UDC 64

THE EFFECT OF RAINFALL ON THE STABILITY OF THE HEAD SLOPE OF DOMESTIC WASTE: A CASE STUDY OF THE FINAL DISPOSAL OF TLEKUNG BATU CITY, INDONESIA

Putra Arfilian Permana, Student
Rachmansyah Arief, **Harimurti**, Lecturers
Master's Study Program, Department of Civil Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia
*E-mail: humas@ub.ac.id

ABSTRACT
Landfills are very susceptible to landslides because the shear angle is very small, it can become very extreme again if the rainy season arrives. For this reason, this study aims to analyze the effect of rainfall on the slope stability of TPA Tlekung. Researchers analyzed using the Limit Equilibrium Method (LEM) and also with the Finite Element Method (FEM) where the results of the analysis were in the form of slope failure along with the value of the Safety Factor (FK). Furthermore, the stability analysis will be modeled into two conditions, namely conditions during the summer so that the groundwater level is normal and the rainy season conditions with very high rainfall, so that the groundwater level is assumed to be in the middle of a domestic waste heap. Under normal conditions, the slope safety number in the LEM calculation is 0.799 and when the rainfall conditions are high it is 0.752. For analysis using FEM the average safety score for normal conditions is 1.117 and for high rainfall conditions it is 1.021. The decrease in slope safety value when the slope receives high rainfall is 5% in the LEM calculation and 10% in the FEM calculation.

KEY WORDS
LEM, FEM, slope stability of landfills, slope safety factor.

The administration is particularly concerned about the volume of rubbish that enters and is accommodated by TPA Tlekung, Junrejo District, Batu City. Because the Tlekung TPA is situated on a natural slope with a small river running underneath it, it is believed that the avalanche of rubbish that happens may obstruct the river's flow.

As a result, the purpose of this research is to examine the landslides that happened at TPA Tlekung. The study entails examining the slopes' stability under normal conditions, that is, without the preceding pile of waste, and then examining the slopes' stability under the situation that the slopes have been burdened by piles of garbage. The Limit was used by the researchers to conduct their research. Researchers used the Limit Equilibrium Method (LEM) and the Finite Element Method (FEM) to assess the data, which included slope failure and the Safety Factor value (FK). Furthermore, the stability study will be divided into two scenarios: one in which the groundwater level is normal throughout the summer, and another in which the rainy season comes with extremely heavy rainfall, and the groundwater level is considered to be in the midst of a mound of domestic garbage.

LITERATURE REVIEW

Slices Method or Limit Equilibrium Method (LEM). The limit equilibrium method or boundary equilibrium method is one of the most commonly used methods to analyze slope wall stability problems. Various methods have also been developed by many researchers to calculate the value of the factor of safety over the years. The formula for calculating The General Limit Equilibrium (GLE) or limit equilibrium method developed in 1970 by Fredlund. This formula includes two equations of factor of safety based on the GLE formula and has some assumptions about the normal forces in the bedrock plane. The GLE calculation provides a Safety Factor value based on the calculation of the moment equilibrium (Fm) and the horizontal force balance (Ff).

Morgenstern and Price (1965) proposed an equation that can handle the shear forces between layers in the GLE and it satisfies the balance between moments and forces. In calculating the slope safety factor in soil slope analysis through the incision method, only landslides that have a slip plane can be calculated. Avalanches with a slip surface, F can be calculated using the slice method according to Fellinius or Bishop. For a slope with the same cross-section, the Fellinius method can be compared with the value of the safety factor with the Bishop method. LEM is a method that uses the principle of balance of forces. This analysis method first assumes the area of the slide that can occur. There are two assumptions for the slide plane, namely: the slide plane is circular in shape and the slide plane is assumed to be non-circular (can also be planar).

Finite Element Method (FEM). The finite element method or Finite Element Method (FEM) is a calculation procedure used to get an approach to mathematical problems that often arise in engineering with various approaches and a series of algebraic equations involving values at discrete points in the part being evaluated. The finite element method equation is created and the solution is sought as well as possible to avoid errors in the final result. The net (mesh) consists of elements connected by nodes. Nodes are points on the net where the value of the primary variable is calculated. For example, for displacement analysis, the primary variable value is the displacement value. Nodal displacement values are interpolated on the elements in order to obtain algebraic equations for displacement, and strain, through the nets formed. The main parts of the Plaxis calculation are:

- Displacement function (shape function). The displacement function or shape function (N) is a function that interpolates the displacement at the node to the displacement in the element using Pascal's triangle. In selecting the displacement function, the basic thing to know is that the displacement function at the point under consideration is always one and zero (0) at other points. Below is Figure 1. displacement function:

Terms in Pascal Triangle	*Polynomial Degree*	*Number of Terms*	*Triangle*
1	0 (constant)	1	
x y	1 (linear)	3	CST
x^2 xy y^2	2 (quadratic)	6	LST
x^3 x^2y xy^2 y^3	3 (cubic)	10	QST

Figure 1 – Displacement Function

- Elements for Two-Dimensional Analysis. Two-dimensional analysis is generally an analysis that uses triangular or quadrilateral elements. The general form of these elements is based on the Iso-Parametric approach in which a polynomial interpolation function is used to represent the displacement of the elements. The general form of two-dimensional elements can be seen in Figure 1 below:

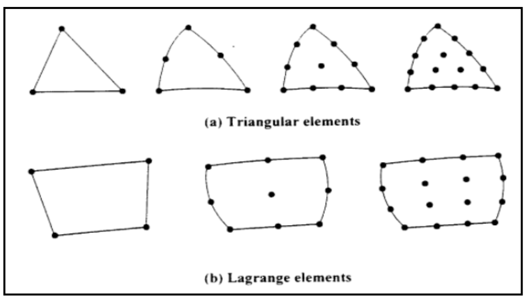

Figure 2 – The General Shape of a Two-Dimensional Element

METHODS OF RESEARCH

Based on the background of the problem and the formulation of the problem that has been described previously, a research framework concept is made as shown in Figure 2 as follows:

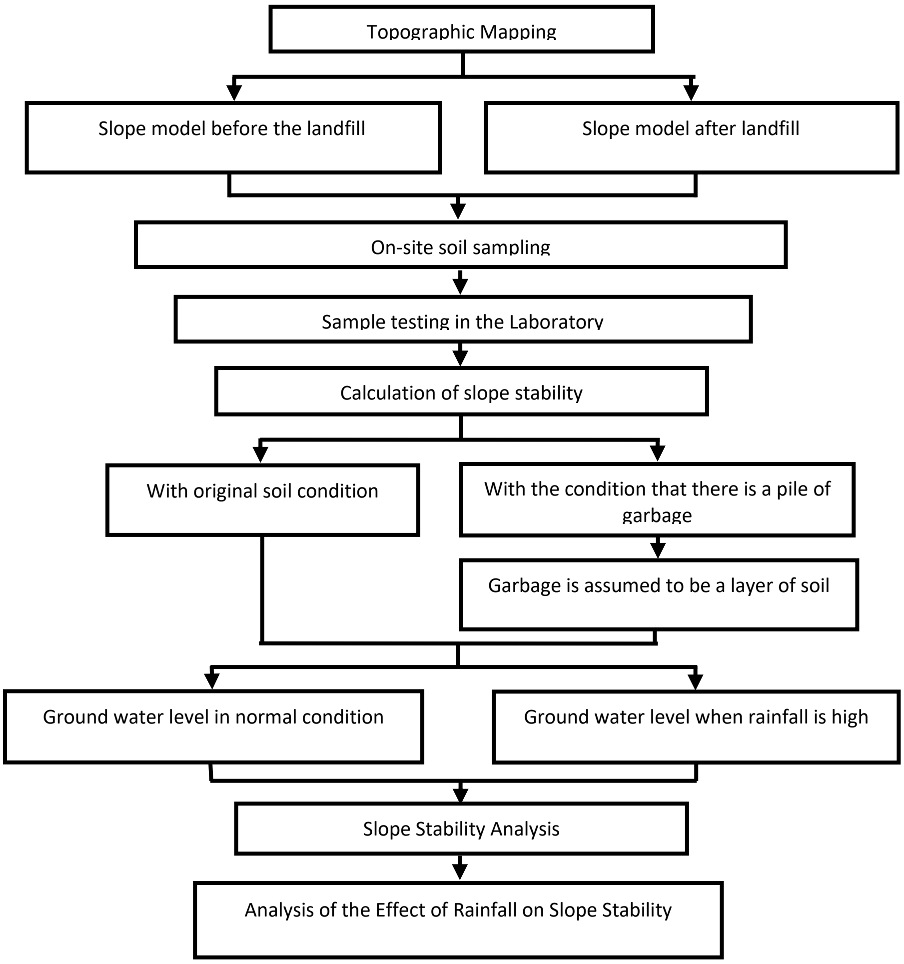

Figure 3 – Flowchart of the Research Concept

RESULTS AND DISCUSSION

In presenting the problem in the formulation of the problem, the following are the results of calculations and analysis from slope stability to planning for reinforcement.

