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Sensitivity analysis of nickel haul road embankment slopes using the coefficient of variation approach

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Abstract

Purpose. The behavior of slope instability is influenced by many factors, both internal, such as the physical-mechanical properties of materials, and external, such as rain and seismic activity. Sensitivity analysis is used to determine the parameters that have the greatest impact on the level of slope stability.

Methods. Sensitivity analysis of embankment slopes uses the coefficient of variation (CV) approach with input parameters namely cohesion and internal friction angle.

Findings. The results of the study confirm that the internal friction angle is the most influential parameter on the embankment slope stability. The evidence is that at the highest percentage of CV, there is the highest probability of avalanches, based on these parameters.

Originality. In this research, the coefficient of variation method is used to determine which parameters have heterogeneous data distribution and the greatest probability of failure, as well as to test mechanical sensitivity with the concept of changing the percentage of parameters to a safety factor value to validate calculations using the coefficient of variation approach.

Practical implications. The sensitivity analysis results are not only limited to values, since the more important is finding out the cause of the influence of these parameters according to field conditions. The reason why the internal friction angle is the most sensitive parameter is the grain size approach, when the limestone mixture in the field has coarse and large grain sizes. Therefore, the surface tends to form rough waves and causes the relatively large grained rocks to have large internal friction angles.

Keywords: *sensitivity analysis, coefficient of variation, probability of failure, slope stability, angle of internal friction, cohesion*

1. Introduction

The embankment slope is a slope formed as a result of stockpiling of material [1]. On the embankment slopes, the material is loose due to backfilling. The results of full-core drilling in this study show variations in different material conditions, due to the relatively remote and different spacing of drilling between drill holes. These variations will affect laboratory test results and physical-mechanical properties. The variability of the laboratory test is assessed as a form of uncertainty that will affect the recommendations for determining slope stability [2]. Thus, the factor of safety that becomes the standard for assessing a slope is considered insufficient to describe the slope uncertainty [3].

The concept of probability is used to take into account the parameters of uncertainty in the physical-mechanical properties of rocks and soils that make up the slopes of mine workings and embankments. The statistical method (Point Estimate Method) has been chosen to calculate the probability because it is relevant to the limited field data, rock lithology variability, which tends to be homogeneous, and it is still at the stage of preliminary design. It does not require a certain probability distribution function and is practical in model computation time. However, the results obtained are quite accurate compared to other statistical methods [4]. In addition, it uses numerical modeling to analyze slope stability and landslide probability using RS2 software.

Sensitivity analysis is presented to complete the slope stability study. This analysis aims to determine which parameters have the greatest influence on slope stability. This needs to be known due to the influence of the uncertainty of the input parameter values used. Thus, each of these values will show which parameters have the most impact on slope stability, which will later be useful in slope handling for short-term and long-term slope planning [5].

The study on sensitivity analysis has been conducted by several researchers with varying results depending on location, slope and material studied. In the first work [6], which studied sensitivity of slopes in the area of Grobogan and Central Java, it has been revealed that the most influential parameter of soil slope stability is cohesion. In another work [7], a soil sensitivity parameter on a slope in Kuala Lumpur has been determined. The analysis of parameters such as range of cohesion values, friction angle, unit weight and groundwater level was carried out with three conditions (maximum, mean and minimum). Sensitivity analysis was carried out by two methods, namely, the Spencer method and General Limit Equilibrium method.

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The order of most sensitive parameters is the groundwater table, friction angle, cohesion, and unit weight. In another work [8], by performing a sensitivity analysis on loose soil slopes, it has been revealed that the order of parameters that most influence on the stability of slopes includes the internal friction angle, bulk density, and cohesion. In another work [9], where sensitivity analysis is conducted using finite element method, the order of parameters that most influence on the slope stability includes the internal friction angle, the slope height, cohesion, slope angle, bulk density, modulus of elasticity and Poisson ratio. The purpose of the sensitivity analysis in this study is to identify the parameters that have the greatest influence on embankment slope stability.

In this study, a sensitivity analysis is conducted to determine the most influential parameter on the haul road embankment slope using a statistical approach to the coefficient of variation, which is validated with a mechanical sensitivity test. The reason for setting parameter is the most reasonable, based on the approach to field conditions, and is also explained below in this paper.

