Slope stability analysis in Ulubelu Lampung using computational analysis program

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Abstract. Ulubelu sub-district is the center of geothermal activity in Lampung Province. The Ulubelu geothermal project supply 25% of electricity to Lampung Province. In the future the Government plans to build a geothermal pipeline network with the aim of maximizing the potential found in Ulubelu. One of the objects that must be examined in the construction of the pipeline is the stability of the slope that will be passed by geothermal pipes. Therefore, this study aims to analyze the stability of landslides in the Ulubelu geothermal pipeline. Soil samples for this study were taken from 5 locations: BH-01, BH-02, BH-03, BH-04, and BH-05. This soil sample is then examined to determine its soil mechanics characteristics in the laboratory. The safety factor of each sample is analyzed using 3 slope analysis methods: the Fellenius method, the Bishop method, and the Janbu method, and calculated in Geostudio (Slope/W). The results showed that all samples showed safety factor values that were not much different that were spread between the numbers 1.7 to 4.3. This shows that all sample locations are safe from landslides. This also shows that the characteristics of the soil and the slope of the study area are almost the same.

Keywords: Slope, safety factor, Fellenius, Bishop, Janbu, Geostudio(Slope/W)

1. Introduction

Tanggamus is one of the areas in Lampung that has a large geothermal potential. The Lampung Provincial Government claims the province has a geothermal potential of 2,867 MW or 10% of Indonesia's total geothermal potential. With this potential, the province is ranked third after West Java and North Sumatra as the province with the largest geothermal potential in the country. Overall, the government said Indonesia's geothermal energy potential was 29,000 MW. The International Geothermal Association (IGA) states that Indonesia has the third largest installed capacity after the US and the Philippines, with a capacity of 1,340 MW as of 2015. Meanwhile, the US and the Philippines have an installed capacity of 3,450 MW and 1,870 MW, respectively. Ulubelu sub-district is the center of geothermal activity in Tanggamus. It is located in the hills with a distance of about 3-4 hours by road from Bandar Lampung, the capital of Lampung Province. To reach the location, we must pass ravines, cliffs and forests. There is the Ulubelu Geothermal Power Plant (PLTP) owned by PT

Pertamina Geothermal Energy (PGE) which has four electricity generating units. PGE is a subsidiary of PT Pertamina (Persero) which focuses on geothermal development.

Geothermal development in the Ulubelu region has actually been carried out since 1991. However, the monetary crisis that occurred 20 years ago made the project halted. PGE only started to develop again in 2008. Ulubelu PLTP is not the only power plant that uses renewable energy. The development and opening of new wells continue at Ulu Belu to meet the supply of fuel to power plants. The contribution of 25% of electricity supply to Lampung Province is the main advantage of the utilization of Ulubelu geothermal energy [1].

Figure 1. Map of Tanggamus District and the location of Ulu Belu

In the future the Government plans to build a geothermal pipeline network with the aim of maximizing the potential found in Ulubelu. To build a geothermal pipe that can last a long time, it is necessary to calculate the soil safety factor so that the foundation of the geothermal pipe is resistant to the load that will be placed on it. Therefore, this study intends to analyze the safety factor of the slope stability at places that will be crossed by geothermal pipelines.

2. Material and Methods

2.1. Soil Sampling

Soil samples were taken from five different points in Ulubelu. Furthermore, the locations of the sampling points are named BH-01, BH-02, BH-03, BH-04, and BH-05. BH is an extension of Bore Hole. The soil samples were then analyzed to find out the profile of the soil mechanics at the Soil Mechanics Laboratory, Faculty of Engineering, University of Lampung. Soil mechanical parameters tested in the Laboratory include:

- Water content (%)
- Density (gr/cm^3)
- Specific Gravity (Gs)
- Passed Sieve No. 200 (%)
- Atterberg limit tests
  - Liquid Limits (LL) (%)
  - Plastic Limits (PL) (%)

