Susceptibility of Landslide Embankment, Based on the Maximum Number of Geotextile for Reinforcement

Putu Tantri Kumala Sari
Civil Engineering Department, Institute Technology of Sepuluh Nopember, Surabaya, 60111, Indonesia
Email: tantrigeoteknik@gmail.com

Siti Nurlita Fitri
Civil Engineering Departement, Sebelas Maret University Surakarta, 57126, Indonesia
Email: nurlitafitri@gmail.com

Abstract—**This aim of this study is to obtain the landslide susceptibility, and the maximum number of reinforcements needed for road embankment. It also aims at verifying the empirical formulation used in the previous research. Based on the value of the safety factor, circular center, resistance moment and other landslide variables, the limit equilibrium method by Bishop simplified, was used to obtain the empirical formulation of the number of reinforcements. The verification process was carried out on an embankment dimension of 8 meter (which is different from the data used in the previous studies). The result obtained indicated that the empirical formulation which was developed to obtain the susceptibility of landslides on road embankment, based on the maximum number of reinforcements is inadequate to generalize all the conditions in the area. This formula is optimal for certain heights and subgrade which are similar to the data used in the other study. The simplification of the previously developed formulation needs to be carried out, in order for it to be used in various field conditions.**

Index Terms—**landslide, embankment, empirical formulation, landslide susceptibility, geotextile reinforcement**

I. Introduction

Landslides are one of the natural disasters with a high fatality rate. The Indonesian National Disaster Management Agency (BNPB), observed an increase in the number of landslides every year. It was one of the three major disasters that frequently occurred in 2012-2014. Furthermore, the increase rate from 2004 to 2018 can be viewed in Fig. 1. Landslides also occurs frequently in other countries, according to several scientific studies and forums related with landslide causes and prevention. The various landslides events discuss by [1] and [2] in South Korea, [3] in Vietnam, [4] in Philippines, [5] and [6] in Singapore, [7] in Thailand, [8] and [9] in Italy, [10] in Taiwan and many other. Additionally, the results obtained from the records of the Center of Research on the Epidemiology of Disaster (CRED) in Brussels, Belgium, states that all landslides which have occurred in the world make up 17% of all-natural hazards. Furthermore, landslides in Korea make up approximately 25% of all-natural disasters in Korea.

The areas for landslide need to anticipate and predicted in advance to determine if reinforcements should be installed. There are several methods that have been developed to predict landslide by analyzing the level of landslides susceptibility. According to [9], the landslide susceptibility is carried out to predict the areas for landslide in a slope. The susceptibility measures the level a slope moves and slides in the future. In other words, susceptibility predicts and estimates the approximate areas for landslides in advance [11]. Several approaches in research have been carried out to predict the landslide areas in advance, by performing geomorphologic mapping, analyzing landslide inventories, heuristic terrain, susceptibility zoning, numerical models and statistical modeling.

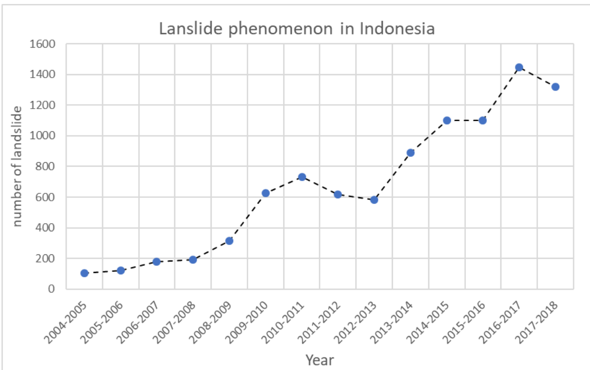

Figure 1. Landslide event in Indonesia based on BNPB data.

Based on a summary made by [12], the approaches and methods used to determine the susceptibility of landslide were based on several assumptions. First, the signs of landslide can be seen, classified, and mapped in the field based on the visual conditions or by using a remote sensing imagery. Second, landslides are controlled according to physical laws which can be analyzed empirically, statistically and determinedly. Third, past

Manuscript received November 6, 2019; revised December 22, 2019.

and present landslide can be the reason for landslides in the future. Furthermore, according to [13], [14], there are 4 fundamental assumptions for risk assessment of landslides. The first is that landslides are always in conditions which are similar to the geological, geomorphological, hydrogeological, and climatic conditions that have occurred in the past. The second assumption is that the main conditions which causes landslides are controlled by identifiable physical factors. The third assumption is that the level of landslide events can be evaluated. The fourth, all types of landslides can be identified and classified. Furthermore, [15] summarized the susceptibility of landslide modeling with qualitative approaches, namely physically-based models, statistical-based correlation analyzes and soft computing techniques.

Additionally, physically-based models contain detailed data which is in form of geotechnical data and geological aspects of landslides in relation to the specific conditions in the field by [16]. This method is considered expensive and difficult to apply on a large scale. The analysis of the statistical-based correlation method is a statistical process, traditionally carried out by assuming the structural modeling and focusing on the conditions of the existing parameters. Classifying the landslide factors is the main method used to produce a susceptibility map for landslides, while soft computing techniques such as using algorithms that study the relationship between the landslide events and the predictions relating to landslides. To obtain a more reliable data in this method, several information is required. The results obtained from other studies carried out by [12], focuses on statistical modeling to determine the landslide susceptibility. In the obtained results, some methods are considered better than other methods and none of them are considered dominant for susceptibility of landslides.

