SENJOp
http://senjop.ppj.unp.ac.id/index.php/senjop

Science and Environmental Journals for Postgraduate
Vol. 5 No. 2 (pp. 172-184) June 2023
p_ISSN 2655-5085
e_ISSN 2655-5239

Analysis of Slope Stability in Embankment Areas 'Shaiful Dump' at PT Agincourt Resources, North Sumatra

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Received: 06 Apr. 2023, Revised: 23 Apr. 2023, Accepted: 01 Jun. 2023

ABSTRACT

The safety factor from the stability of a slope is one of the important things that must be considered, especially in open pit mine planning such as the system implemented by PT Agincourt Resource. Research on the 'Syaiful Dump' dumping area aims to find the FK value on the embankment slopes, as well as evaluate the initial design plan that has been determined by the company at an Overall Slope angle of 12°. The research was carried out by making a redesign based on an evaluation of the initial slope design with an overall slope of 12°. Slope redesign made with overall slope values of 15°, 20°, 25° and 30°. Variation of slope angle aims to get a value Safety Factor (FK) which is close to or above a predetermined standard, namely FK> 1.3. The assumptions used in the modeling, namely the groundwater level is 3 MBGL, the seismic factor is 0.25 g, and the arc avalanche trajectory is assumed to cross colluvium material (low strength material). . Using the Morgenstern – Price calculation method, the FK value for a slope angle of 12° is 1.7; 15° by 1.6; 20° by 1.4; 25° by 1.2; and for a slope angle of 30° the FK value is 1.0. From the calculation results, it can be recommended for an overall slope angle of 20° with a value of FK = 1.4. This value is by the standards set.

KeyWords: Dumping, Slope, Safety Factor, Morgenstern-Price.

INTRODUCTION

Mining slope stability can be caused by various factors including errors in designing the mining front geometry such as height and slope, rock type, and soil material which results in a driving force greater than the retaining force, and physical and mechanical properties of the rock. As well as the influence of water that can be caused by groundwater and rainwater (Sadarviana et al., 2016; Putra et al., 2018). Therefore, FK which is a calculation indicator in determining the safety of a mining slope becomes very important, by analyzing the factors that affect the value of FK in the embankment area (Syaiful dump) on the Martabe site, so that the optimal FK figure is obtained with the standard that has been applied by the company FK = 1.3, which is then used as the basis for determining the slope geometry design in this research area (Cahyono, 2022; Riyanto, 2023; Zhao et al., 2023).

The purpose of this study is to try to analyze the stability of the slopes so that uncertainty about the value of FK can be overcome by designing safe slopes. Broadly speaking, the research aims to evaluate the initial design design on an overall slope plan of 12°, then make a slope geometry design and conduct an FK analysis so that it can be seen whether the slope meets the specified standard requirements. Thus, the results of this study are expected to be used as a material consideration in making decisions regarding the geometric design plan of Syaiful's slope dump at PT Agincourt Resources Batang Toru (South Tapanuli).

METHODS

2.1 Slope Stability Theory

A slope is a plane on the ground surface that connects a higher ground level with a lower ground level. In an open pit mine, the greatest danger faced is when an avalanche occurs on deep slope surface mining (Putra et al., 2018). Landslide can be avoided if it is influenced by several factors such as the Ultimate pit limit, namely the maximum slope of an open pit mine that does not cause landslides (Triyatno et al., 2020). In soil/rock in nature, it is generally in a state of equilibrium (equilibrium). This means that the condition in which the stress distribution in the rock and soil is in a steady state. If an activity occurs in excavation, transportation, and compaction (Compaction) the soil or rock or other activities so that the balance of the soil is disturbed, then the soil or rock in theory has tried to reach a new equilibrium state by reducing the load which often occurs, especially in the form of landslides (Shaorui et al., 2014).

