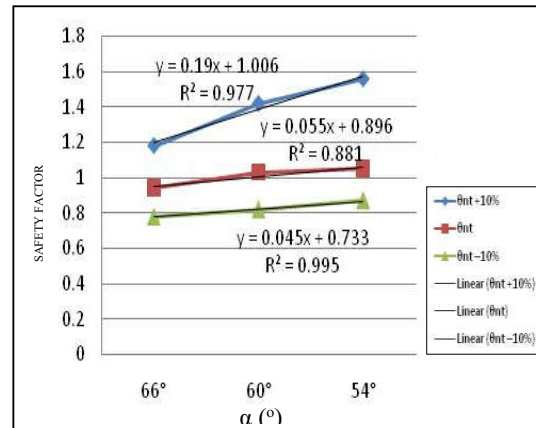


**Figure 9.** Plaxis Safety Factor Charts for Modeling of Angular Variants.

Table 3 shows that the relationship of variant of shear angle and cohesion to the value of security factor which can be seen in graphic form in figure 10.

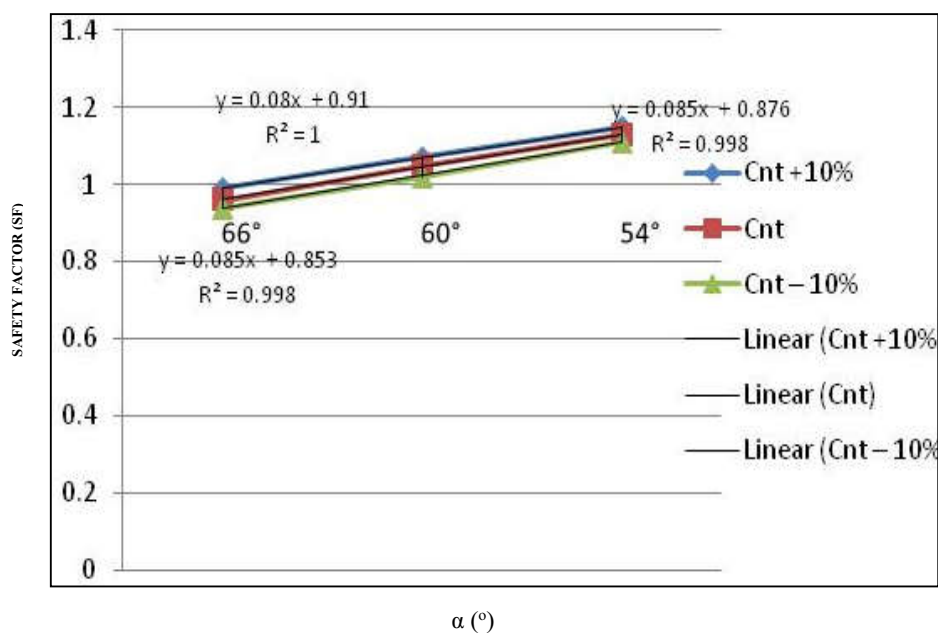


**Figure: 10** Plaxis Safety Factor Chart For Modeling of Cohesion Variants ( $C \text{ kN/m}^2$ )

Figure 10 shows the variant of the cohesion variant ( $c$ ). The graph line depicts the lower angle of the slope, the higher the security factor. The safety factor values obtained in the cohesion variant are very close together, so that the graph line is visible on the image above as a thick line.

#### 9.4. Analysis of K3 with Job Safety Analysis Method (JSA)

Analysis of K3 using JSA method in mine detected by landslide, the result obtained that there are some landslide point which have an effect on the safety can inhibit the process of taking coal even fatal. Based on JSA analysis result there is work sequence done where in the case of safety assessment on open mine slope is only analyzed on two items of work that is, Coal getting coal mining and Coal hauling coal hauling. Hazard potential is based on the calculation of slope stability using plaxis program on the quarry where some slopes do not meet established safety factor criteria.

#### 9.5 Risk Analysis

Results of workplace risk analysis at Coal getting and Coal hauling stage. When clearing the soil mixture from the coal surface, the risk of a landslide pumped machine has a value of 3 acceptable risks, its countermeasures of the intensity that poses a reduced risk seminal. Then at the stage of coal scavenging and coal gathering there is a risk value of 750 and 450 so that enter in the category of very high-risk level, which means the activity is stopped until the risk can be reduced to reach the allowable or acceptable limits. The result of the risk analysis is shown in table 5.