The methods that have been developed to determine the susceptibility of landslides are effective in predicting landslides, especially on natural slopes. These methods will be difficult to apply to slopes or man-made embankment and the application of these methods are time and cost consuming if applied to man-made slopes or embankment. Furthermore, the speed of design is very important because the construction of man-made embankments is always in a competition with time and irrespective of that an embankment is certainly needs to be safe to prevent landslides which may occur. Landslides on embankments and natural slopes have similar effects which causes loss of several fatalities. For this reason, in stabilizing an embankment against landslides, is very important to determine and analyze the areas that are intensively involved in road construction.

The construction of high embankment especially for roads and bridges, is becoming necessary in Indonesia. The toll road development policy which was accelerated by the government, made the implementation of this project to be intensively carried out in 2000 km of new toll roads and it has operated within the past 4 years. This toll road is mostly built on an embankment, which was constructed on subgrade that varies consistency from soft soil to hard soil and this condition leads to landslides if it is not anticipated beforehand. By adopting the landslide susceptibility methods for natural slopes, an analysis of man-made slope or embankment is carried out. The physically-based model and statistical-based correlation analysis can be adopted to determine the landslide susceptibility of varying embankments dimension that was built on subgrade with varying conditions.

The simplest but applicable method used in analyzing the embankment landslides and reinforcement needed is the limit equilibrium, which is based on the statistical-based correlation method. This method is generally used to determine the smallest factor of safety in several predicted landslide areas in the embankments. Several studies to find the best method for finding general slip surface locations based on the equilibrium method limit have been carried out. Greco [17] uses a Monte Carlo method based on the technique of the random walk type to find the location of a critical slip surface. The trial solutions are randomly generated and the compared with the best solutions for improvement. But the implementation of this method to search for results automatically is still unsatisfactory. Furthermore, [18] developed an effective approach to obtain the location of critical slip surfaces based on the Monte Carlo technique. This method is used because it is considered simply structured, random searching and optimization technic. In this method, a large number of trial surfaces can be generated to ensure a minimum factor of safety. In the previous period, s conducted a study to obtain the SF minimum value in non-circular slides. The study offers numerical procedures to obtain the location of critical non-circular surfaces that produce the smallest SF value. This research was developed based on Janbu's simplified method with mathematical programming technique.

The value of the factor of safety is also used as a determining factor to calculate the number of reinforcements required. However, the lowest value of the factor of safety does not necessarily produce the highest amount of reinforcements needed ([19], [20]). Furthermore, there were predictions made for several landslides areas which have different factor of safety values. The various predicted areas of the landslide, which is in a single embankment dimension and soil subgrade condition, can be seen in Fig. 2. In Fig. 2, most of the predicted landslides area are below 1 (SF<1), which makes it difficult to estimate the actual region it is likely going to occur in the field. This has an impact in deciding which factor of safety value is most appropriate for designing the numbers and dimensions of reinforcements to be used in preventing landslides. Predicting the areas for landslide in the field and the landslide areas to be used as determinants for analyzing the calculation of reinforcement required, is still uncertain.

Analyzing landslide susceptibility with complicated methods (which has been previously developed), is extremely difficult to apply when there are numerous variations of data used. Furthermore, the time factor can also be an obstacle if there are numerous variations of data used for designing, then it becomes time-consuming to construct those designs. By adopting the previously developed simplest method for obtaining landslide susceptibility, [20] and [21], developed an approach with empirical formulations to predict the embankment landslide susceptibility based on the highest number of reinforcements. This empirical formula aims to facilitate planners in designing the reinforcements required for the most critical landslide conditions which have been predicted to occur. Furthermore, it is asserted to be capable of shortening the planning time for reinforcements, which usually takes a long time in obtaining the predictions for landslide susceptibility.

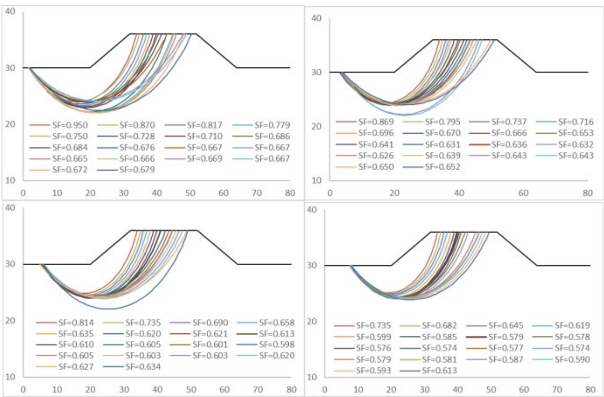

Figure 2. Landslide are of embankment H=6 meter stand on the compressible soil.