Hermon et al (2018) add, there are three kinds of slopes that we need to pay attention to in mining slopes, namely: 1) Natural slopes, namely slopes that are formed due to natural processes, for example, the slopes of a hill; 2) Slopes made with native soil, for example when land is cut to make roads or canals for irrigation purposes; and 3) Slopes made of compacted soil, as embankments for roads or earthen dams. Every type of slope has the possibility of an avalanche. Therefore, an analysis of a slope's avalanche potential is required. The principles and methods used to determine slope stability apply to the three types of slopes above. It is usually clear that the landslide moves on a certain area, usually called a slip area (slip surface). If a landslide occurs, this means that the shear strength of the soil has been exceeded, that is, the shear resistance of the sliding plane is insufficient to withstand the forces acting on the plane. So it can be concluded that the shear strength of the soil is important in calculating slope stability.

2.2 Basic Definition of Slope Stability

If there is an object located on an inclined plane with an angle α, then the object will slide because of a force equal to W.sin α. The object remains in place if there is a reaction force of magnitude W.sin α in the opposite direction. When an object is in a stable state. This means that there is a contact area between the object and the slope that holds the magnitude of W.sin α. For more details, it can be seen in the discussion regarding avalanches due to gravity loads and images of the forces acting on an inclined plane as shown in Fig 1 below.

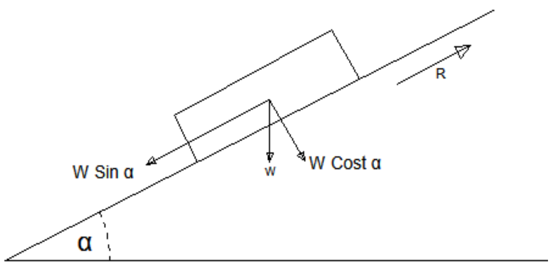

Figure 1. The force acting on an inclined plane

Based on the above understanding, it is extended to the soil/rock slopes. Then the slope will be stable if the object/material on the slope will resist the downward pulling force. The mutually resisting forces against these resisting forces are shear shear' or shear strength (Fedorova & Gubanova, 2018). Where this shear strength is the sum of the cohesion and the sliding force itself (c, tg, φ). The conclusion from the above explanation is, that to be able to guarantee its stability, the restraining force must be greater than the driving force.

2.3 Factors Affecting Slope Stability

Factors that can cause failure on natural or artificial slopes are usually caused by changes in topography, seismic, groundwater flow, loss of strength, and changes in stress and weather (Leroueil, 2001). As a result of external forces acting on the slope-forming material, the slope-forming material tends to slide. This sliding tendency is resisted by the shear strength of the material itself. Even though a slope has been stable for a long time, it can become unstable due to several factors such as 1) The type and condition of the soil layer/rock forming the slope; 2) The geometric shape of the slope section (eg height and slope); 3) The rise of the water surface on the ground (for example, there is water seepage or rain infiltration); 4) Weight and load distribution; and 5) Vibration or earthquake.

Factors affecting the stability of a slope can produce shear stresses throughout the soil mass, and movement will occur unless the shear resistance at any failure surface is greater than the acting shear stress (Bowles, 1991).

2.4 FK

FK Generally FK "Safety Factor" is defined as (Wibowo, 2022):

$$F = \frac{\text{Shear Strength Available}}{\text{Shear Strength for Stability}}$$

Or also the definition used for FK in the form of a comparison between the landslide resisting force and the landslide causing force.

$$\text{Safety Factor(FK)} = \frac{\text{Retaining Style}}{\text{Driving Style}}$$

The FK (F) of the soil slope can be calculated by various methods. Slip surface failure, F, can be calculated using the slice method according to Fellenius or Bishop. For a slope with the same cross section, the Fellenius method can be compared with the Bishop method. In anticipating landslide slopes, it is best if the F value taken is the smallest F value, thus maximum anticipation will be made. The data needed in a simple calculation to find the value of F (FK slope) is as follows:

a. Slope data (especially needed to make slope sections) include: slope angle, slope height, or slope length from the foot of the slope to the top of the slope.
b. Soil mechanics data 1) internal shear angle (φ; degrees); 2) unit weight of wet soil (γwet ; g/cm^3 or kN/m 3 or ton/m^3); 3) cohesion (c; kg/cm^2 or kN/m^2 or ton/m^2); and 4) soil water content (ω; %).