**Table 5.** Risk Analysis Results

| No                  | Job details                                                                  | Risk                                                                     | Risk Value | Level of risk     | Action                                                                               |
|---------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------|------------|-------------------|--------------------------------------------------------------------------------------|
| <b>Coal Getting</b> |                                                                              |                                                                          |            |                   |                                                                                      |
| 1                   | Cleaning impurities from coal surfaces.                                      | The water pump machine is buried in landslides and coal mixed with soil. | 3          | <i>Acceptable</i> | The intensity that poses a risk is reduced to a minimum                              |
| 2                   | Loose (hard coating)                                                         | Backhoe or hammer buried by landslide                                    | 750        | <i>Very high</i>  | Activity is stopped until the risk can be reduced to the limits allowed or accepted. |
| 3                   | Collection / accumulation at the mine site for loading onto conveyance means | Backhoe or bulldozer slipped and rolled over                             | 450        | <i>Very high</i>  | Activity is stopped until the risk can be reduced to the limits allowed or accepted. |
| <b>Coal Hauling</b> |                                                                              |                                                                          |            |                   |                                                                                      |
| 1                   | Loading of coal to the conveyance & preparation of road access.              | Dump trucks buried by landslides and dozer                               | 450        | <i>Very high</i>  | Activity is stopped until the risk can be reduced to the limits allowed or accepted. |
| 2                   | Transportation of coal from the mine site (pit) to the processing unit       | Roads buried by landslides, cars overturned                              | 50         | <i>Priority 3</i> | It needs to be watched and watched on an ongoing basis.                              |

Kramer [14], based on site visit survey there are no any hazard anticipation actions during the cut and hauling process. As a result, risk and level risk value from Table 5 cannot be reduced [14].

## 10. Conclusion

Based on the results of risk analysis on the open pit slopes using JSA method and calculate the stability of the slope using plaxis 8.2 software it can be explained some conclusions and suggestions as follow,

- (1) Based on field observations and soil sampling on the slopes of excavated tested in the laboratory, it is found that the surface soil which is the slope of the excavation can be categorized as vulnerable to stability, the soil is quite hollow, less dense composed of yellowish light clay with cohesion values and low shear angle values respectively;  $c = 0.5 \text{ kN/m}^2$ ,  $\phi = 6.2^\circ$ ,  $\sigma = 0.3 \text{ kN/m}^2$  and darkys black soil with cohesion values and the shear angle values are also low respectively  $c = 2.1 \text{ kN/m}^2$  and  $\phi = 8.8^\circ$ ,  $\sigma = 0.4 \text{ kN/m}^2$ .
- (2) Analysis of slope stability at the excavation of coal mining quarry at the mine at Meurebo sub-district, West Aceh Regency, resulted in  $FS > 1$  condition which means that the condition indicates the condition of the slopes is safe and there are also results showing  $FS < 1$  which means the slopes are not safe.
- (3) From unsafe conditions, the safety risk risk analysis using JSA method and risk analysis method, from the analysis of the coal extraction stage Coal getting concluded the existence of the acceptable small risk and there is a very high risk to safety, when cleaning the soil mixture Which is derived from the coal surface, the risk of pumping machine buried by landslide has a risk value of 3 acceptable, then at the stage of coal combustion and coal collection there is a risk value of 750 and 450 so that enter the category of very high-risk level, which means the activity is stopped until the risk Can be reduced to the limits allowed or accepted.
- (4) At the Coal hauling coal hauling stage there is a risk value of 450 very high in coal loading activities to the transportation equipment & the preparation of road access, and in the transportation activities of coal from the mine site to the processing unit there is a risk value of 50 (priority) monitored and cared for on an ongoing basis.

## Suggestion

The suggestions that the author exposes for the perfection of safety studies on the open slopes include the following:

- In the analysis of slope stability that has a very high-risk value it is necessary to do technical risk mitigation such as the installation of site pile, soil reinforcement, making the slopes more sloping, so that landslides that cause risks do not occur.

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