> ➢ Plasticity Index (PI) (%)
- Consolidation tests
  - ➢ CV (cm^2/s)
  - ➢ Cc
- Triaxial tests
  - ➢ Cohesion (c) (kg / cm^2)
  - ➢ Internal Shifting Angle (φ) (°)
  - ➢ Free Compressive Strength Test (kg/cm^2)

2.2. The Analysis of Slope Stability

An open ground surface that stands at a certain angle to the horizontal direction is called a slope without reinforcement. Slopes can occur scientifically or man-made. If the ground is not horizontal, a component of gravity will tend to move the ground down. If the gravity component is large enough, a slope failure will occur, that is, when the mass of the landslides down. The launching force affects the resistance of shear strength along the surface of the collapse. Civil engineers are often asked to make calculations to check the safety of natural slopes, excavated slopes, and embankment slopes. This check includes determining the shear strength that builds along the surface of the collapse and differentiating it from the shear strength of the soil. This process is called slope stability analysis. In determining the stability or instability of a slope, the term safety factor (F) is introduced. The value is a comparison between the forces that resist the movement and the forces that move the ground. Interpretations of the value of safety factor are [2]:

- F > 1.0: the slope is stable
- F = 1.0: the slope is balanced, and ready for landslides
- F < 1.0: slope is not stable

In this research, the analysis of slope stability is conducted based on the philosophy of Fellenius method, Bowles method, and Janbu method. All the works of stability analysis is undertaken using built-in computer programming called *Geostudio slope/w 2012*.

2.3. Fellenius Method [3]

This method is also called ordinary method of slice. The assumptions used in this method are:
- Field of landslides in a circle
- The landslide field is divided into several upright slices
- The width of each slice does not have to be the same
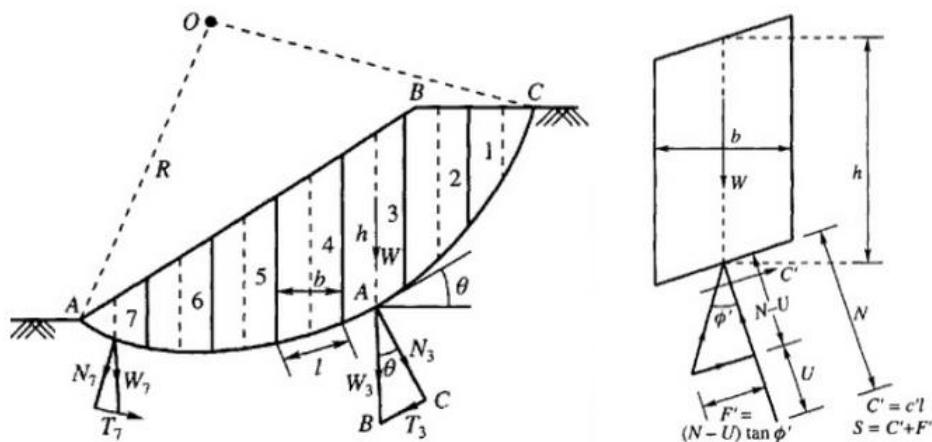- More suitable for soil that has values of c and φ

Figure 2. Forces acting on landslides for Fellenius slope analysis method

This simple method of slices assumes only the overall moment equation of equilibrium written with respect to the center of the slip surface. The shear and normal forces between blocks X_i and E_i are neglected. Then SF is calculated directly from the following expression:

$$FS = \frac{1}{\sum_i W_i \sin \alpha_i} \sum_i (c_i l_i + (N_i - u_i l_i) \tan \varphi_i) \qquad (1)$$

where:

u_i	=	pore pressure within block i
c_i, φ_i	=	effective values of soil parameters
Wi	=	block weight
N_i	=	normal force on the segment of the slip surface
α_i	=	inclination of the segment of the slip surface
l_i	=	length of the segment of the slip surface