However, the empirical formulation is only carried out in limited conditions which affect the embankment dimensions and subgrade. Therefore, it is important to verify and demonstrate the use of this empirical formulation. [20], obtained an empirical formula with simple statistical modeling used for obtaining the predicted areas. The most critical landslides are based on three variations of slope height with the same slope. Furthermore, [21] obtained results by using an empirical formula with two variations in the height and three variations in the slope of the embankment. Both studies obtained several empirical formulations and the capability of these formulas to be used for all conditions has not been verified or proven. This research aims at verifying the existing formulas by using simple modeling on the dimensions of the embankment and a different condition from the previous study. The results from this study are expected to provide an overview of the verification of the empirical formula and the probability of it being widely used with variations in field conditions.

II. Previous Study

There are several methods used to determine a landslides susceptibility. However, the study which was developed by [20] and [21] specifically examines the empirical formulation to obtain the susceptibility of landslides based on the maximum number of reinforcements required. The calculation method used in the previous study is the limit equilibrium, which was developed by [22]. In this study however, the reinforcement used as a landslide prevention is geotextile with the strength ultimate equal to 200 KN / m. There are several analysed subgrade conditions under the embankment load in this previous study and the three soil-subgrade conditions are:

1) Compressible clay layer: it consists of a very soft soil with a thickness of 6 meters, a soft soil with a thickness of 10 meters and a medium-stiff soil with a thickness of 4 meters.
2) Compressible clay layer: it consists of a very soft soil with a thickness of 2 meters, a soft soil with a thickness of 10 meters and a medium-stiff soil with a thickness of 8 meters.
3) Compressible clay layer: it consists of a very soft soil with a thickness of 0 meters, a soft soil with a thickness of 6 meters and a medium-stiff soil with a thickness of 14 meters.

The embankment material is a mixture of sand and gravel and its unit weight is 1.85 t/m^3, the undrained cohesion is 0, and the friction angle is 30. The embankment dimensions analyzed are 6 and 7 meters with the slope angles of 1: 1.5, 1: 2 and 1: 3.

The method used to obtain the empirical formulations is:

1) Determination of the soil subgrade consistency based on field condition
2) Determination of the slope stability analysis using 180 trials for each variation
3) Calculation of the number of geotextiles needed for all the results and for determining the critical landslide area that requires maximum number of geotextile for reinforcement.

A. *Slope Stability Methods and Geotextile Design*

Slope stability was evaluated in terms of the Factor of Safety (SF) which was obtained by inputting deterministic parameter values into the limit equilibrium equation. According to the summary of research by [23], there are three types of factor of safety which is usually used for design analysis: 1) The strength reserve factor of safety is obtained by reducing the strength of the rock and soil mass, 2) the overload reserve factor of safety is obtained by increasing the exterior load, 3) The driving force overloading reserve factor, is a design value of the landslide trust which is calculated by amplifying the driving force along the slope while keeping the corresponding resisting force constant. Limit Equilibrium Method (LEM) are adopted by strength reserve factor, for obtaining the factor of safety.

It is regarded as the most popular method used for analyzing embankment stability. The main advantage of this method is that the data and parameters used such as soil profile, seepage and loading are the easiest to use. Although the method has several variations in the development of its application, the results obtained from comparing it to the existing methods indicates that the difference between their factors of safety calculation is less than 6% [24]. However, the bishop simplified method (1955) is widely used to predict the stability of the embankment in both drained and undrained conditions. The results obtained from the embankment

©2019 Int. J. Geol. Earth Sci.

stability analysis of these methods are further used as a parameter for determining the design requirements for reinforcement.

The calculation for geotextile reinforcement needed to prevent the landslides, is carried out based on the factor of safety and the moment obtained from the slope stability analysis. The allowable stress of the geotextile used in the embankment of reinforcement, is defined as the ultimate tensile strength divided by the reduction factor. The allowable stress values of the geotextile are in accordance with the following equation:

$$\sigma_{all} = \sigma_c \left(\frac{1}{f_d} \cdot \frac{1}{f_{env}} \cdot \frac{1}{f_m} \cdot \frac{1}{f_c} \right)$$

The allowable tensile strength of the reinforcement (T_{allow}) is calculated as:

$$T_{allow} = \frac{T_{ult}}{RF} = \frac{T_{ult}}{RF_D x RF_{ID} x RF_{CR}}$$

Factor of safety is an overall measure that accounts for all uncertainties in problems associated with geometry, soil variability, applied loads and it has a minimum value of 1.2. Since the overall factor of safety is accounted for in the stability analyses, the slope reinforcement, *FS* becomes 1. By using the Bishop method of analysis, a solution for the factor of safety was obtained by applying the following equation:

$$FS = \left(\frac{Mr}{MD} \right)_{unreinforced} + \frac{\sum T_{allow} x R_t}{MD}$$

This study used a geotextile with an allowable tensile strength equivalent to 20 KN/m'.