Soil mechanics data should be taken from undisturbed soil samples. Soil water content (ω) is needed especially in calculations using a computer (especially if you need data on γdry or unit weight of dry soil, namely: γdry = γ wet /(1 + ω). On slopes affected by the groundwater table the F values (with the Fellenius incision method) are as follows:

$$F = \frac{cL + \tan\phi \, \Sigma\,(Wi \cos \alpha i \; - \; \mu i \; x \; li\,)}{\Sigma\,(With\; \alpha\; i\,)}$$

The stability values of a slope can be shown as follows:

F > 1.3 : Soil mass on a stable slope

F < 1.3 : Soil mass on an unstable slope

F= 1.3 : The mass of soil on a slope on the verge of sliding.

With a note for the stability of the slope in the long term, the slope is said to be stable if the FK value is > 1.3.

2.5 Classification and Forms of Avalanches

Based on the landslide process, landslides are divided into four types, namely:

Bow Avalanche (Circular Failure)

It is an avalanche that has a semicircular, hyperbolic or irregularly curved avalanche field. Generally classified as follows: slope failure (slope circle), Foot slide, and Basic avalanche. These slides generally occur in very weak materials such as landfills or on slopes with a joint system that is very dense and does not have a regular structural pattern (Fig 2).

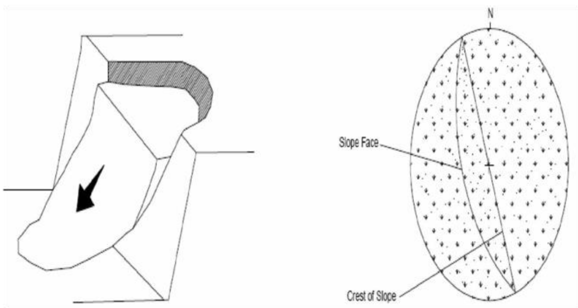

Figure 2. Arc slide

Field Avalanche (Plane Failure)

Landslide where the mass of the landslide moves along a flat surface is generally determined by the presence of bedding areas or weak areas such as joints, faults. This slide generally occurs in rocks that have rocks that have a sliding plane that is free to lead to the slope. The mechanism of a plane slide can be likened to the sliding of a block of objects against an inclined plane and the forces acting on the conditions of the equilibrium boundary. The rock block is in an unstable condition if the total resisting force is less than the sliding force (Fig 3).

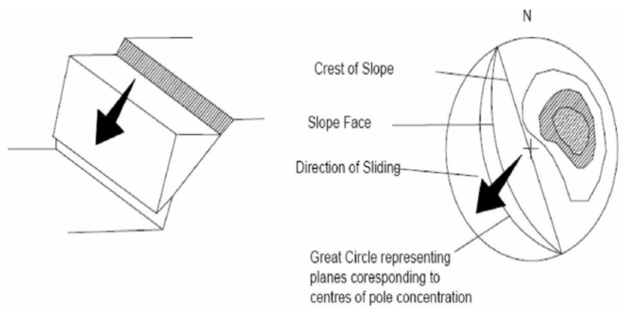

Figure 3. Landslide fields

Landslides usually occur when the following conditions are most important: 1) The slope of the sliding plane occurs less than the slope of the surface of the slope (Ψp > Ψp); 2) The slope of the sliding plane is greater than the inward shear angle or Ψp > φ; 3) There is a free field which is the lateral boundary of the rock mass that slides; and 4) The strike of the landslide plane is parallel or nearly parallel to the surface of the slope with a maximum difference of 20°.