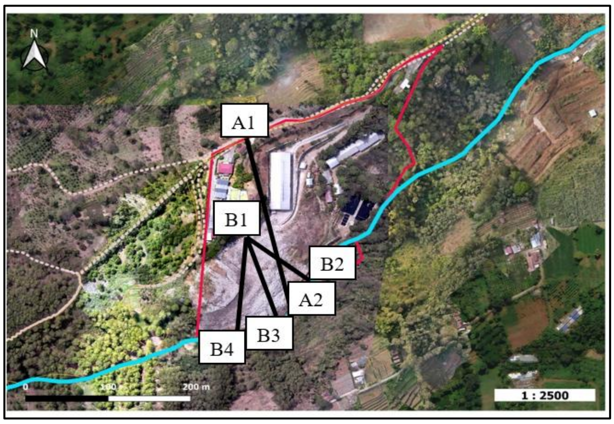

Figure 4 – Topography of TPA Tlekung

Topography of the Slopes of the Tlekung TPA Landfill. For slope stability analysis, three models of slope sections will be made to represent the condition of the slopes in the presence of piles of waste symbolized by sections B1-B2, B1-B3, and B1-B4. Then one piece of the slope that does not have a pile of garbage or the condition of the original slope is symbolized by pieces A1-A2. For more details, see Figure 3.

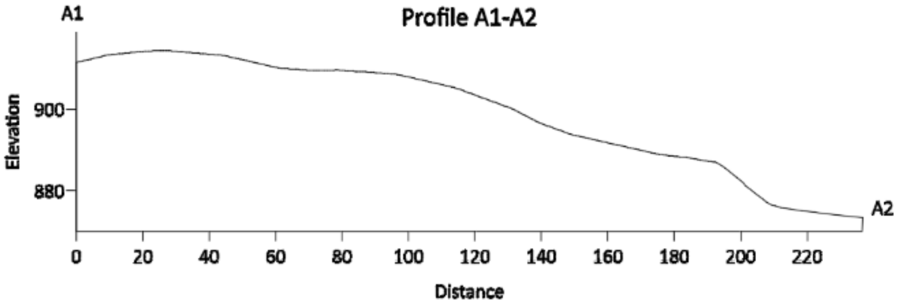

Figure 5 – Slope of the Original Condition of Pieces A1-A2

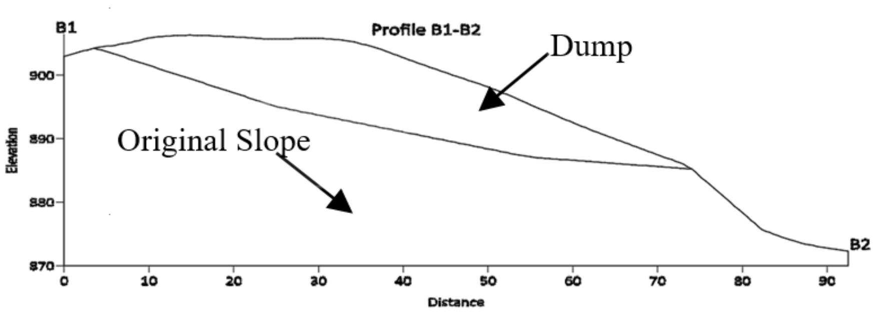

Figure 6 – The Slope of the Dump Pieces B1-B2

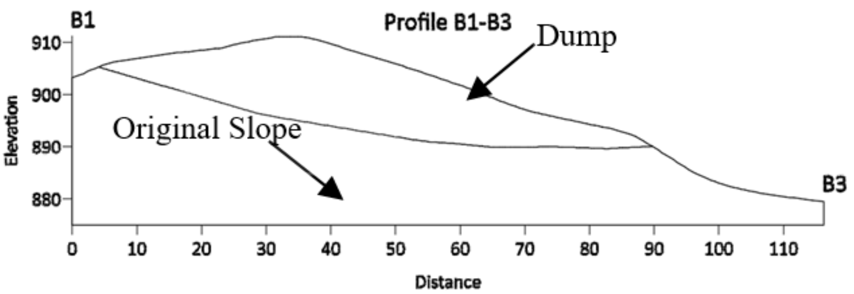

Figure 7 – The Slope of the Dump Pieces B1-B3

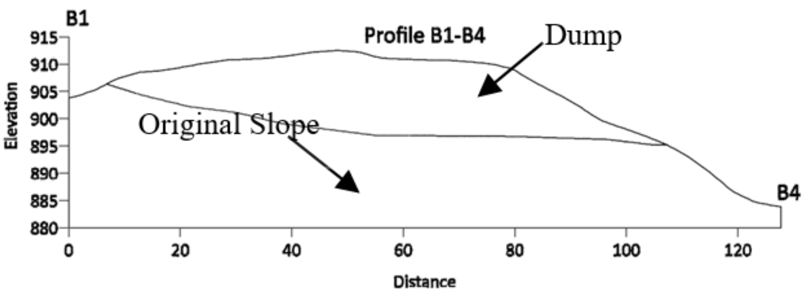

Figure 8 – The Slope of the Dump Pieces B1-B4

Based on the results of the topography above, the detailed slope model is obtained when the slope is in original condition and when the slope has a landfill, which later the detailed modeling results above will become a model for analysis of slope stability of domestic waste piles.