2.4. Bishop Method [4]

The Bishop method is a very popular method in slope stability analysis due to its simple and fast calculation. This method also provides a fairly thorough calculation of the safety factor. The Bishop method calculates the force components (horizontal and vertical) by considering the moment balance of each piece. This method assumes zero Xi forces between blocks. The method is based on satisfying the moment equation of equilibrium and the vertical force equation of equilibrium. The FS is found calculate a consecutive iteration as follows:

$$FS = \frac{1}{\sum_i W_i \sin \alpha_i} \sum_i \frac{c_i b_i + (W_i - u_i b_i) \tan \varphi_i}{\cos \alpha_i + [\tan \varphi_i \sin \alpha_i]/FS} \qquad (2)$$

where:

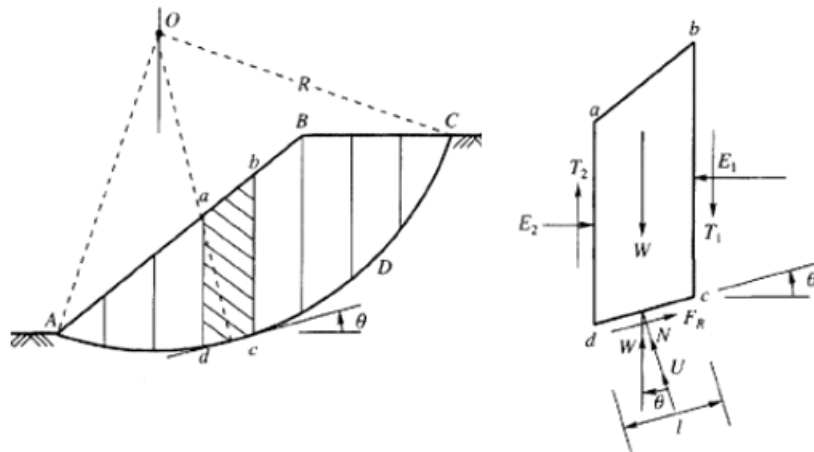|		
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Figure 3. Forces acting on landslides for Bishop slope analysis method

2.5. Janbu Method [5]

Janbu is a soil slice method developed based on boundary balance. It takes a balance of power and satisfying moments that work on a particular block plane. Sliced soil is made by dividing the soil on the slip surface as a plane. The forces acting on each slice can be seen in the following figure:
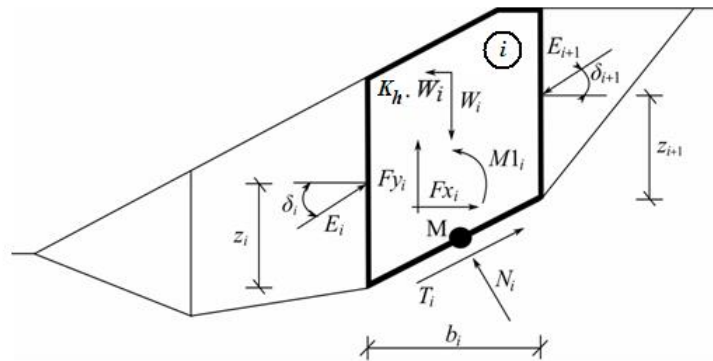

Figure 4. Forces acting on landslides for Janbu slope analysis method

Each slice block is assumed to contribute due to the following forces:

W_i = block weight, including material surcharge having the character of weight including the influence of the coefficient of vertical earthquake K_v

$K_h W_i$ = horizontal inertia force representing the effect of earthquake, K_h is the factor of horizontal acceleration during earthquake

N_i = normal force on the slip surface

T_i = shear force on the slip surface

E_i , E_{i+1} = forces exerted by neighboring blocks, they are inclined from horizontal plane by angle δi resp. δ_{i+1} and lie at the height z_i resp. z_{i+1} above slip surface

Fx_i, Fy_i = other horizontal and vertical forces acting on block

$M1_i$ = moment from forces Fx_i, Fy_i rotating about point M, which is the center of the ith segment of slip surface