B. Safety Factor, Moment and the Number of Geotextiles

The results obtained from the analysis which was carried out in the previous studies, indicated that the smallest SF value did not produce the highest number of reinforcements. Furthermore, the value difference between the moment of resistance, safe conditions and landslide conditions (which must be held by geotextiles), does not result from the smallest SF value. Similarly, in the landslide radius, no exact pattern (range of landslide radius) is obtained, and this results in the highest number of reinforcements. Those results can be viewed in Fig. 3-Fig. 5, for soil type 1, 2 and 3, respectively. Based on the analysis results shown in Fig. 3 to Fig. 5, the sloping slope produces a higher safety factor value and produces a delta moment resistance value that is slightly higher than the slope which is steeper, but the difference is not too significant. In addition, the lowest value of the safety factor does not produce the highest amount of reinforcement. This condition occurs in 3 types of soil analysed in this study. In addition, the same conditions are also found in piles with 2 different heights. This result is well explained by [21].

From this analysis, an empirical formula of landslide area, which produces the highest number of reinforcements is obtained for determining its circular center (Table I), and area (Table II). An illustration of the circular center and landslide area location is shown in Fig. 6.

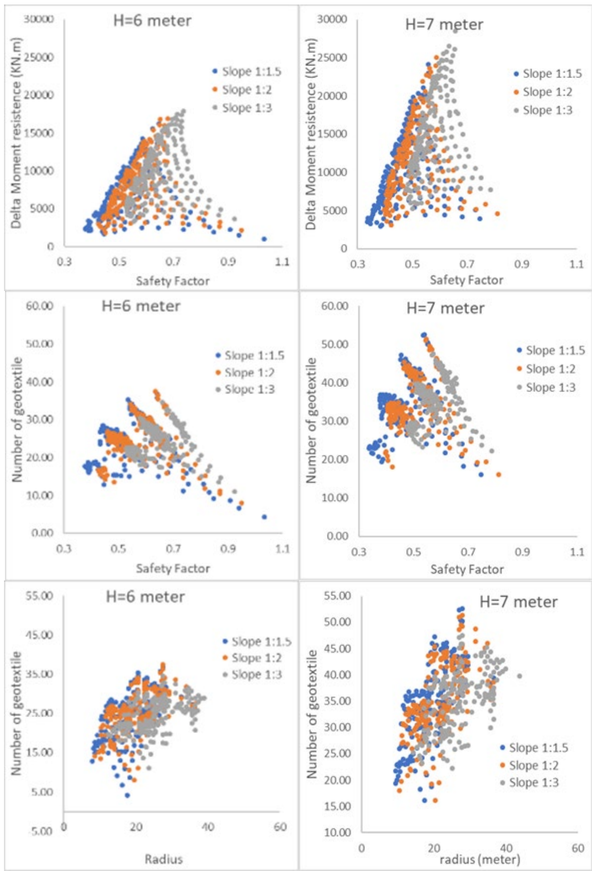

Figure 3. The relationship between the safety factor, resisting moment, radius of landslide and the number of geotextile (soil type 1).

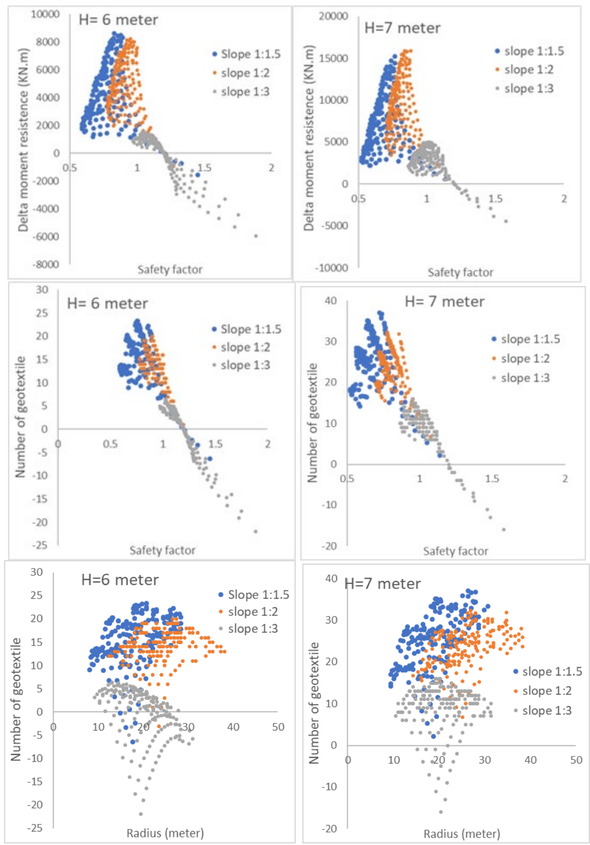

Figure 4. The relationship between the safety factor, resisting moment, radius of landslide and the number of geotextile (soil type 2).

©2019 Int. J. Geol. Earth Sci.