2. Methods

2.1. Research location

Administratively, the PT SCM IUP area is located in the Routa District, Konawe Regency. Geographically, the PT SCM WIUP is located within the coordinates of 121°43′15″-121°56′0″ East Longitude and 3°4′0″-2°55′7″ South Latitude. Regional geological map is presented in Figure 1 and drilling results are presented in Figure 2.

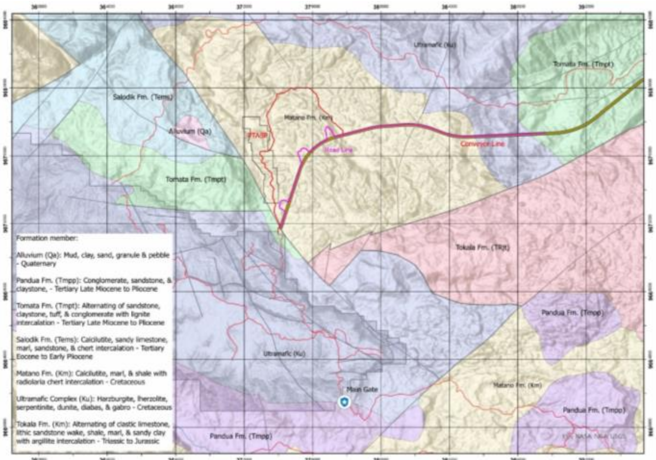

Figure 1. Regional geological map of transport roads of PT. SCM

Figure 2. Full-core drilling results GT-07

The regional geology in the haul road area mostly belongs to the Matano Formation, which is generally dominated by limestone, as shown in Figure 1. Of the 17 drilled holes, logging results from 15 drilled holes show Limestone lithology, a small amount of carbonate sedimentary rocks (marl), and two drilled holes GT-16 and GT-17 show ultramafic rock lithology. This statement is supported by the results of drilling at one point (GT-07), which shows the presence of limestone with an RQD of 71%, as shown in Figure 2.

2.2. Probability analysis method

Probability with the Point Estimate Method is used to determine the most influential random parameter. This method has been chosen because the application is simpler and can run modeling programs faster, which is due to using fewer samples of modeling. In this method, the probability density distribution (PDD) of a random variable is simulated using a mass "point" with a location plus or minus one standard deviation (σ) from the mean (μ).

One of the advantages of using the Point Estimate method, in addition to its practicality with sufficient statistical parameters (mean and variance), is that this method does not require additional probability distribution functions. The avalanche probability calculation is based on the average value (μ) and standard deviation (σ) of the FOS values, which are considered normally distributed according to Christian and Baecher [10] as follows:

– reliability index:

$$\beta = \frac{\mu - 1}{\sigma}; \quad (1)$$

– probability failure:

$$PK = 1 - \phi[\beta]; \quad (2)$$

where:

ϕ – value from standard normal distribution table.

2.3. Sensitivity analysis using coefficient of variation

The coefficient of variation approach has been chosen as the sensitivity analysis method because it is suitable for using the point estimate method in determining the probability of a landslide, where the required parameters are the average and standard deviation. The coefficient of variation (CV) is the ratio between the standard deviation and the average [11]. The two deviation measures described above are included in the absolute dispersion group, and the coefficient of variation is in the relative dispersion group. CV is used to compare the variation of several random variable data, where the smaller the coefficient of variation data, the higher the quality of the data.

$$COV = \frac{\sigma_x}{\mu_x} \cdot 100\%. \quad (3)$$

The coefficient of variation approach can be included in the sensitivity analysis, where subsequently the parameter having the largest percentage of the variation coefficient will be assessed as the parameter that has the greatest influence on slope stability. This is due to the fact that these parameters have large data variability, high uncertainty and lead to an increase in the probability of failure.

2.4. Research flow chart

A systematic research requires a flowchart to present the steps that must be taken to obtain reliable research results Figure 3.

