Effect of cement injection on sandy soil slope stability, case study: slope in Petang district, Badung regency

I W Arya¹, I W Wiraga¹ and I GAG Suryanegara¹
¹Civil Engineering, Bali State Polytechnic, Jalan Kampus Bukit Jimbaran, Kuta Selatan, Kabupaten Badung, Bali - 80364

E-mail : wayanarya@pnb.ac.id

Abstract: Slope is a part of soil topography formed due to elevation difference from two soil surface. Landslides frequently occur in natural slope, because shear force is greater than shear strength in the soil. There are some factors that influence slope stability such as: rain dissipation, vibration from earthquake, construction and crack in the soil. Slope instability can cause risk in human activity or even threaten human lives. Every year in rainy season, landslides always occur in Indonesia. In 2016, there was some landslide occurred in Bali. One of the most damaging is landslide in Petang district, Badung regency. This landslide caused main road closed entirely. In order to overcome and prevent landslide, a lot of method have been practiced and still looking for more sophisticated method for forecasting slope stability. One of the method to strengthen soil stability is filling the soil pores with some certain material. Cement is one of the materials that can be used to fill the soil pores because when it is in liquid form, it can infiltrate into soil pores and fill the gap between soil particles. And after it dry, it can formed a bond with soil particle so that soil become stronger and the slope as well. In this study, it will use experimental method, slope model in laboratory to simulate a real slope behavior in the field. The first model is the slope without any addition of cement. This model will become a benchmark for the other models. The second model is a slope with improved soil that injects the slope with cement. Injection of cement is done with varying interval distance of injection point is 5 cm and 10 cm. Each slope model will be given a load until the slope collapses. The slope model will also be analyzed with slope stability program. The test results on the improved slope models will be compared with unimproved slope. In the initial test will consist of 3 model. First model is soil without improvement or cement injection, second model is soil with cement injection interval 5 cm and third model is soil with cement injection interval 10 cm. The result is the shear strength (θ value) the soil is increase from 32.02˚ to 47.57˚. The increase value of internal friction angle (θ) shows that an increase in shear strength of the cement improved soil. While, the value of cohesion (c) is zero indicating there is no cohesion in the soil. This is common for sand soil or sandy soil. The calculation of safety factor with GeoStructural Analysis obtained an increase of safety factor from 0.78 if the soil without cement injection to 1.07 and 1.17 if the soil is injected with cement at a distance of 10 cm and 5 cm.

1. Introduction

Slope is part of soil topography formed due to the elevation difference of two ground surface. The slope consist of the top of the slope, foot of the slope and the base of the slope. Slope legs can be in vertical form or form a certain angle with horizontal plane. The formation of the slope can be distinguish into two type: natural slope and made by human for a specific technical need. Natural slope is usually found in the highland.

Natural slope is often tend to slide. Landslide occurs when shear force is greater than shear strength in the soil. The factors of disturbance of the slopes stability are: water dissipation, vibration...
from earthquake or moving load, construction and crack. Landslide due to rainfall dissipation is a common problem in residual soil slopes in the tropical area/region. If there is a crack on the soil slope, then this condition will further aggravate the stability of the slope. According to Chowdhury [1] the two main factors causing slope instability and landslide are the high intensity of rainfall and the movement of the soil due to the earthquake.

Every year in the rainy season there is always a landslide disaster in the Territory of Indonesia. In 2016 some landslide disaster occurred in Bali. One of the worst and still unfinished is in Petang sub-district, Badung Regency, Bali. Economic loss and loss of life have been caused by landslides. Attempt to overcome and prevent it are also widely practiced and more sophisticated methods of forecasting slope stability are sought.

In the treatment of slope that has been landslide, often have difficulty in terms of soil compaction to form a slope body. After a landslide, the soil particles is not compact so the strength of the soil will be very low. One of ways to improve soil strength after a landslide is to fill the soil pores with a certain material. One of those material is cement. Cement is chosen because it can be seep and fill the soil pores when it is in a liquid form and then strengthen soil after it dry and so that the slope is strengthen as well. Filling cement into soil pores can be done by injecting a liquid cement.

Slope stability has been widely discussed and examined by scientists from various countries. Due to the many factors that influence the stability of the slope, each research result will be a very important input for practitioners and academics in terms of understanding slope collapse. However, it is widely recognized that an interdisciplinary approach is required for a complete understanding of slope performance and for the choice of model and analytical methods for a particular, realistic location. [1].

Leroueil and Picarelli [2] examine and monitor slopes, understand slope behavior, and for numerical simulations plus hydromechanical problems on saturated / unsaturated soils. The methodology for assessing slope stability is presented. This includes both qualitative and quantitative approaches and, separately, the characterization of the post-lapse stage. Finally, there is some discussion about the use of safety factors, the use of numerical models and risk considerations.