U_i = pore pressure resultant on the i_{th} segment of slip surface

The Janbu method takes several assumptions to calculate the balance of force and moment limits on individual blocks:

- The divider between the blocks is always vertical
- The W_i block weight action line passes through the center of the slip surface segment which is represented by point M
- The normal force N_i works in the middle of the slip surface segment, at point M
- The position of z_i force E_i acting between blocks is assumed, at the end point of the slip surface is $z = 0$

The determination of safety factor value is determined by employing the following iteration process:

- The initial value of angles are set to zero $\delta_i = 0$ and positions z_i to approximately one third of interface height
- The safety factor for a given value of δ_i follows from equation (5), while assuming the value of $E_{n+1} = 0$ at the end of the slip surface

$$A = \frac{[(W_i - Fy_i)\cos\alpha_1 - (K_h W_i - F_x)\sin\alpha_i - U_i + E_i\sin(\alpha_i - \delta_i)]\frac{\tan\varphi_i}{FS}}{\sin(\alpha_i - \delta_{i+1})\frac{\tan\varphi_i}{FS} + \cos(\alpha_i - \delta_{i+1})} \tag{3}$$

$$B = \frac{\frac{c_i}{FS}\frac{b_i}{\cos \alpha_1} - (W_i - Fy_i)\sin \alpha_1 - (K_h W_i - F_x)\cos \alpha_i - U_i + E_i \cos(\alpha_i - \delta_i)]}{\sin(\alpha_i - \delta_{i+1})\frac{\tan \varphi_i}{FS} + \cos(\alpha_i - \delta_{i+1})} \tag{4}$$

$$E_{i+1} = A + B \tag{5}$$

- The value of δ_i is provided by equation (5) using the values of E_i determined in the previous step.
- The steps are then repeated until the value of FS does not change.

Unstable solutions have to be avoided for successful iteration process. Such instabilities occur at points where the equation is division by zero, for example:

$$FS = \tan \alpha_1 \tan(\delta_{i+1} - \alpha_i) \tag{6}$$

Another check to avoid numerical instability is the verification of parameter m_α:

$$m_\alpha = \cos \alpha_1 \frac{\sin \alpha_1 \tan \varphi_i}{FS} > 0{,}2 \tag{7}$$

2.6. GeoStudio

GeoStudio is integrated software products for geotechnical modeling & analysis. This software has been developed in Canada since 1977. GeoStudio has the ability to overcome planning problems related to strengthening soil structure such as deformation analysis and soil stability. In the analysis, the properties of structural components can be included in the stress deformation analysis so that the forces and moments in the structure can be calculated together with the interaction between the structure and the soil. Stability analysis can also be carried out with all or part of structural load components that are assumed to be applied to the shear mass. Structural components can be used or ignored to simulate actual field conditions.
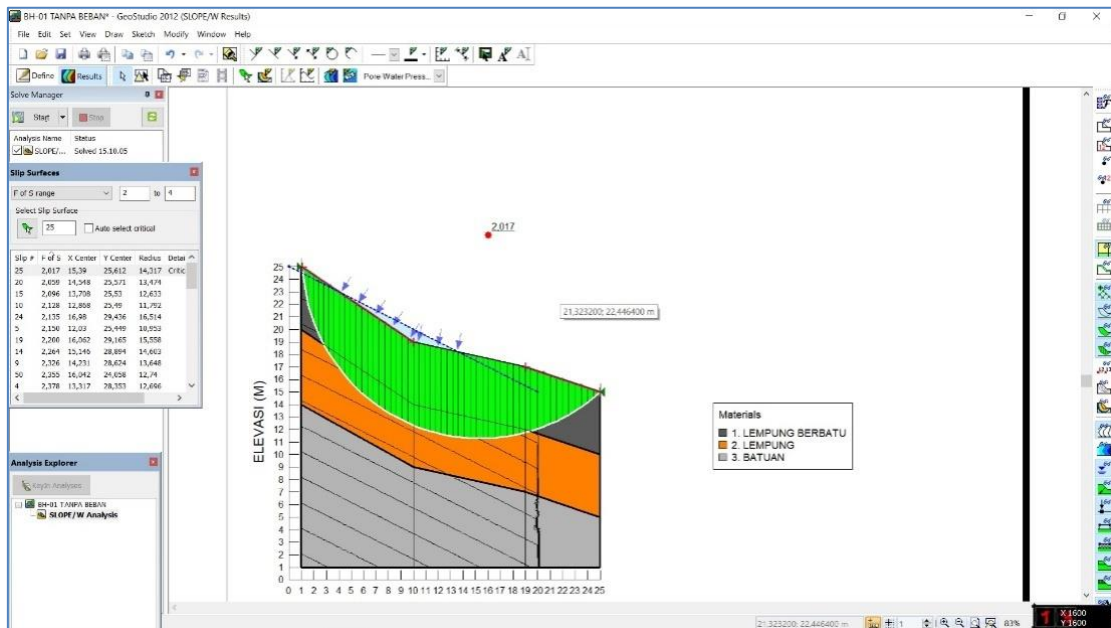

