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GROUNDWATER INFLUENCE TO SLOPE STABILITY ANALYSIS AT MAIN ROAD OF MALINO-MANIPI, INDONESIA

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ABSTRACT

Malino-Manipi main road is a short cut way to connect western and eastern part of South Sulawesi Province Indonesia. This road crosses the Bawakaraeng Moutain in which suffer easily with slope failure particulary in rainy season. To understand the slope condition, it was studied to develop new design for the slope to meet standard of safety factor. A field study have been done to observed actual slope at present condition. The slope consist of volcanic tuff with mechanical properties of unit weight (γ) is 20.336 kN/m^3; cohesion (c) is 4.089 kN/m^2; and internal friction is (ϕ) 34.314^o. The slope stability analysis was performed by using finite element method of Phase2-6.0 software. Simulation result showed the estimated of safety factor (SF) in actual slope without considering the groundwater influence is 0.503 and by considering of groundwater level became 0.473. This simulated result shows that factor of safety actual slope indicated the slope in unstable condition. In order to overcome the problem, redesign of slope geometry is needed. A new design of slope was proposed consisting 4 benches with bench height is 8.5 meters, bench width is 6 meters, overall slope is 37° and single slope is 53°. Simulation without considering the groundwater level estimated SF of 1.396 and 1.268 for 500 and 1,500 element respectively, whereas by considering groundwater level resulted SF of 1.343 and 1.250. This simulation was also figure out distribution of mean stress, maximum shear strain, and total displacement.

Keywords: factor of safety, stress, strain, material displacement, cut-back slope.

INTRODUCTION

Landslide is the collapse of the land mass located below a slope. This condition was happened on the land mass movement downwards and outwards. It could have happened in some ways that is slowly, suddenly, and with or without visible causes (Terzaghi *et al*, 1987).

Instability is the main problem in knowledge engineering slope also as the big challenge for professional engineer and researchers. Gravitation forces and seepage tend to cause instability on the natural slopes, the slope formed by excavation, embankment and soil retention (Craig, 1987). Instability condition does require the slope stability analysis which can be planning a more safely slope geometry. One of the methods used in slope stability analysis is finite element method (Griffits *et al*., 1999).

Slope stability analysis by finite element method use model stress and strength of soil involved to calculate the stress in the soil mass. This stress then can be used to calculate the factor of safety. The method is also referred to as a numerical modeling method or continuum method (Stead *et al.,* 2006). Griffiths *et al.* (1999) and Zheng *et al.* (2005) use the finite element method for analyze slope stability with the Mohr Coulomb criterion collapse or can be mentioned as elasto- plastic.

RESEARCH METHODOLOGY

Data collecting

Data was collected at slope on main road of Malino - Manipi South Sulawesi, Indonesia. Geographically, observed slope is located in the S 5° 11' 29.2" and E 119°58' 13.1". The data collected in this study composed of slope geometry and sample of slope material. The sample of the slope is then analyzed in the laboratory in order to know the physical property (unit weight - γ) and mechanical properties of the soil (cohesion - c and internal friction - ϕ). Measurement of the slope geometry corvers slope inclination and slope length.

Data processing

The data was collected through a field investigation and a laboratory test as a requirement for numerical analysis. The field and material data were processed and analyzed by using Phase2 version 6.0 software. The software was used to estimated the value of Strength Reduction Factor (SRF). This value was obtained by a numerical approach using the equation:

$$SRF = \frac{C}{C_f} = \frac{\tan\phi}{\tan\phi_f} \quad (1)$$

with SRF is strength reduction factor, C is cohesion of soil, C_f is cohesion of soil along critical plane, ϕ is internal friction of soil, and ϕ_f is internal friction of soil along critical plane. In addition, the software also can be used to represent distribution of mean stress, maximum shear strain and total displacement that occurred during the slope collapse.

Slope stability analysis was performed by employing two kinds of number of elements, 500 and 1,500 elements, to ensure the consistency of numerical results. The simulation was carried out to learn the slope stability for the current slope geometry by avoiding and considering the groundwater level. Furthermore, the simulation was done to find a new design of the slope geometry that more stable compared with the current slope geometry. The new design of cut-back slope was

developed by trial-and-error for each design geometry combining with numerical simulation proceses. The numerical results for those conditions provide the stress distribution, the maximum strain, and the total displacement of slope material.

RESULT AND DISCUSSIONS

Geological setting

Geological condition of this area consists of two rock formation, namely Volcanic Rocks of Baturape-Cindako and Volcanic Rocks of Lompobattang (Soekamto *et al* 1982). The Volcanic Rocks of Baturape-Cindako is a tertiary pleistocene rock consisting of lava and breccias interbedded with some conglomerate and tuff. The Volcanik Rocks of Lompobattang is a product of a quartenary volcanic activity composed with lava and andesitic tuff rock.

On the west side of the research location, a structural fault exists to cut the Volcanic Rocks of Lompobattang along the North to South direction. This fault causes a development of joint set on these both rock formations that can be observed in many places of outcrops. The rocks formations are also show a highly weathered rock. Both this condition may give effect to the high intensity of slope failure. These indicated by most of the sliding formed through the surface of fracture or joint.