Avalanche (Toppling Failure)

These slides occur on slopes with weakly inclined rocks opposite the slope and usually on hard rocks where the weak structure is columnar (Fig 4). Based on the shape and process of the slide, this slide is divided into: 1) Flexural Toppling namely the type of rolling avalanche after experiencing bending; 2) Block Toppling is a type of rolling avalanches in the form of avalanches of rock blocks; and 3) Block flexural toppling is a type of overturned avalanche which is a combination of the two types of avalanche above.

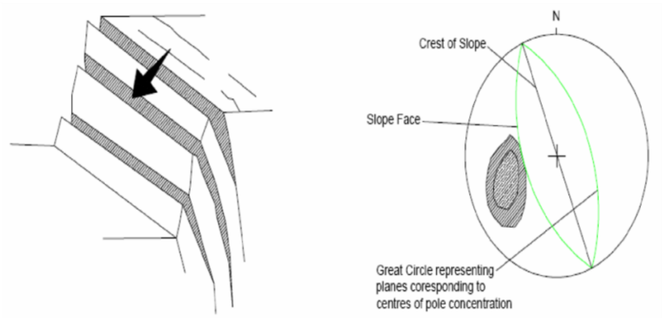

Figure 4. Avalanche toppling

Wedge avalanches (Wedge Failure)

This slide occurs when two or more weak planes intersect with the angle of intersection of the two planes (Ψf) greater than the inside shear angle (φ) and smaller than the slope angle (Ψ1) (Fig 5).

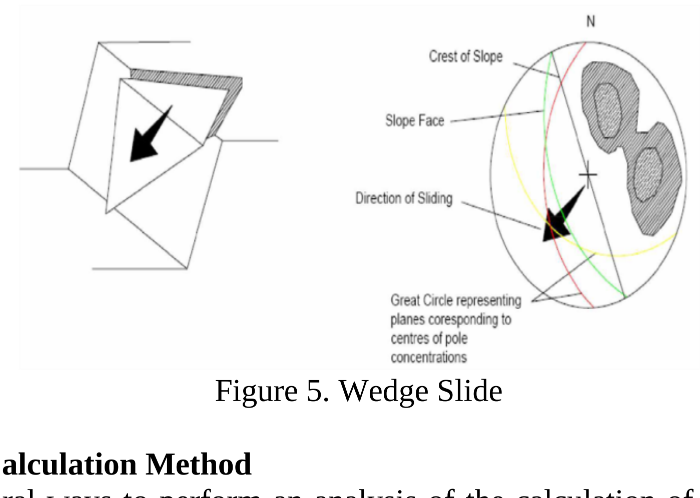

Figure 5. Wedge Slide

Slope Stability Calculation Method

There are several ways to perform an analysis of the calculation of the stability of the slope. One way to calculate the stability of a slopeLimit Equilibrium Method' (limit equilibrium method), which is a method that calculates the amount of shear strength required to maintain slope stability by comparing it with the existing shear strength. The following is an example of the limit equilibrium method.

Method Bishop

A simplified sectional method is given by Bishop (1955). This method assumes that the forces acting on the sides of the slice have a zero resultant in the vertical direction. In principle, the BISHOP method is as follows:

$$F = \frac{\sum_{i=1}^{i=m} \left[c'bi + (wi - ui.bi)tg\emptyset'\right] \frac{1}{cos\alpha i(1 + tg\alpha i.tg\emptyset'/F)}}{\sum_{i=1}^{i=m} wi.sin\alpha i} \geq 2$$

Information:

F = safety factor
c' = Effective soil cohesion
Phi' = angle of shear in the soil
with a = Width of the ith slice
Wi = Soil weight of i-th slice
αi = Angle defined in Fig 6
ui = Pore water pressure at the i-th section

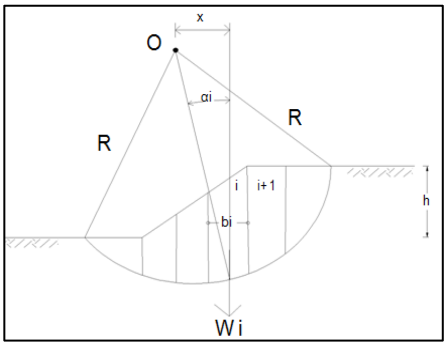

Figure 6. Bishop's method

The Bishop method is preferred because the critical landslide trajectory generated from the calculation results is close to the results of observations in the field, besides that this method is more detailed and more thorough.