Figure 4. Graphical User Interface (GUI) of GeoStudio (Slope/W) software

Slope/W is a component that is part of GeoStudio. The conventional Limit Equilibrium method is the basis for calculating slope stability analysis in the GeoStudio (Slope/W) Program. The Limit Equilibrium method is formulated in the form of moments and calculates the value of the safety factor from the moment equation balance. In this analysis, the safety factor is defined as the ratio of the shear resistance available to the one that needed for balance condition. The analysis of slope stability in this research uses Fellenius, Bishop, and Janbu in the Geostudio (Slope/W) software.

3. Results and discussions

Soil samples taken from the field are then brought to the laboratory to investigate the characteristics of soil mechanics through several tests. The results of the test are presented in the following table:

Table 1. The characteristics of soil mechanics of the samples

Bore Hole	Depth	Water content (%)	Density (gr/cm^3)	Specific Gravity (Gs)	Passed Sieve No. 200 (%)	Liquid Limits (LL) (%)	Plastic Limits (PL) (%)
BH-01	-5 m	43,53	1,465	2,471	68,65	65,17	46,39
	-10 m	63,46	1,435	2,569	62,95	65,81	53,21
BH-02	-5 m	53,24	1,478	2,515	31,64	64,86	45,94
BH-03	-5 m	56,7	1,428	2,565	19,21	96,71	61,38
BH-04	-5 m	60,91	1,415	2,586	28,4	62,71	38,07
	-15 m	45,55	1,547	2,529	35,8	56,02	32,16
BH-05	-5 m	74,62	1,469	2,585	61,02	106,79	68,83
	-10 m	42,33	1,421	2,522	46,02	81,72	56,35
	-15 m	32,62	1,527	2,5	70,05	59,88	35,26

Table 2. The characteristics of soil mechanics of the samples (cont.)

Bore Hole	Depth	Plasticity Index (PI) (%)	CV (cm^2/s)	Cc	Cohesion (c) (kg/cm^2)	Internal Shifting Angle (φ) (o)	Free Comp. Strength Test (kg/cm^2)
BH-01	-5 m	18,78	0,07	0,204	0,13	11,8	0,4
	-10 m	12,6	0,057	0,234	0,103	13,4	0,38
BH-02	-5 m	18,93	0,148	0,238	0,185	15,9	0,07
BH-03	-5 m	35,33	0,072	0,239	0,099	15,4	0,39
BH-04	-5 m	24,64	0,068	0,258	0,033	14,4	0,13
	-15 m	23,86	0,108	0,2	0,092	13,5	0,25
BH-05	-5 m	37,96	0,083	0,301	0,05	20,7	0,36
	-10 m	25,37	0,094	0,234	0,121	20,5	0,47
	-15 m	24,62	0,089	0,213	0,184	19,4	0,53