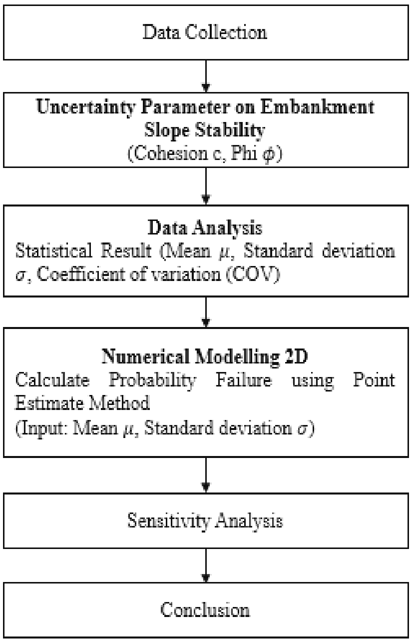

Figure 3. Research flow chart

The sensitivity analysis process begins with determining the range of coefficients of variation that will be simulated (for this study 15, 45, and 75%). The standard deviation can then be found by dividing the average value of each parameter by the simulated CV range. This value will then be used as an input parameter for the analysis of slope stability and landslide probability using the Point Estimate method and RS2 software. The results of modeling are presented as FOS average and standard deviation, then based on the FOS results and standard deviation, the CV coefficient can be found. The repetition continues through the number of analyzed parameters, so that later the parameters that have the greatest influence on the slope stability are obtained. Sensitivity analysis is carried out on the embankment slopes in Section A-C and Section B-C on the Main Transport Road at PT Sulawesi Cahaya Mineral.

A mechanical sensitivity test is carried out to validate the results of statistical sensitivity test. The parameters to be tested for sensitivity are the cohesion and internal friction angle. The first step to obtain the value of the sensitivity analysis input parameter is to find the range (highest value – lowest value) of the parameter (for example, Cohesion), then the range is multiplied by the percentage increase starting from 10, 20, 30 and so on. Then the lowest value of the cohesion parameter is added to the result value by multiplying the percentage by the range. Validation will be proven if the final value of the input parameter is equal to the largest value of the test parameter. This value is then entered into the modeling to obtain the SRF value.

3. Results and discussion

3.1. Sensitivity input parameter

The results of data processing for the sensitivity analysis input parameters are presented in Table 1. The sensitivity analysis input parameters are entered into the numerical modeling using RS2 slope stability analysis software (Fig. 4). Numerical modeling gives FOS, standard deviation and failure probability. The FOS and standard deviation are then used to find the coefficient of variation as a reference for determining the most sensitive parameter using a statistical approach.

Table 1. Input parameters for sensitivity analysis

Parameter	Embankment cohesion (KPa)	Embankment Phi (°)
Mean	44	32.33
CV	Standard deviation	
15%	6,6	4.84
45%	19,8	14.54
75%	33	24.24

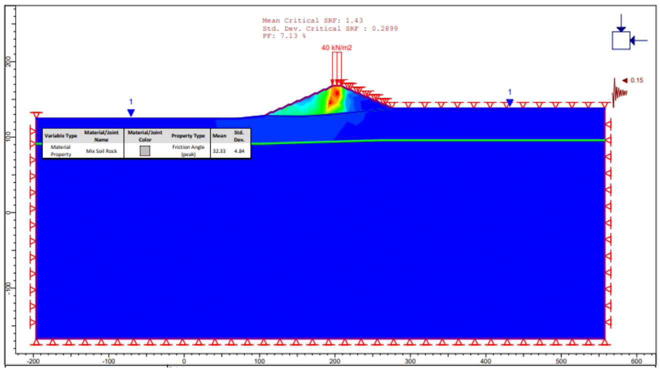

Figure 4. Results of RS2 slope stability modeling

3.2. Embankment slope section A-B

The results of the sensitivity analysis on the embankment slope section A-B are presented in Figures 5, 6 and 7, the probability of landslides in Figure 8.