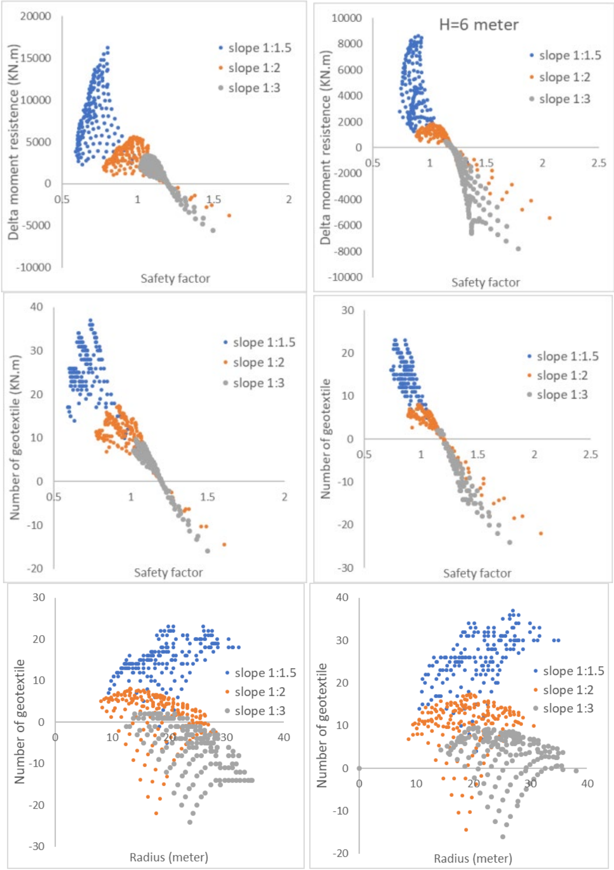

Figure 5. The relationship between the safety factor, resisting moment, radius of landslide and the number of geotextile (soil type 3).

TABLE I. EMPIRICAL FORMULATION OF LANDSLIDE AREA FOR EMBANKMENT

Slope/Soil type	Distance from embankment toe – left side	Distance from embankment toe – right side
Slope 1:1.5/ Type 1	y=-2x+30	y=2.01x+13.18
Slope 1:1.5/Type 2	y=3.78x-12.46	y=5.14x-7.73
Slope 1:1.5/Type 3	y=2.22x-7.32	y=7.86x-30.92
Slope 1:2/Type 1	y=0.22x+12.68	y=0.87x+24.02
Slope 1:2/Type 2	y=12.22	y=2x+17.1
Slope 1:2/Type 3	y=4x-20	y=5.76x-16.22
Slope 1:3/Type 1	y=-1.78x+22.68	y=-2.13x+49.02
Slope 1:3/Type 2	y=-2x+22.22	y=-2x+49.1
Slope 1:3/Type 3	y=1.33x-5.98	y=-0.64x+33.35

x = height of embankment; y = distance from embankment toe – left side (the beginning of landslide) ; y = Distance from embankment toe – right side (the end of landslide)

TABLE II. EMPIRICAL FORMULATION OF CIRCULAR CENTRE OF LANDSLIDE FOR EMBANKMENT

Soil type	Distance from subgrade elevation	Distance from toe – right side
Slope 1:1.5/ Type 1	y=-0.27x+21.12	y=1.75x-9.17
Slope 1:1.5/ Type 2	y=4x-9.27	y=0.27x+2.71
Slope 1:1.5/ Type 3	y=4.48x-17.71	y=0.41x+3
Slope 1:2/Type 1	y=0.54x+16.26	y=5.33
Slope 1:2/Type 2	y=0.73x+13.88	y=0.71x+1.97
Slope 1:2/Type 3	y=4.06x-15.19	y=0.41x+3
Slope 1:3/Type 1	y=0.54x+16.26	y=2x-4.67
Slope 1:3/Type 2	y=0.24x+17.31	y=2.23x-4.67
Slope 1:3/Type 3	y=0.29x+11.42	y=1.65x-0.94

y = circular centre; x = embankment height

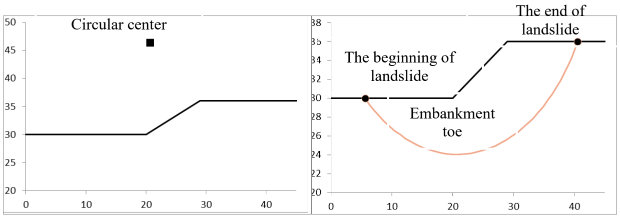

Figure 6. (left). The illustration of circular centre of landslide; (right). The illustration of landslide area.

III. VERIFICATION OF EMPIRICAL FORMULATION

Verification of the empirical formulation on the landslide susceptibility, was determined by using the heights of the embankment areas. The location and the circular center of the landslide were obtained by using the empirical formulations, however, the results from the elaboration graph using the formula was inadequate. Furthermore, the most critical landslide area and circular center obtained an adequate result only at heights 6 and 7 meters (which was the height of the embankment used in the previous study). However, at other heights, the graph trend is observed to have an exorbitant increase or decrease. and in some cases, the results have negative values, nevertheless, this condition are impossible in the field. Based on this graph, the empirical formula verification is only possible at an embankment height of H = 8 meters. The varying heights of embankment for soil types 1, 2 and 3, can be viewed in Fig. 7 to Fig. 9 respectively.