The height the actual slope on research location is 34 meters with a slope angle is 87°. The site area is composed of volcanic lava rocks and andesitic tuff. In fresh rocks are gray of tuff and in weather condition gray tanned. Mineral composition consists of quartz and plagioclase with a specific gravity (SG) is 2.690.Based on laboratory test, the physical property of unit weight (γ) is 20, 34 kN/m^3, and mechanical properties of cohesion (c) is 4, 09 kN/m^2, and internal friction (ϕ) is 34,3^O.

Stability analysis for the present slope geometry

Slope stability analysis was carried out by with some scheme. Numerical analysis was mainly performed with number of elements are 500 and 1,500 for condition of the present and the new design of slope geometry. For the present slope geometry by avoiding the effect of groundwater condition was estimated the FS 0.500 and 0.503 for the 500 elements and 1500 elements. The strees occured at bottom was greater than at top of the slope. This due to loading force of the body forces and the influence of gravity leads to stress accumulation at the bottom of the slope. Stress magnitude at the top surface of the slope at 0 kPa while at the bottom about 960 kPa.

Distribution of maximum shear strain occurs around the surface of the slope that can lead to landslide occurence in the area. Analysis with the 500 elements shows the distribution of strain that occured around the surface of the slope is 0.03 to 0.36. Distribution of maximum shear strain on the slopes with 1,500 elements is 0.03 to 0.48. Based on both results, using a big number of elements provide a wide range of distribution of maximum shear strength.

In addition, with this simulation result the actual slope condition at present situation showed that slope will collapse eventhough without groundwater influence. Therefore, this area is quite sensitif with the slope failure occurence. Distribution of the total displacement along the surface shows unstable condition and displacement direction showed with arrow sign on Figure-1. By using simulation with 1,500 elements results total displacements in the slope of materials ranging from 0.02 meters to 0.36 meters.

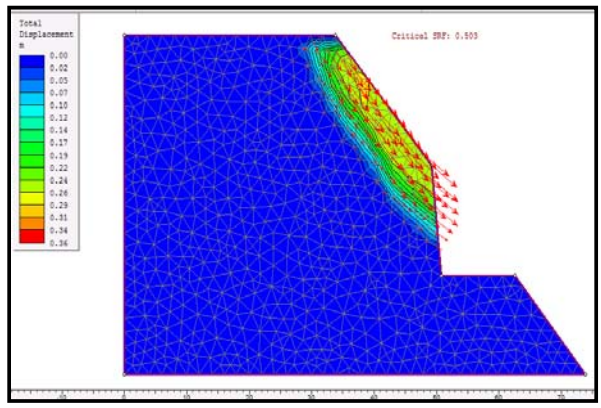

Figure-1. Total displacement distribution on the current actual slope geometry without groundwater effect.

The simulation by considering the groundwater level effect for this current slope geometry estimated the SF value of 0.452 and 0.473. This groundwater causes decreasing value of the SF of 0.500 to 0.452 and of 0.503 to 0.473. Total displacement for this condition from 0.10 meters to 1.44 meters showed in Figure-2.

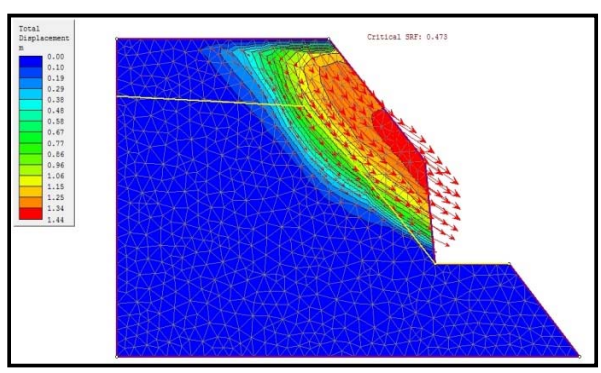

Figure-2. Total displacement distribution for the current slope with groundwater level.

Stability analysis for cut-back slope redesign

Cut-back slope is used for the proposed new design of slope geometry. Redesigning the slope geometry was carried out since the value of safety factor for the present slope geometry was less than 1.25. There are six designs of cut-back slope have been evaluated in order to find a proper design. The cut-back slope was designed by dividing into four benches in which each bench has high

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of 8.5 meters and berm width of 6.0 meters. There two main approaches for this design, that are slope inclination for a single bench and slope inclination for overall slope. The slope for a single bench various from 35° to 87° with overal slope inclination various from 37° to 66°. Each design was analyzed to estimated the SF and to predict its stability shows at Table-1. The simulation results show that the stable slope if inclination for each bench is 53° with overall slope inclination of 37°.

Table-1. Estimated SF for several slope design without considering groundwater effect.