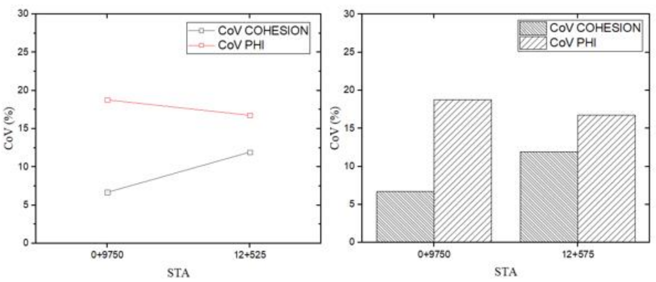

Figure 5. Effect of cohesion and phi parameters based on the coefficient of variation (CV range 15-45%)

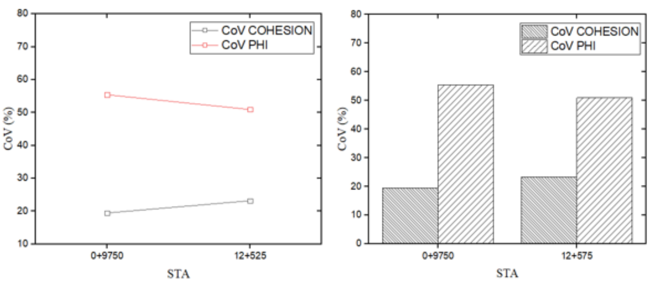

Figure 6. Effect of cohesion and phi parameters based on the coefficient of variation approach (CV range 45-75%)

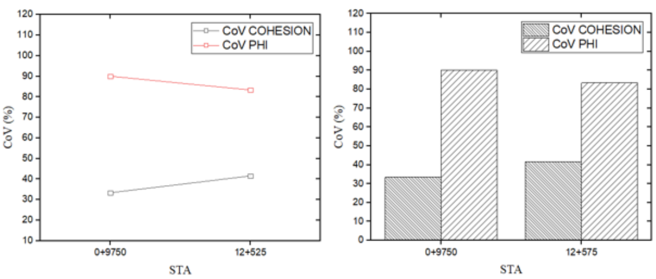

Figure 7. Effect of cohesion and phi parameters based on the coefficient of variation approach (CV range 75-100%)

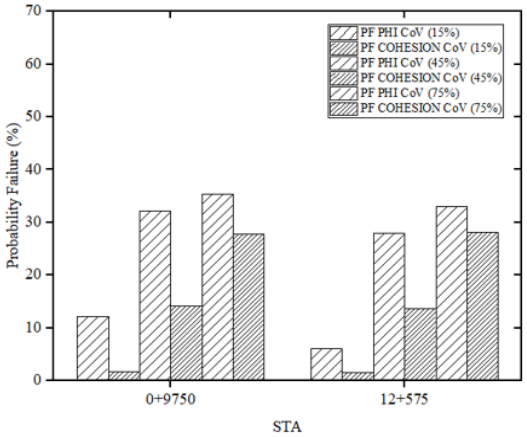

Figure 8. Probability of A-B embankment avalanches based on sensitivity analysis parameters

The results of the sensitivity analysis of the three CV variations show that the internal friction angle is the most influential parameter in the stability of the embankment slopes in sections A-B, since it has the largest CV percentage from the CV modeling of 15, 45 or 75%. The influence of internal friction angle on slope stability is also evidenced by the highest percentage of failure probability compared to the cohesion parameter.

3.3. Embankment slope section B-C

The results of the sensitivity analysis on the embankment slope Section B-C are presented in Figures 9, 10 and 11.

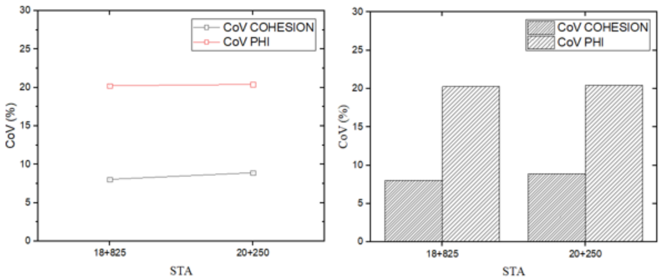

Figure 9. The effect of cohesion and phi parameters based on the coefficient of variation approach (CV range 15-45%)