Limit Equilibrium Method (LEM)

LEM is a method that uses the principle of force balance. This analysis method first assumes a failure area that can occur. There are two assumptions for the slip plane, namely: the slip plane is shaped circular (Fig 7) and the assumed shape of the slip plane non-circular or it could be planar (Fig 8). The limit equilibrium method used in the analytical calculations for slope stability divides the mass of the slip plane into small slices. The shear forces acting on the wedge are assumed to represent all the equal parts of the rock/soil shear strength on which these shear forces act.

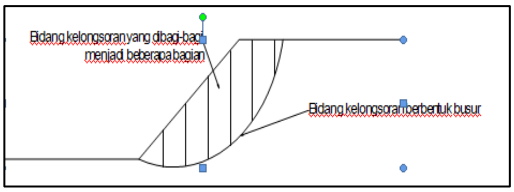

Figure 7. Landslide fields circular

While in the field of landslidesnon–circular shown in (Figure 8) below.

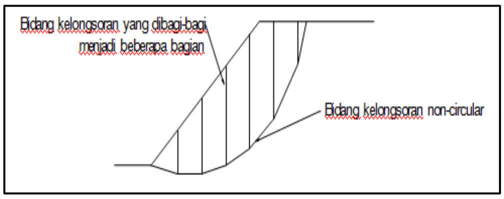

Figure 8. Landslide fields non–circular

For the force acting on the plane of the slice is described in Figure 9 below.

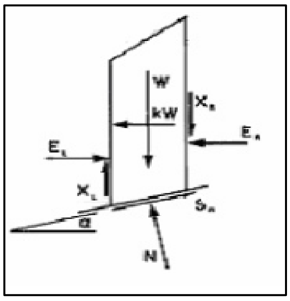

Figure 9. The force acting on the plane of the slice

The calculation is done by dividing the soil in the landslide plane into slices as shown above, because of that this method is also known as the slice method. Figure 9 depicts the soil mass and the forces acting on the wedge. A variety of different solutions to the slice method have been developed over the years, starting withFellenius, Taylor, Bishop, Morgenstern-Price to others. The difference between one method and another depends on the boundary equilibrium equation and the assumed inter-slice strength (interslice force) is taken into account.

Method Morgenstern – Price

Morgensten Price developed earlier than the general limit equilibrium method. This method can be used for all forms of failure planes and satisfies all equilibrium conditions. Method Morgenstern–Price using the same assumptions as the general limit equilibrium method, namely that there is a relationship between the shear force between the slices and the normal force between the slices which can be expressed by the following equation:

$$X = \lambda \,.\, f(x) \,.\, E$$

The form of several functions f(x) that can be used can be seen in the following figure:

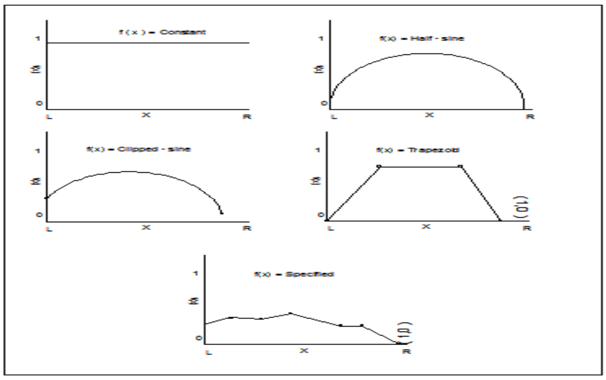
Figure 10. The shape of the function that describes the distribution of forces between slices

There are differences in the method of calculating FK between methods Morgenstern–Price and the general limit equilibrium method. In the general limit equilibrium method, the calculation of FK is carried out by using the balance of forces in the horizontal direction and the balance of moments at the center of slip for all slices. Meanwhile method Morgenstern–Price, the FK calculation uses the force and moment equilibrium conditions of each slice. The principle of the FK calculation in the method Morgenstern–Price is to find pairs of FK values and scale factors, so that the boundary conditions on the last slice can be met. Other requirements that must be met are that there is no normal force on the slice that has a negative value and all the work points of the force between the slices must be in the slip time.