Soil and waste parameters are the first steps that must be sought in this study, which will later be used as input at the beginning of planning in the Slope/W 2012 application. Parameters that must be sought include: cohesion, shear angle, and specific gravity. For this reason, in determining these parameters, it is necessary to test soil and waste samples in the laboratory, here are the results of the analysis of sample testing:

Soil sample testing was taken into 3 samples, representing one sample at the top of the slope, one sample at the bottom of the slope, and another sample on soil that has been contaminated with leachate or water from garbage on the slope. The test uses direct shear test to determine the cohesion and shear angle of the soil. The following are the test results from soil samples:

Table 1 – Parameters of the soil layer on the slopes of TPA Tlekung

Soil Sample	Specific gravity (γd)	Cohesion (c)	Sliding angle (φ)
	gr/cm^3	kg/cm^2	°
Top of the Cliff	2,619	0,374	22
Contaminated Garbage	2,118	0,504	20
Under the Cliff	2,654	0,354	23

For testing existing waste samples by reviewing the composition and content of waste in cities in Indonesia, this study takes the parameters of the physical properties of waste in previous journals, written by: Saman, Determination of Cohesion Value and Shear Angle of City Garbage Case Study: Laboratory Scale Landfill, published by: National Seminar on Technology and Engineering (SENTRA) 2018, Civil Engineering, University of Muhammadiyah Malang. The results of this study are in the form of parameters from the waste as follows:

Table 2 – Parameters of the Soil

Sliding angle (φ)	15 - 20	°
Cohesion (c)	1,2	kg/cm^2
Wet specific gravity (γ_{wet})	3,16	gr/cm^3

Source: Journal of the National Seminar on Technology and Engineering (SENTRA), vol. II page 82.

Slope Stability With Limit Equilibrium Method (LEM). This is the original condition of the slopes in the Tlekung area of Batu city, where the slopes are in a condition where there is no garbage pile. Calculations using the help of the Slope/W 2012 application program by entering the geometry, soil parameters and waste parameters that have been obtained previously.

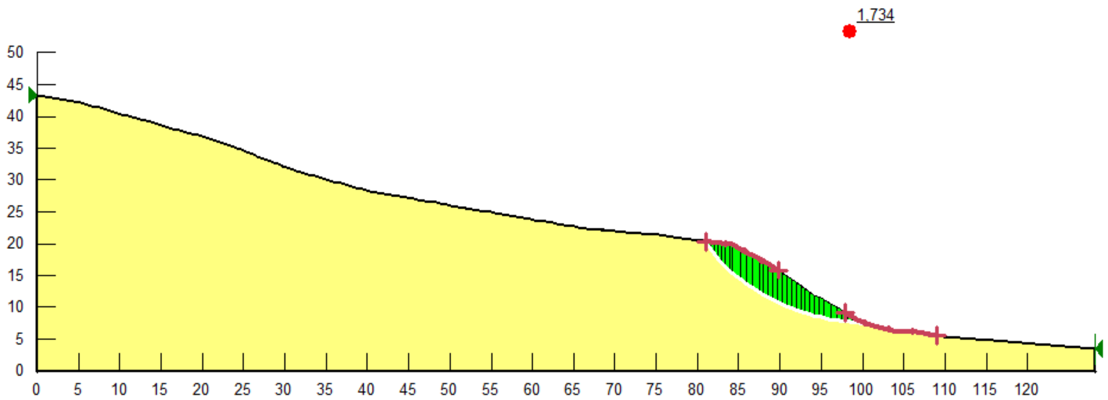

Figure 9 – Original Slope Stability

The results of the Slope/W analysis above can be obtained the value of the safety factor of the slope before the landfill is equal to 1.734 where the value of the safety factor is in the safe category so that the slope in its original condition is still stable.

In this modeling, there is already a pile of garbage that is divided into 3 layers of soil where the green color represents the waste layer, the yellow color represents the soil layer contaminated with waste water or leachate, and the purple color represents the original soil layer. This analysis is divided into 2 possibilities, namely slope stability when under normal conditions and slope stability when high rainfall occurs.