Then, using Geostudio software, all samples from each location were analyzed with the final goal of finding the value of the slope safety factor of each location based on calculations from the Fellenius method, the Bishop method, and the Janbu method. The results are:

Table 3. Safety factor value for each bore hole based on calculations using the Fellenius method, the Bishop method, and the Janbu method

Bore hole	Load variation	Safety factor value		
		Fellenius method	*Bishop* method	*Janbu* method
BH-01	0 Ton	2.017	2.185	2.020
	5 Tons	2.064	2.190	1.965
	10 Tons	2.020	2.189	1.964
	15 Tons	2.021	2.190	1.965
	20 Tons	2.020	2.190	1.965
BH-02	0 Ton	3.987	4.357	4.168
	5 Tons	3.524	3.458	3.443
	10 Tons	2.599	3.335	1.857
	15 Tons	2.310	2.326	1.711
	20 Tons	2.245	2.015	2.056
BH-03	0 Ton	3.711	3.873	3.702
	5 Tons	3.711	3.581	3.412
	10 Tons	3.418	3.579	3.411
	15 Tons	3.418	3.579	3.411
	20 Tons	3.259	3.419	3.251
BH-04	0 Ton	2.028	2.093	2.386
	5 Tons	2.028	2.093	2.386
	10 Tons	2.000	2.035	2.007
	15 Tons	1.986	2.035	2.040
	20 Tons	1.947	1.862	1.749
BH-05	0 Ton	2.126	2.232	2.034
	5 Tons	2.256	2.318	2.096
	10 Tons	1.948	2.042	1.936
	15 Tons	1.804	2.006	1.811
	20 Tons	1.822	1.882	1.748

The table shows that the safety factors for slope stability at the study locations are always > 1, which means that all the land at the location that is reviewed is safe from landslides. Physically, it is known that the type of soil in the study area is soil that has layers that have moderate to good quality. In addition, the slopes reviewed are not too steep so the soil tends to be stable from landslides. The highest safety number value is achieved when the load = 0. Load variations are added to the soil model analyzed by adding a load with a multiple of 5 tons. The calculation results also show that there is a decrease in the value of the safety factor along with the increase in burden. However, the decrease is not significant when compared to the value before being given a burden. This shows that the physical properties of the soil are quite uniform from the surface to a certain depth. The difference in computation among the Fellenius method, the Bishop method, and the Janbu method does not produce too different safety factor values. This shows that all three models have the same accuracy in estimating landslide hazards. Such statements are supported by several previous studies. Research comparing the results of the calculation of the three methods with the results of the calculation of finite difference numerical method (FDM) shows a very close relationship between these results [6].

However, until now there has been no expert who states that one method is better than another method. One expert stated that each model has its own specificity in its use. For example, the Bishop method is only good when used to analyze circular slip surfaces. On the other hand, Janbu's method is best when used to analyze shallow and elongated slip surfaces and the Fellenius method is good when used to analyze any type of slip surface. Some others said that the However, most experts argue that the greatness of a method in analyzing slope slides depends on the type of slope and soil under investigation.

4. Conclussions

Slope stability analysis in Ulubelu Lampung for geothermal pipeline network development has been analyzed. Three method of slope stability analysis: Fellenius method, Bishop method, and Janbu method have been used to calculate safety factor of each sampling location. The calculation is undertaken using GeoStudio (Slope/W) Program. The characteristics of soil mechanics at the five studied locations indicate similarity. Therefore, the values of the safety factors that are produced are also not much different from each other. The results also showed that the value of the safety factor produced was 1.8 to 4.3 which showed that all the land in all locations studied had sufficient security against landslides. However, from the three methods used to calculate the safety factor in this study, it can be concluded that the accuracy of each model is not much different. According to experts the superiority of a method in analyzing slope slides depends on the type of slope and the soil under investigation.

Acknowledgements

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