Conditions of water that seep into the slopes also cause a lot of slope slope. This has been investigated by Ali, Huang [3]; Le, Gallipoli [4]; Rahardjo, Lee [5]; White and Singham [6]; Zhang, Wang [7], Tohari, Nishigaki [8], and Zhu, Griffiths [9]. The effect of rainfall on slope stability is more due to the absorption of rainwater which then causes excess pore pressures and also decreases the shear strength of the soil.

Other influences are also investigated such as the presence of cracks or cracks on the ground, proposed by Mochtar [10, 11]. That cracks formed on the slopes should be calculated on the calculation of slope stability as the beginning of slope weakness. Because of this fracture will be entered by water during the rain and will trigger the slump.

Slope repair is done by pile into the slope to penetrate the sliding field. The research undertaken by Dhatrak and Bhagat[12], Tehrani, Nguyen [13] describes the results of several experimental studies conducted on lateral loads and sloping loads on long piles near the slopes. At the beginning of this paper, test results are presented on long piles loaded with lateral loads, on a 1V: 2V homogeneous slope with load slope 15° and 30°. The increase in ultimate pile loads depends greatly on the number of geogrid layers, the relative pile location against the slope top, and the slope angle of the load.

The use of reinforcement from geotextile is also a common choice for slope stability improvement. The influence of the use of geotextiles has been shown by several studies (Fuggini, Zangani [14]; Narejo, Li [15]; Palmeira and Tattu [16]).

The objective of this study is to get an ideal injection interval distance for slope improvement and knowing the percentage increase on slope safety factor when it injected with cement. From the background that have been discussed, then the formulation of the problem in this study are:

1. To get an ideal distance interval of cement injection for slope stability
2. To know the increase of safety factor of the cement injected slope.
2. Method

2.1 Research Design

In this research will be used experimental model in the laboratory scale. The research design is to make slope model to simulate actual slope behavior. The first model is the slope without any addition of cement. This model will become a benchmark for the other models. The second model is a slope with improved soil that injects the slope with cement. Injection of cement is done with varying number of injection point: 1 injection point, 2 injection point, 4 injection point. Interval distance of injection point is 5cm and 10cm. Each slope model will be given a load until the slope collapses. The slope model will also be analyzed with slope stability program. The test results on the improved slope models will be compared with unimproved slope. In the initial test will consist of 3 model. First model is soil without improvement or cement injection, second model is soil with cement injection interval 5cm and third model is soil with cement injection interval 10cm.

![Figure 1. Slope model in laboratory](image)

The scope of research

Due to breadth of slope stability problems and the number of variables involved, this research need to be limited as follows:

1. Slope model is made from sandy soil
2. Cement used is type 1 Portland cement
3. Injection interval distance is 10 cm and 5 cm

Input Data

Data collected for this study is primary data:

1. Physical properties of the slope soil
2. Physical properties of cement
3. Shear strength of the slope soil
4. Shear strength after cement injection

2.2 Research Procedure

Slope model

a. Slope model corresponded to initial condition
Based on field properties data, then made slope model on model tube that have been prepared. Let sit about 3 days and then loaded until the slope collapse. In another model, soil sample were taken to test the shear strength using direct shear test. Direct shear test results are used for soil data in slope stability analysis.

b. Cement Injected Slope Model
Slope model geometry is made just like the first model. Once slope model formed, it is injected with liquid cement in one point. The slope model let dry for 3 days and then loaded until it collapse. Another similar slope model is made for direct shear test.

1. Water content test
2. Bulk density test
3. Soil density test
4. Sieving analysis
5. Proctor Test
6. Direct shear test

3. Results and Discussions
3.1 Soil Properties of Sample
This research use sample which is obtained from Petang Sub-district, Badung Regency. Before the soil formed in to slope model, it is sieved with 2mm sieve, so that the soil is sand.
Proctor test conduct to get the optimum water content. This value of water content will be used in the slope model. From proctor test, the optimum water content for the soil is 18%.

3.2 Initial Result of Slope Model
The first slope model without any cement injection has a density 0.99 gr/cm3. The second slope model which has an interval injection of 10 cm has a density 1.057 gr/cm3 and the third model which has an interval injection of 5 cm has a density 1.207 gr/cm3. There is an increase of density with the increase of cement injected.

Direct shear test is conducted for all three slope model. Figure 2 represents that the result for the sample without any cement injection are c=0 and $\phi = 32.02$. The second and the third slope model which has an interval injection of 10 cm and 5 cm, the direct shear results are: c = 0 and $\phi = 41.26$ and c = 0 and $\phi = 47.57$ respectively, as shown at Figure 3 and 4. Value of $\phi$ increases as cement injected into slope model. Value of cohesion (c) = 0 indicates that it was cohesion-less soil. It is commonly found in sand soil.
The result of calculating the safety factor using GeoStructural Analysis was found that, the safety factor for the slope model without cement injection was 0.78 while the safety score increased to 1.07 at injection at 10 cm intervals and $F_s = 1.17$ on cement injection at 5 cm intervals, as shown in Figure 5, figure 6 and figure 7.