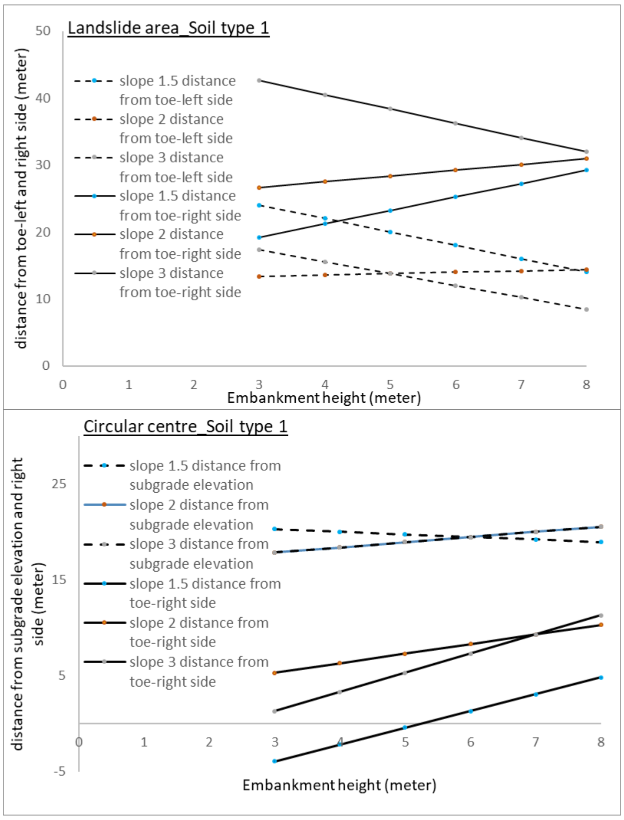

Figure 7. Landslide area and circular centre for soil type 1 based on the empirical formulation.

©2019 Int. J. Geol. Earth Sci.

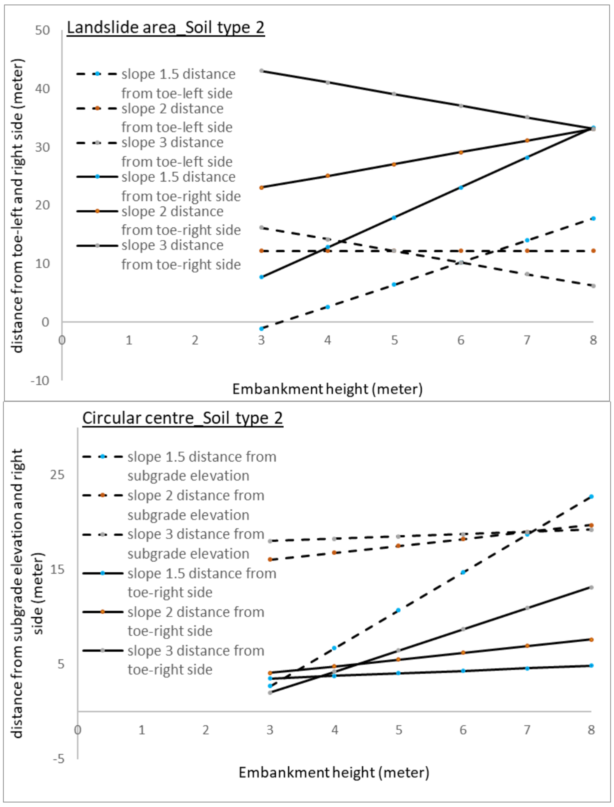

Figure 8. Landslide area and circular centre for soil type 2 based on the empirical formulation.

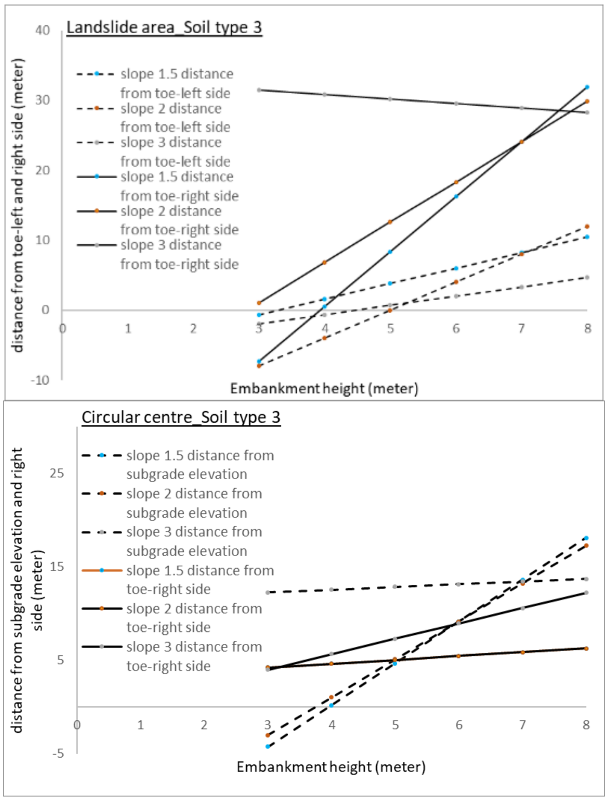

Figure 9. Landslide area and circular centre for soil type 3 based on the empirical formulation.