Single Slope (^{O})	Overall Slope (^{O})	SF for employed elements number		Slope condition
		500	1,500	
87	66	0.500	0.503	Unstable
80	55	0.732	0.704	Unstable
70	49	0.975	0.828	Unstable
65	45	1.116	0.967	Unstable
60	42	1.147	1.172	Unstable
53	37	1.396	1.268	Stable

Through number of simulation schemes were decided that the proper slope design by constructing slope with slope bench of 53° and overall slope angle of 37°. The value of the safety factors for this design by avoiding of groundwater influence are 1.396 and 1.268 Distribution of maximum shear strain occurs around the top surface of the slope that can lead to landslide in the site. The analysis by using 500 elements shows that the stress distribution occured around the top surface of the slope of 0.06 to 0.96. Distribution of maximum shear strain on the slopes by using 1, 500 elements are 0.10 to 1.44. Furthermore, the total displacement distribution about 0.48 to 7.20 meters and movement direction showed with arrows on Figure-3.

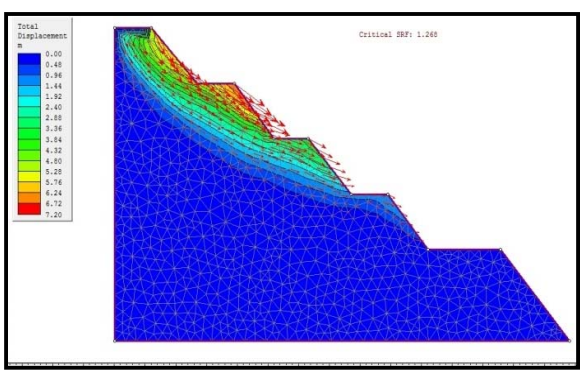

Figure-3. Total displacement distribution on cut-back slope without considering groundwater effect.

The simulation of slope stability by considering was also performed for all 6 new cut-back slope designs above mentioned. The simulation results shows at Tabel-2 with the SF various from 0.542 to 1.343 for simulation with 500 elemenst, and various from 0.473 to 1.250 for simulation with 1,500 elements. Similar with the resulted SF without considering the groundwater level, the slope with bench inclination of 53° and overall slope inclination fo 37° is still stabel. For this slope design, the groundwater level affected the SF for the cut-back slopes by decreasing value from 1,396 to 1.343 and from 1.268 to 1.250. Based on these estimated safety factors, the proposed new design of cut-back slope is quite stable with groundwater changes. This indicates with small decrease of the SF value by considering the groundwater condition. Influence of groundwater level simulation results a total displacement 0.40 to 6.0 meters (Figure-4).

Table-2. Estimated SF for several slope design by considering groundwater effect.

Single Slope (^{O})	Overall Slope (^{O})	SF for employed elements number		Slope condition
		500	1,500	
87	66	0.452	0.473	Unstable
80	55	0.744	0.699	Unstable
70	49	0.850	0.839	Unstable
65	45	1.046	0.917	Unstable
60	42	1.163	1.048	Unstable
53	37	1.343	1.250	Stable

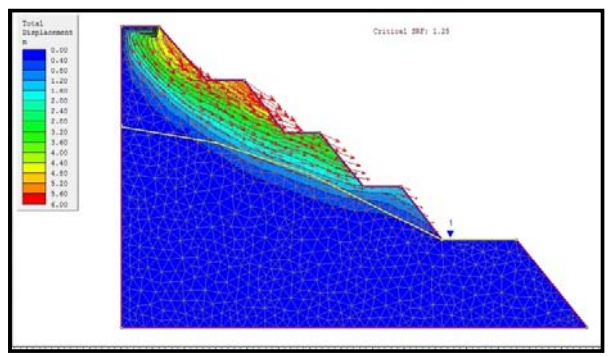

Figure-4. Total displacement distribution on cut-back slope with groundwater level simulation.

Figures 25 and 26 show that the number of elements which used in slope stability analysis influencing the factor of safety. More little the element that used, the factor of safety was greater but the bias was greater too and the accuracy of measurement was lower.

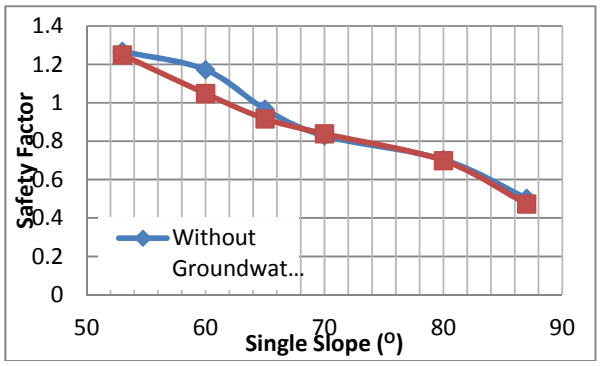

Figure-5. Comparison the simulated SF by with and without groundwater consideration.

CONCLUSIONS

Slope stability analysis was performed with kinds main approaches, the actual slope for current condition and a proposed new design of cut-back slope. By simulating the present condition of the slope with height 34 m and inclination angle 87° leads to result of unstable slope. As a result, with small increasing the groundwater level become a big trigger for slope failure.

Various of a new design of cut-back slope have been evaluated by considering the actual condition at present situation to a stable slope geometry. The final result recommend that slope should be modified into 4 benches with each bench has height 8.5 m, width 6 m, and single slope angle is 53°. With this new geometry, it was estimated slope become stable eventhough under influence of groundwater level.

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