RESULTS

Based on the results of the analysis of slope stability in the Syaiful area Dump PT Agincourt Resources, several things affect stability, which will be discussed in this chapter, including: 1) Slope stability analysis; 2) Factors causing slope instability; and 3) Efforts to stabilize embankment slopes (Saiful Dump).

3.1 Slope Stability Analysis

Based on the results of the analysis carried out with the help of the SLIDE V.6.0 program with an overall slope design plan at a slope of 12°, 15°, 20°, 25°, and 30°. Then the FK obtained from each plan and the following for an explanation of the results of the overall slope plan:

- Overall Slope 12°: From the calculation results using the help of the SLIDE V.6.0 program, FK = 1.7 which means that in the results of this calculation, the condition of the slopes on the embankment soil (Saiful dump) is still in a safe condition (FK > 1.3), because it is this condition that makes it possible to maximize the slope at 12° to get the optimal slope with a safe FK number and the slope conditions are still in a stable condition.
- Overall Slope 15°: After calculating using the help of the SLIDE V.6.0 program, we get an FK number of 1.6. For FK numbers from the results of this calculation, it is assumed that they tend to be less close to or still far from the parameter reference for the overall slope angle (FK > 1.3), therefore consideration or re-designing the slope design plan by increasing the slope angle is carried out to find The optimal angle size with FK value > 1.3 is considered to be a stable slope.
- Overall Slope 20°: After the results of calculations using the SLIDE V.6.0 program, the FK at the overall slope angle is obtained at FK = 1.4, which means that the slope is still in a stable condition and is still above the limit of the FK (FK) value that has been determined by the company, namely FK > 1.3. Therefore, the slope conditions with an overall slope angle of 20° can be assumed to be safe and recommended as an optimal slope design plan whose FK value is close to FK > 1.3 which is still within the limits of stable slope conditions and in addition to this research this is still being done, to find the most optimal slope limit.
- Overall Slope 25°: After the calculation results using the SLIDE V.6.0 program, the FK obtained is FK = 1.2, which means that the slope is at an unstable number based on the FK value that has been determined by the company, namely FK = 1.3. If slopes are made at an overall slope angle of 25°, the tendency for landslides to occur is very high.
- Overall Slope 30°: After calculating with the help of the SLIDE V.6.0 program, the FK

obtained is FK = 1, which means that the slope is at an unstable numerical scale assuming that the FK value limit has been determined by the company, namely FK > 1.3. This condition can be said to be critical, therefore, based on this research, the slope angle of 30° is taken in the last condition to plan the slope angle at the Syaiful slope location. Dump to find the optimal slope limit.

At the research location, the geometry of the slopes at the end of the mining stage is irregular, this is due to process activities dumping the backfill material carried out by heavy equipment working on the embankment area (Syaiful Dump) which causes uneven pressure on the embankment area. In the slope geometry, that is, the overall slope with an overall slope height of 50 meters and a slope angle of 12° has a higher value of FK (FK) compared to the planned slope angle with values of 15°, 20°, 25°, and 30 °. After doing the calculations, it is obtained that the FK limit meets the standards set by the FK company = 1.3. In the results of this study for an angle of 20° with an FK value = 1.4, based on this study it can be concluded that, from the plan to determine the magnitude of the overall slope of the embankment area (Syaiful Dump), the slope can still be increased to a slope of 20° from the initial design plan, namely at a slope of 12° with consideration of the standard reference, to obtain an optimal and efficient level and in terms of safety it is still above the standard set by the company, namely FK = 1.3.