Trial verifications were carried out on 12 landslides with an embankment height, H of 8 meters. The trials were carried out in the circular center and landslide area using the results obtained from the empirical formulation, Furthermore, the results obtained from comparing the 8 meter height and slope of 1: 1.5 in soil type 1, indicated that the maximum number of reinforcements needed, cannot be obtained by using the formula.

However, a back analysis using the formulation was carried out on the landslide area and circular center embankment, and the results obtained, indicated that the number of reinforcements needed is minimal. Therefore, if a landslide area is calculated by applying the back analysis on the formula without considering the circular center, then the number of reinforcements required will be maximum in comparison to the other 11 landslide trials. Fig. 10 shows the results obtained from calculating the number of geotextile reinforcements for the safety factor carried out on the 12 trials. The highest number of reinforcements obtained at SF is 0.61, which was based on the landslide area only, without considering the circular center resulting from the empirical formulation.

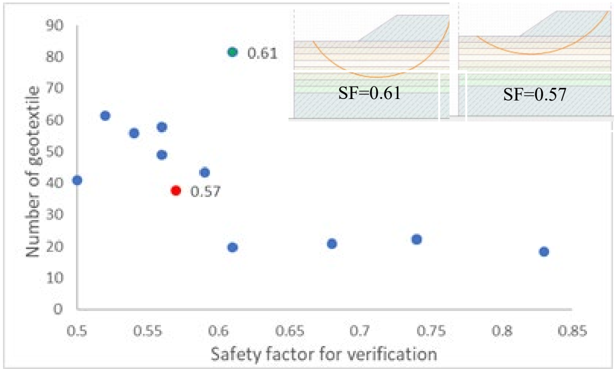

Figure 10. Result obtained from the verification of the empirical formulation using 12 trial.

Similar conditions in the trend are in landslides that have slopes and other soil types. This shows that, the empirical formulation results obtained from the previous studies have not been able to generalize all the conditions that specifically exist in different soil and dimensions of the pile. The empirical formula for obtaining landslide susceptibility in road embankment, based on the highest number of reinforcements, is optimally used only based on the conditions applied in the study.

IV. Conclusion

The existence of the empirical formulations for the susceptibility of landslides, based on the highest number of reinforcements is very effective for implementing in real field conditions. Besides being able to shorten time, this formula is also asserted to be capable of increasing the work productivity, especially in terms of analyzing the stability of the road embankment plan with varying variables in the area. The extremely varied geographical conditions of the region cause the construction of roads using mostly embankment with high elevation because they are in accordance with the contours of the region. Furthermore, the varied conditions of subgrade, makes planning time-consuming, when the construction needs to be carried out immediately. Due to this situation, the empirical formulation needs to be further developed.

The developed empirical formulations are adequate to facilitate all conditions and variations that may occur in the areas. However, the past formulas were inadequate for that because the dimensions of the embankment and subgrade conditions were not determined. Therefore, It is extremely necessary to develop the empirical formulations which will be useful and effective for the variations that affects the area. Furthermore, in field application, it is a method used for preventing landslides during the construction of road embankment.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Siti Nurlita Fitri, as a co-author in this research has assisted in completing the analysis of slope stability with a variety of used using Geo-studio program. Putu Tantri K. Sari has done an analysis of all the results that have been obtained and did the literature study to comparing the result with the previous study. The two authors in this research have jointly written the script for published in this journal and all authors had approved the final version.

References

[1] M. Hong, J. Kim, and S. Jeong, "Rainfall intensity-duration thresholds for landslide prediction in South Korea by considering the effects of antecedent rainfall," *Landslides*, vol. 15, pp. 523-534, 2018.

[2] S. Jeong, J. Park, M. Hong, and J. Kim, "Unified prediction method for the rainfall-induced landslides and debris flows,"in *Geotechnics for Transportation Infrastructure. Lecture Notes in Civil Engineering*, Singapore: Springer, 2019, vol. 28.

[3] B. D. Province, "Rainfall-triggered large landslides on 15 December 2005 in Van Canh District, Binh Dinh Province, Vietnam," *Landslides*, vol. 10, no. 2, 2013.

[4] A. Indelicato, "Landslides in the Philippines: Assessing the role of bioengineering as an effective alternative mitigation," presented at International Conference on Landslides and Slope Stability, September 2015.

[5] H. Rahardjo, X. W. Li, D. G. Toll, and E. C. Leong, "The effect of antecedent rainfall on slope stability," *Geotechnical and Geological Engineering*, vol. 19, no. 3, pp. 371-399, 2001.

[6] C. Kristo, H. Rahardjo, and A. Satyanaga, "International soil and water conservation research effect of variations in rainfall intensity on slope stability in Singapore," *Int. Soil Water Conserv. Res.*, vol. 5, no. 4, pp. 258-264, 2017.

[7] S. Soralump, "Rainfall-triggered landslide: From research to mitigation practice in Thailand," *Geotechnical Engineering*, March 2010.