The height of the slope at the site is 25 meters with the previous modeling, it was found that the pile of garbage that occurred on the original slope, then due to the absence of geotextile reinforcement in the model of the waste slope heap, there was infiltration of waste water or leachate on the soil, so it is assumed that the influence of leachate infiltration into the soil to a depth of 2 meters. The following is the result of the analysis of slope stability after entering the model and parameters above:

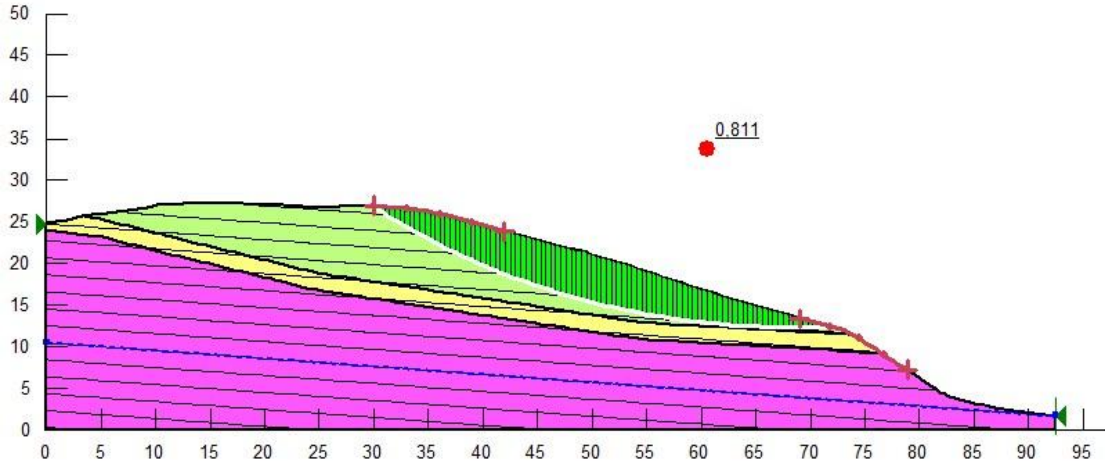

Figure 10 – Cut slope stability B1-B2 (normal condition)

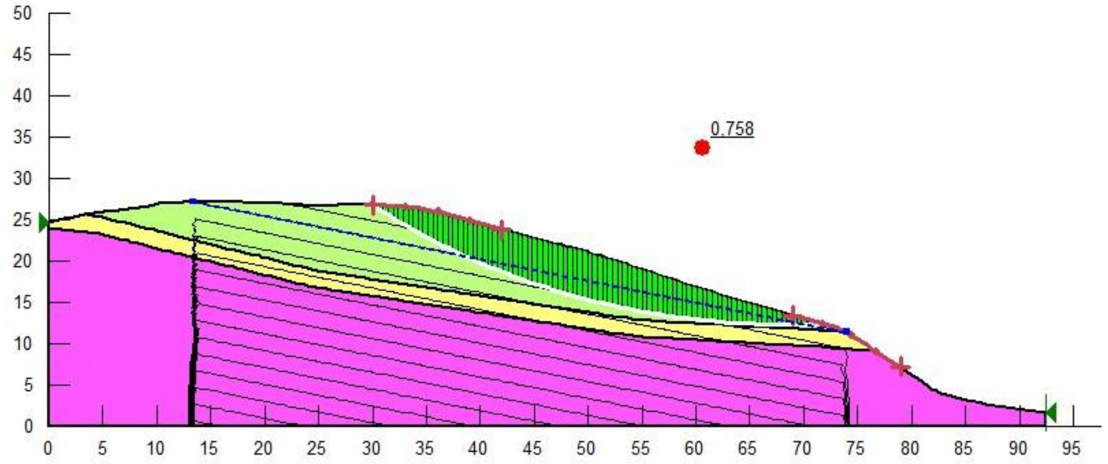

Figure 11 – Cut slope stability B1-B2 (high rainfall conditions)

For the analysis of slope stability at sections B1-B2 in Figure 9 and Figure 10 shows the results of the Slope/W analysis produce a slope safety number at sections B1-B2 of 0.818 when conditions are normal and 0.774 when conditions are high rainfall, and the results of these safety figures very critical and fall into the category of unstable slopes. The results of the calculation of the slope stability analysis in the next section will be displayed through the recap in Table 3 below:

Table 3 – The results of the value of the safety value of slope stability with LEM

Slope Cut	Safety Score		Description
	Normal	High Rainfall	
B1-B2	0,811	0,758	Critical
B1-B3	0,914	0,836	Critical
B1-B4	0,671	0,662	Critical

According to the Bowles table (1991), the FK value is based on the intensity of the landslide in the results of the above analysis, the slope stability is in the critical category which has a safety factor of less than 1.25, so the slope requires reinforcement so that the slope becomes stable.