3.2 FK Conditions on a Single Slope

The single slope (single slope) of each slope design plan is 12°, 15°, 20°, 25°, and 30°, although previously in this study the overall FK value was calculated, it is often found that there are several landslide problems on a single slope (single slope). For this reason, it is necessary to calculate the FK value on a single slope carried out in this study, to be able to find out the FK value on each single slope contained in the overall slope design plan.

Calculations were carried out using the SLIDE V.6.0 program as a tool to find out the FK number on each single slope using the same method and mechanical properties from the previous calculation. In this calculation, it is assumed that a single slope avalanche arc traverses across the material so that in design modeling there is only one type of material. The following is an explanation for the results of calculating the FK value of a single slope at an overall slope angle of 20° which has been recommended as a reference before deciding on the planned slope angle. Single slope FK calculation results for overall slope plan recommendations on a slope of 20°. Calculation results on a single slope for a 20° overall slope cross-sectional design which has become a recommendation after researching several slope plans including 12°, 15°, 20°, 25°, and 30°, which in this modeling is on a single slope calculation (single slope) with a slope height of 10 m, widthbench 3 m and a slope of 22°. Based on the results of these calculations, the condition of a single slope is in a stable state, due to the FK value obtained from the single slope calculation results on the entire slope cross-section, a value of FK > 1.3 is obtained.

Table 1. FK results on each slope of the slope design plan

No	Information	Slope geometry		Safety Factor
		H (meter)	α (°)	
1	overall slope	50	12	1.7
2	overall slope	50	15	1.6
3	overall slope	50	20	1.4
4	overall slope	50	25	1.2
5	overall slope	50	30	1.0

3.3 Causes of Slope Instability Slope Geometry

In the analysis of slope stability, slope geometry that affects slope stability includes slope height (H) and slope angle (a). Where, if a slope has a fixed height, an increase in the slope angle will reduce the FK value, similarly if a slope with a fixed slope angle, an increase in slope height will reduce the FK value of the slope in question.

Differences in Fill Weight, Cohesion Value, and Inner Shear Angle

Syaiful slope building material Dump in the research area consists of waste material, colluvium, and bedrock, each of which has a different cohesion value and internal shear angle. The strength of the slope material to resist avalanches is highly dependent on the bonding force between the grains (cohesion) and the internal shear angle, which affects the size of the shear strength, so it will affect the size of the slope FK value. According to the Mohr-Coulomb shear strength equation, this relationship can be expressed in the following equation:

$$\tau = c + \tan \tan \Phi \quad (4)$$

Thus, the greater the value of cohesion and shear angle in a material, the greater the shear strength of the material to resist avalanches. Conversely, the smaller the value of cohesion and shear angle in a material, the smaller the shear strength of the material to resist avalanches. The results of the analysis of slope stability in the study area show that the colluvium material has very poor shear strength compared to the material waste and bedrock.

Efforts To Stabilize Slopes

In general, measures to support slope stability are carried out to reduce the mobilized force on the body of the slope and increase the retaining force on the embankment slope. Reducing the mobilized force can be done by excavating part or all of the potentially unstable material and/or unstable material, as well as reducing the pore water pressure or groundwater level on the slope body. Increasing the retaining force of the slope is carried out by draining the groundwater table to increase the shear strength of the material, reduce the slope load, and construct a retaining structure. To achieve a FK value below the required FK value FK = 1.3, the actions to support slope stability that can be taken are:

Surface Water Handling

Surface water that flows and seeps into the body of the slope causes erosion on the surface, accelerates the weathering process, and increases the groundwater level.

Surface water handling on slopes can be done by: 1) Sealing the cracks on the slope body with waterproof material (see Fig 10); and 2) Make canals at every level (cross fall) on the body of the slope both on the top of the slope (cress) and toe of the slope (then), see Fig 10 below.