[8] F. Guzzetti, A. Carrara, M. Cardinali, and P. Reichenbach, "Landslide hazard evaluation: A review of current techniques and their application in a multi-scale study, Central Italy," *Geomorphology*, vol. 31, no. 1-4, pp. 181-216, 1999.

[9] F. Guzzetti, P. Reichenbach, M. Cardinali, M. Galli, and F. Ardizzone, "Probabilistic landslide hazard assessment at the basin scale," *Geomorphology*, vol. 72, no. 1-4, pp. 272-299, 2005.

[10] A. Rahimi, H. Rahardjo, E. Leong, and M. Asce, "Effect of antecedent rainfall patterns on rainfall-induced slope failure," *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 137, pp. 483-491, 2011.

[11] F. Guzzetti, P. Reichenbach, F. Ardizzone, M. Cardinali, and M. Galli, "Estimating the quality of landslide susceptibility models," *Geomorphology*, vol. 81, no. 1-2, pp. 166-184, 2006.

[12] P. Reichenbach, M. Rossi, B. D. Malamud, M. Mihir, and F. Guzzetti, "A review of statistically-based landslide susceptibility models," *Earth-Science Rev.*, vol. 180, pp. 60-91, 2018.

[13] D. J. Varnes, *Landslide Hazard Zonation: A Review of Principles and Practice*, Paris: UNESCO, 1984, p. 63.

[14] J. H. Hutchinson, "Landslide hazard assessment," in *Proc. 6th International Symposium on Landslides*, 1995, vol. 1, pp. 1805-1841.

[15] H. Reza and O. Rahmati, "Catena prediction of the landslide susceptibility: Which algorithm, which precision ?" *Catena*, vol. 162, pp. 177-192, 2018.

[16] D. Tien, B. Pradhan, O. Lofman, I. Revhaug, and O. B. Dick, "Computers & geosciences landslide susceptibility mapping at Hoa Binh Province (Vietnam) using an adaptive neuro-fuzzy inference system and GIS," *Comput. Geosci.*, vol. 45, pp. 199-211, 2012.

[17] V. R. Greco, "Efficient monte carlo technique for locating critical slip surface," *Journal of Geotechnical Engineering*, vol. 122, no. 7, pp. 517-525, 1996.

[18] A. I. H. Malkawi, W. F. Hassan, and S. K. Sarma, "Global search method for locating general slip surface," *J. Geotech. Geoenvironmental Eng.*, vol. 127, no. 8, pp. 688-698, 2001.

[19] B. K. Low, R. B. Gilbert, and S. G. Wright, "Slope reliability analysis using generalized method of slices," *J. Geotech. Geoenvironmental Eng.*, vol. 124, no. 4, 1998.

[20] P. T. K. Sari and Y. Lastiasih, "A general formulation to describe the empirical prediction of the critical area of a landslide," *JESTEC*, vol. 13, no. 8, pp. 2379-2394, 2018.

[21] Y. Sari and P. T. K. Lastiasih, "The empirical prediction of the critical area of road embankment landslide using limit equilibrium method," in *Proc. Jt. Conf. ICoEE IIGC*, 2019.

[22] A. W. Bishop, "Stability of slopes the use of the slip circle in the stability," *Géotechnique*, vol. 5, no. 1, pp. 7-17, 1954.

[23] H. Lin, W. Zhong, W. Xiong, and W. Tang, "Slope stability analysis using limit equilibrium method in nonlinear criterion," *Sci. World J.*, 2014.

[24] J. M. Duncan, "State of the art: Limit equilmrium and finite-element analysis of slopes," *Journal of Geotechnical Engineering*, vol. 122, no. 7, pp. 577-596, 1996.

Copyright © 2019 by the authors. This is an open access article distributed under the Creative Commons Attribution License (CC BY-NC-ND 4.0), which permits use, distribution and reproduction in any medium, provided that the article is properly cited, the use is non-commercial and no modifications or adaptations are made.

Putu Tantri K. Sari was born in Surabaya, Indonesia on November 2nd of 1986. She received a B.S in Civil Engineering Department, Sepuluh Nopember Institute of Technology (ITS) in 2008. She received her magister in Geotechnical Engineering, Civil Engineering Department, Sepuluh Nopember Institute of Technology (ITS) in 2011. From 2007-2011 she worked as a project assistance in Soil and Rock Mechanic Laboratory in ITS. She works as a lecturer and researcher in the same institution since 2012. Her specifications of research are soil improvement and slope stability.

Siti Nurlita Fitri was born on February 21st 1994 in Bangka Barat, Indonesia. She completed her Bachelor degree in Civil Engineering Department, Sepuluh Nopember Institute of Technology (ITS) in 2016. After she finished her B.S, she continued her study in magister of Geotechnical Engineering, Civil Engineering Department, Sepuluh Nopember Institute of Technology (ITS) in the same year and graduated in 2018. From 2016-2018, she worked in many project of geotechnic engineering and foundation analysis in ITS and she works as a lecturer in Sebelas Maret University in 2019.