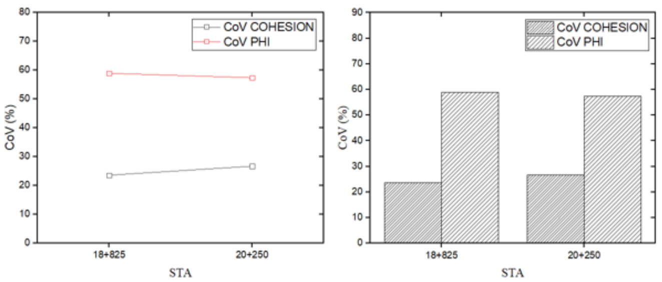

Figure 10. The effect of cohesion and phi parameters based on the coefficient of variation (CV range 45-75%)

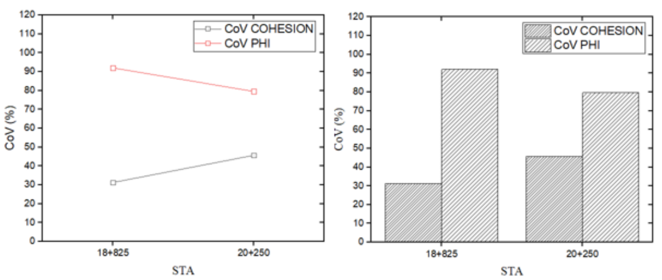

Figure 11. The effect of cohesion and phi parameters based on the coefficient of variation (CV range 75-100%)

The results of the sensitivity analysis of the three CV variations show that the internal friction angle is the most influential parameter in the stability of the embankment slopes in section B-C, since it has the largest CV percentage from the CV modeling of 15%, 45%, and 75%. The failure probability based on the sensitivity test parameters is presented in Figure 12.

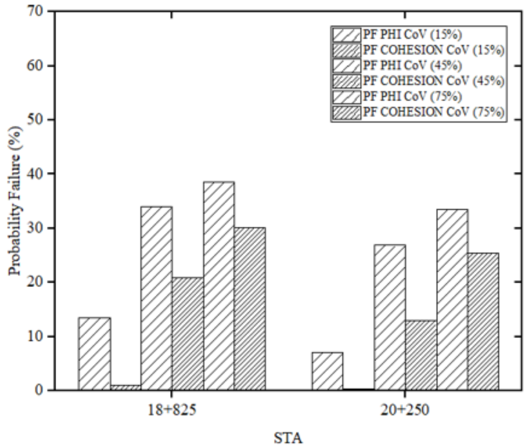

Figure 12. Probability of B-C embankment avalanches based on sensitivity analysis parameters

The influence of internal friction angle on slope stability is evidenced by the percentage of the highest failure probability compared to the cohesion parameter.

3.4. Sensitivity analysis validation

The results of the mechanical sensitivity test are presented in Figure 13.

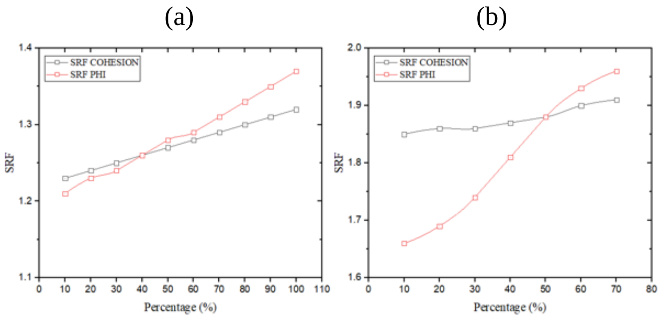

Figure 13. Effect of cohesion and Phi on SRF at STA: (a) 0 + 9750; (b) 20 + 250

The sensitivity test results show that the internal friction angle is the most influential parameter on slope stability. The internal friction angle is the most sensitive parameter because it causes a large SRF change for each percentage increase in the value of internal friction angle. Further research has been conducted to find out why the internal friction angle is more influential parameter than cohesion (both statistically and mechanically). The field study results show that the embankment material is a mixture of limestone and soil. The percentage of limestone is greater than the percentage of soil. The stockpiled limestone is the material taken from the embankment.