The calculation using the Finite Element Method or known as the Finite Element Method (FEM) is to strengthen and also as a comparison of the slope stability calculations carried out previously. For this reason, the following are the results of calculations using the Finite Element Method using Plaxis 2D.

Table 4 – Material Parameters

Soil	Specific gravity (γd)	Cohesion (c)	Sliding angle (φ)	Poisson Ratio (v)	Modulus of Elasticity (E)
	kN/m^3	kN/m^2	°		MPa
Waste	21,60	20,24	23	0,2	2000
Leachate	31,18	34,40	18	0,4	3000
Original	26,19	22,14	21	0,3	5500

The results of the finite element method analysis with Plaxis 2D. After entering the material parameter data and the slope model in Plaxis 2D, the following are the results of the calculation of the slope stability of TPA Tlekung:

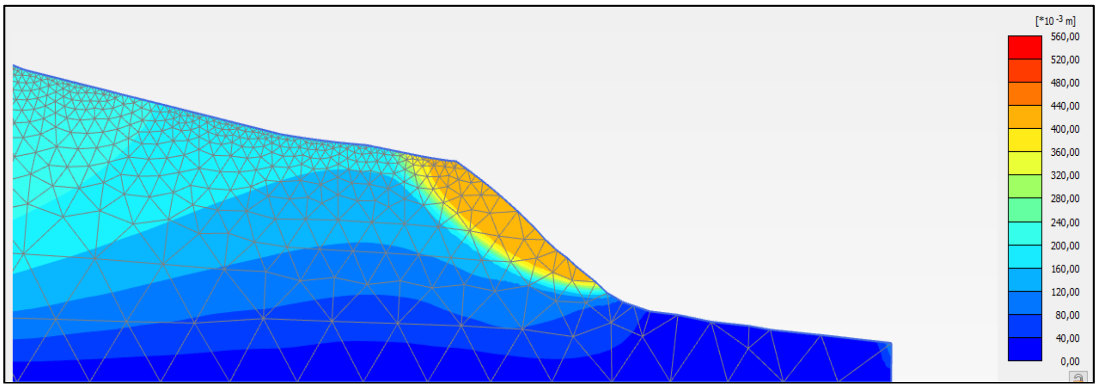

Figure 12 – Forms of Original Slope Failure

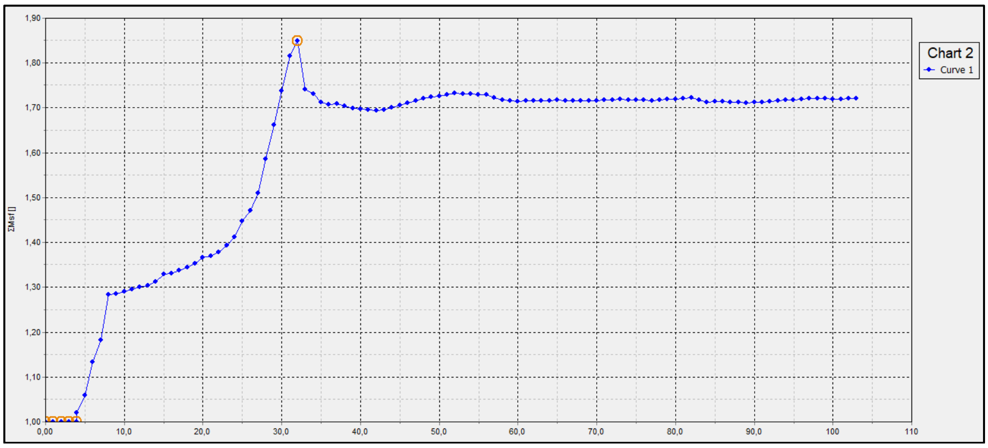

Figure 13 – Original Slope Safety Number Curve

The results of the calculation analysis with FEM on Plaxis produce a safety value of 1.721 where this number is still included in the safe category so that the slope is still stable in its initial condition or before the waste piles up.

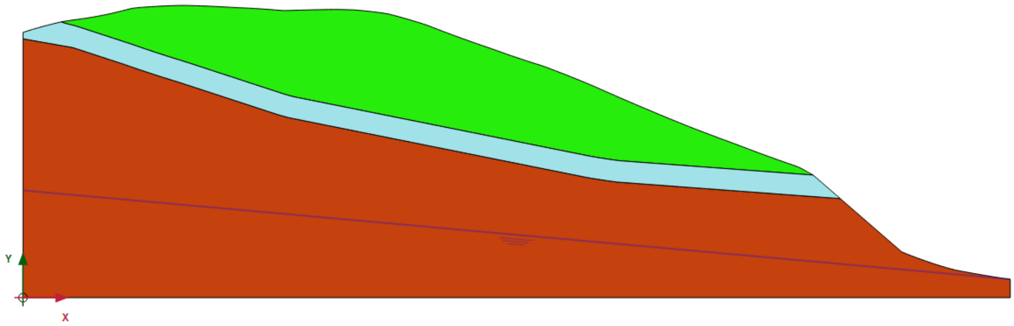

Figure 14 – Slope model under normal conditions of sections B1-B2 (Normal Condition)