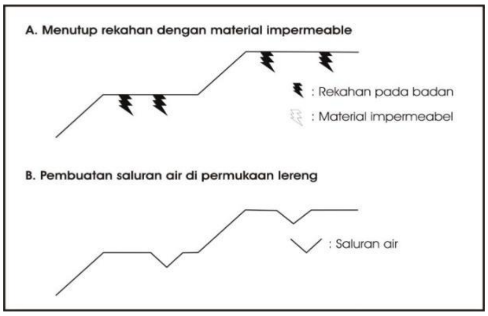

Figure 10. Surface water handling

Lowering of Ground Water Level: The lowering of the groundwater level is carried out in order to reduce or eliminate the force of water values and increase the shear strength of the slope material. Lowering the groundwater level can be done by, vertically, making pumping wells at the top or level of the slope (see Fig 11).

Monitoring

Periodic slope monitoring needs to be carried out to determine if any ground movements may occur, both those that are visible on the surface and those that are not visible on the surface. Thus, if there are symptoms of instability, preventive action can be taken immediately. Slope monitoring with optical surveys is carried out by periodically measuring the positions of several points with periodic measurements of the positions of several points on the slope to a fixed place so that the movement of soil or rock masses will be visible when the position of the slope point changes at a fixed place. Slope monitoring with optical surveys can only detect the movement of rock or soil masses that are quite large. The presence of tensile strain on the body of the slope is an indication of slope instability where the tensile strain formed indicates a release of stress (Distressed) on the body of the slope. Monitoring of the movement of soil or rock masses in tensile strain is carried out using an extensometer which is installed between the tensile strains (Fig 12).

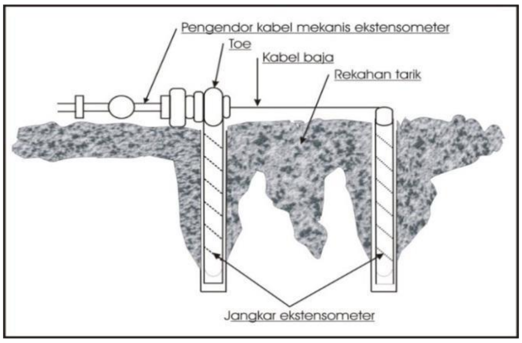

Figure 12. Extensometer

To find out if there is movement of soil or rock masses on the body of the slope that may not be visible on the surface, monitoring can be done by: an inclinometer which is a flexible pipe attached to the body of the slope containing a sensing unit or torpedo which will move following the movement of the slope and provide an indication of the movement of the body of the slope which is recorded on a reader on the surface (Fig 13).

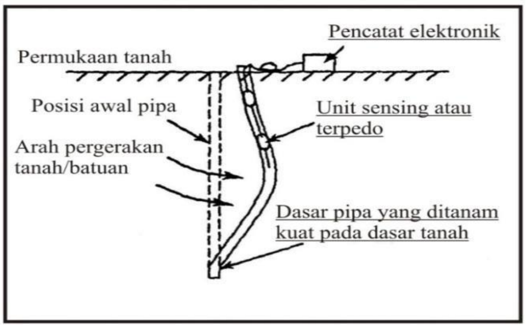

Figure 13. Inclinometer

CONCLUSIONS

The conclusions of this research are 1) FK Calculation results for a slope angle of 12 ° and a total height of 10m, from the modeling assumptions at a groundwater level of 3 MBGL, Seismicity Factor of 0.25 g, With the arc trajectory of the avalanche it is assumed to cross the material colluvium and calculations using the Method Morgenstern – Price with the limit equilibrium theory Limit Equilibrium) so that the results of the Safety Factor are obtained for a large Slope Angle of 12°, FK = 1.7; 2) In the results of the FK calculation for the overall slope angle of 15°, FK = 1.6; 3) The FK calculation results still use the same modeling assumptions and calculation methods, using an overall slope angle of 20°, the FK obtained by FK = 1.4; and 4) The FK calculation results still use the same modeling assumptions and calculation methods, using an overall slope angle of 25°, the FK obtained by FK = 1.2. The FK calculation results still use the same modeling assumptions and calculation methods, using an overall slope angle of 30°, the FK obtained by FK = 1.

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