**Figure 3.** Direct Shear Test from Model with Cement Injection interval 10 cm

**Figure 4.** Direct Shear Test from Model with Cement Injection interval 5 cm
Figure 5. Slope Safety Factor when Soil Without Improvement

Figure 6. Slope Safety Factor when Soil was Injected Cement by Interval 10 cm
Figure 7. Slope Safety Factor when Soil was Injected Cement by Interval 5 cm

By injecting the soil with a cement, there is an increase in the safety rate of 37.2% of the soil without injection compared to the cement-injected soil with a distance of 10 cm. An increase in safety factor of 50% if the soil is injected with cement at an interval of 5 cm.

Figure 8. Incretion Safety Factor
4. Conclusion
The sand slope model was made to obtain the effect of cement injection on slope stability in the case of slope collapse in Petang, Badung regency, Bali. From direct shear result, it is found that the shear angle of soil is increased from $\phi = 32.02$ for model without cement injection to $\phi = 41.26$ and $\phi = 47.57$ if the soil is injected by cement with 10 cm and 5 cm.

The calculation of safety factor with GeoStructural Analysis obtained an increase of safety factor from 0.78 if the soil without cement injection to 1.07 and 1.17 if the soil is injected with cement at a distance of 10 cm and 5 cm.

5. Acknowledgment
This research is funded by P3M Bali State Polytechnic.

6. Reference
[1]. Chowdhury, R., 2010, Geotechnical Slope Analysis. Netherlands: CRC Press/Balkema.
[2]. Leroueil, S. and L. Picarelli, 2012, Assessment of Slope Stability. Geotechnical Engineering State of the Art and Practice: Keynote Lectures from GeoCongress 2012. 226: p. 122.
[3]. Ali, A., et al., 2014, Simplified quantitative risk assessment of rainfall-induced landslides modelled by infinite slopes. Engineering Geology. 179: p. 102-116.
[4]. Le, T.M.H., et al., 2015, Stability and failure mass of unsaturated heterogeneous slopes. Canadian Geotechnical Journal. 52(11): p. 1747-1761.
[5]. Rahardjo, H., et al., 2005, Response of a residual soil slope to rainfall. Canadian Geotechnical Journal. 42(2): p. 340-351.
[6]. White, J.A. and D.I. Singham, 2012, Slope Stability Assessment using Stochastic Rainfall Simulation. Procedia Computer Science. 9: p. 699-706.
[7]. Zhang, G., et al., 2012, Effect study of cracks on behavior of soil slope under rainfall conditions. Soils and Foundations. 52(4): p. 634-643.
[8]. Tohari, A., M. Nishigaki, and M. Komatsu, 2007, Laboratory rainfall-induced slope failure with moisture content measurement. Journal of Geotechnical and Geoenvironmental Engineering. 133(5): p. 575-587.
[9]. Zhu, H., et al., 2015, Undrained failure mechanisms of slopes in random soil. Engineering Geology. 191: p. 31-35.
[10]. Mochtar, I.B. 2012, Kenyataan Lapangan Sebagai Dasar Untuk Usulan Konsep Baru Tentang Analisa Kuat - Geser Tanah dan Kestabilan Lereng. in Geotechnical Challenges in Present and Coming Nationwide Construction Activities. Jakarta: HATTI.
[11]. Mochtar, I.B. 2016, Cracks In Soil and Their Implication For Geotechnical Engineering. in Geotechnical Role to Accelerate Infrastructure Construction in Indonesia. Jakarta: HATTI.
[12]. Dhatrak, A. and G. Bhagat, 2016, Behaviour of Long Pile in Reinforced Slope Subjected to Inclined Load. International Journal of Engineering Science. 2551.
[13]. Tehrani, F.S., et al., 2016, Comparison of Press-Replace Method and Material Point Method for analysis of jacked piles. Computers and Geotechnics. 78: p. 38-53.
[14]. Fuggini, C., et al., 2016, Innovative Approach in the Use of Geotextiles for Failures Prevention in Railway Embankments. Transportation Research Procedia. 14: p. 1875-1883.
[15]. Narejo, D., et al., 2013, A monolithic layered nonwoven–woven geotextile for use with drainage geocomposites in coal combustion residual projects. Geotextiles and Geomembranes. 37: p. 16-22.
[16]. Palmeira, E.M. and J. Tatto, 2015, Behaviour of geotextile filters in armoured slopes subjected to the action of waves. Geotextiles and Geomembranes. 43(1): p. 46-55.