According to the approach of Wentworth [12], the grain size of limestone is included in the calcirudite group (coarse-grained) with a size of > 2 mm (it occurs in the field in the form of lumps and gravel). The grain size is associated with the approach of Bandis et al. [13] regarding the effect of the shear strength parameter on the grain size. If the rock is composed of small grains, the bonds between the grains tend to be very tight, so the cohesion value is higher than that of large grains. Although the rocks have a relatively large grain sizes, the shear surface tends to form rough waves (roughness). This causes relatively large-grained rocks to have large internal friction angles. It is concluded that for case studies of embankments with mixed limestone material, the internal friction angle parameter has a greater influence than cohesion. Figures 14 and 15 present the state of the STA 20 + 250 embankment and its materials.

Figure 14. Embankment slope of STA 20 + 250

Figure 15. Embankment material for STA 20 + 250

The statement that the internal friction angle is the most sensitive parameter, which influences the slope stability, is confirmed by the results of the study [14] "Effect of Materials Quality on Stability of Embankment Dam". This study discusses the effect of material on dam stability. Two types of these materials are Rock fill and Mix Shell soil. When parameters of two types of materials, such as cohesion, internal friction angle and bulk density, are included in the sensitivity analysis. The results for both Rock fill and Mix Shell soil show that the internal friction angle parameter is the most influencing parameter on the dam slope stability.

4. Conclusions

The most influential parameter for the embankment slope stability in sections A-B and sections B-C is the internal friction angle, both statistically using the coefficient of variation approach and mechanically using the mechanical sensitivity test. Another indication that the internal friction angle is the most sensitive parameter is the grain size approach, when the limestone mixture in the field has coarse and large grain sizes (calcirudite). As a result, the shear surface tends to form rough waves (roughness) and causes relatively coarse-grained rocks to have a large internal friction angle.

In order to develop further research on sensitivity analysis, it is necessary to study additional parameters more comprehensively, as well as to validate the results of this study. Additional parameters such as physical properties (unit weight), modulus of elasticity and slope geometry can be included in further sensitivity analysis studies.

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Аналіз чутливості укосів насипу нікелевого відкатного шляху із використанням методу варіації коефіцієнтів

С. Саптоно, Д.М. Резкі

Мета. Аналіз чутливості укосів насипу нікелевого відкатного шляху використовується для визначення фізико-механічних властивостей, які мають найбільший вплив на рівень стійкості укосів.

Методика. Аналіз чутливості укосів насипу використовує підхід коефіцієнта варіації (CV) із вхідними параметрами, а саме когезією та кутом внутрішнього тертя. Для визначення найвпливовішого випадкового параметра використовується ймовірність із методом точкової оцінки. У цьому методі розподіл щільності ймовірності (PDD) випадкової змінної моделюється за допомогою масової "точки" розташуванням плюс або мінус одне стандартне відхилення (σ) від середнього (μ).

Результати. Результати дослідження підтверджують, що найбільш впливовим параметром на стійкість укосу насипу є кут внутрішнього тертя. Доведено, що за найвищого відсотка CV існує найвища ймовірність завалів, виходячи з цих параметрів. Зроблено висновок, що для прикладів насипів зі змішаним вапняковим матеріалом параметр кута внутрішнього тертя має більший вплив, ніж когезія та представлено стан насипу STA 20 + 250 та його матеріалів.

Наукова новизна. Встановлено коефіцієнти варіації для визначення того, які параметри мають неоднорідний розподіл даних і найбільшу ймовірність обвалу, а також для перевірки механічної чутливості з концепцією зміни відсотка параметрів до значення коефіцієнта безпеки для перевірки розрахунків за допомогою підходу коефіцієнта варіації.

Практична значимість. Результати аналізу чутливості показують, що найбільш впливовим для умов розглянутого родовища є кут внутрішнього тертя фракцій насипу. Причиною того, що кут внутрішнього тертя є найбільш чутливим параметром, є підхід до розміру зерен, коли суміш вапняку на родовищі має грубі та великі розміри зерен. Таким чином, поверхня має тенденцію утворювати шорсткі хвилі, що призводить до того, що відносно крупнозернисті породи мають великі кути внутрішнього тертя.

Ключові слова: *аналіз чутливості, коефіцієнт варіації, ймовірність обвалу, стійкість укосу, кут внутрішнього тертя, когезія*