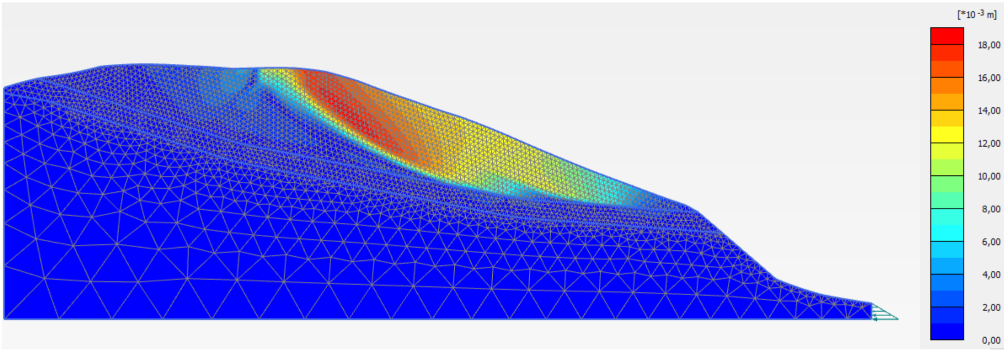

Figure 15 – Slope failure shape under normal conditions of sections B1-B2 (Normal Condition)

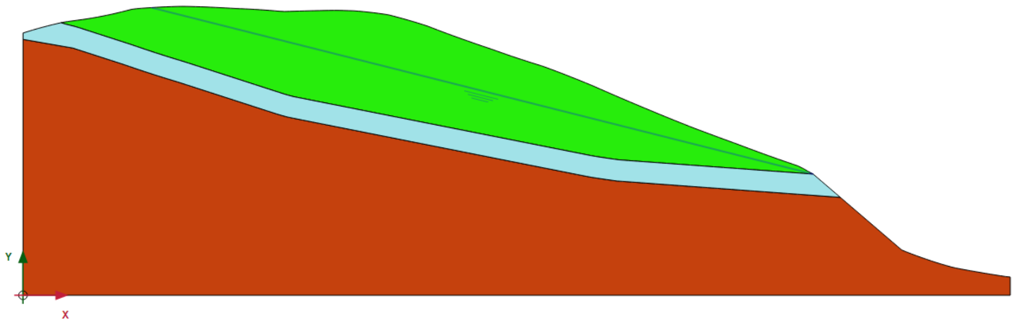

Figure 16 – Slope model in sections B1-B2 (High rainfall conditions)

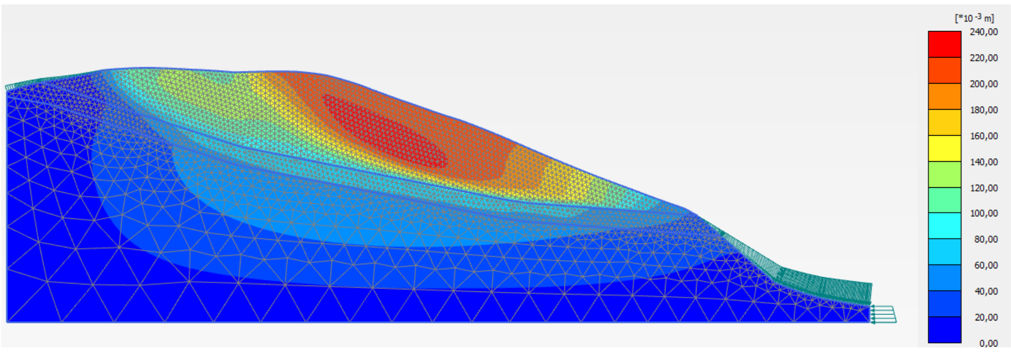

Figure 17 – The shape of the slope failure in sections B1-B2 (High rainfall conditions)

In Figures 14 and 16 the green layer indicates the layer of garbage and the blue one is the soil layer that has been contaminated with waste water, while the original soil is represented in brown. The blue line is the groundwater level. In Figure 15 and 17 are the forms of slope failure, so that the results of the slope safety number when conditions are normal and when rainfall conditions are high are:

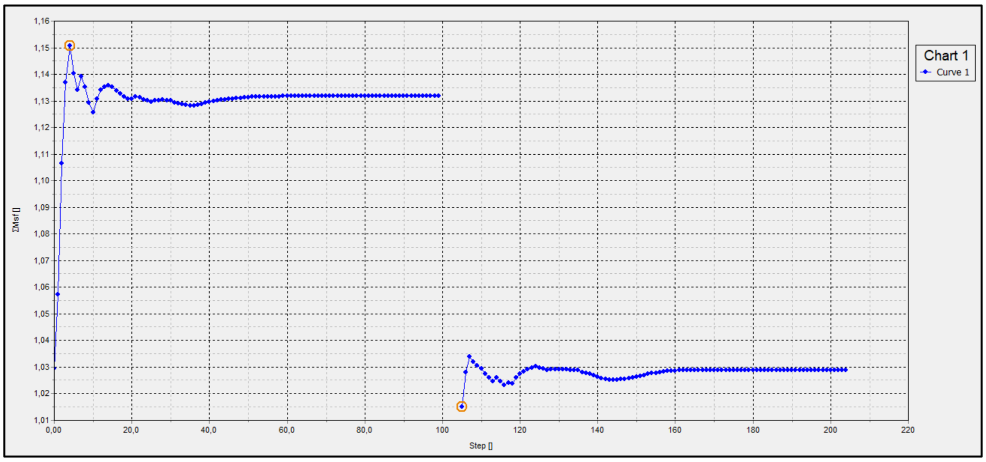

Figure 18 – Garbage Heap Slope Safety Curve

In the curve of Figure 18 it is known that the slope safety number when conditions are normal, the slope has a safety number of 1.132 and when the rainfall is high the slope safety number drops to 1.029. With the results of the value of the safety number, the slope is included in the critical category.

Table 5 – Results of slope stability safety scores with FEM

Slope Cut	Safety Score		Description
	Normal	High Rainfall	
B1-B2	1,132	1,029	Critical
B1-B3	1,126	1,038	Critical
B1-B4	1,093	0,995	Critical

Based on the results of FEM using Plaxis 2D, slopes with a pile of garbage has a critical safety rating. Under normal conditions, the slope has a safety rating of less than 1.25.

Table 6 – Percentage of Decrease in Slope Stability with LEM

Slope Cut	Safety Score		Percentage Decrease in SF
	Normal	High Rainfall	
B1-B2	0,811	0,758	5,3
B1-B3	0,914	0,836	7,8
B1-B4	0,671	0,662	0,9

Table 7 – Percentage of Decrease in Slope Stability with FEM

Slope Cut	Safety Score		Percentage Decrease in SF
	Normal	High Rainfall	
B1-B2	1,132	1,029	10,3
B1-B3	1,126	1,038	8,8
B1-B4	1,093	0,995	9,8

Based the results of the analysis carried out previously with the Limit Equilibrium Method (LEM) and with the Finite Element Method (FEM) the slope shows a relatively small safety value so that the slope is categorized as a critical slope according to Bowles (1991) which is less than 1.25, if you look at from the table presented. The modeling carried out in the previous calculations is divided into two, namely under normal conditions and in conditions of high rainfall. This was done to find the percentage of the effect of rainfall on decreasing slope stability.

The results from the tables above can be concluded that the average decrease in the value of the slope safety value in the LEM calculation is 5% and in the FEM calculation it is 10%.

CONCLUSION

Based on the results of the calculation of the slope stability of the Tlekung landfill waste in the previous discussion, it can be concluded that:

1. Slopes with the original condition or before the landfill was stable, as evidenced by the safety factor or FS generated in the analysis with LEM of 1.734 and analysis with FEM of 1.721;
2. When there is a pile of waste on the slope, the value of slope stability decreases. Under normal conditions, the slope safety number in the LEM calculation is 0.799 and when the rainfall conditions are high it is 0.752. For analysis using FEM the average safety score for normal conditions is 1.117 and for high rainfall conditions it is 1.021;
3. Rainfall conditions can affect the value of the slope safety factor so that the slope becomes very critical; it is evidenced by a decrease in the slope safety value when the slope receives high rainfall, with a decrease of 5% in the LEM calculation and 10% in the FEM calculation.

Suggestions that can be given based on the results of this study are:

1. For the next planning, it is necessary to plan for landslide prevention, namely with the right retaining wall by looking at the existing location conditions;
2. High rainfall can affect the safety factor of slope stability, so for the next planning it is necessary to process rainfall data in the area to be an accurate planning material;
3. Reinforcement of the slopes with a geogrid layer prior to the accumulation of garbage greatly affects the stability of the slopes, because water from the waste that enters the soil can affect the stability of the slopes.

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