CONFERENCE PROCEEDING

2017 International Multidisciplinary Conferences on Productivity and Sustainability
Jakarta, 5-7 December 2017

Comparison of Probabilistic Slope Stability Analysis Using Finite Element Method and Design Charts

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Design charts are relatively new method to perform probabilistic slope stability analysis rather than finite element method (FEM). Therefore, it is important to assess the validation of this method. In this paper, the results of probabilistic slope stability analysis obtained from FEM were compared to design charts. Then, statistical parameters of coefficient of determination (R-squared) and standard error were calculated to evaluate the correlation of both methods. Generally, the mean factor of safety and probability of failure obtained from FEM resemble to design charts. This result confirms that the design charts are valid. Therefore, for the case of simple slopes, the use of design charts is more recommended rather than FEM.

Keywords: *probabilistic analysis, slope stability, finite element method, design charts*

1. Introduction

Finite element method (FEM) is widely used approach to perform the probabilistic slope stability analysis. Singh et al. has been presented the well performance of FEM-based software in calculation of the probability of failure of slope in the Amiyan region of India[1].

Another method for estimation of the factor of safety of slope is using design charts. Slope stability design charts are generally used to assess the stability of slopes with simple geometry, isotropic, and homogeneous soil properties[2]. Recently, Baker and Steward et al applied deterministic limit equilibrium analyses to produce their slope stability design charts[3,4]. The limitation of deterministic limit equilibrium analyses is that it only takes into account the average value of geomechanical parameters in slope stability analysis. Even though, spatial variability of soil properties might cause nominal similar slopes have the same factor of safety but different probabilities of failure[5-8]. Therefore, probability analysis is necessary to be conducted in determination of probability of failure of a slope by considering the variability of its soil properties.

The study of Javankhoshdel and Bathurst was the first that proposed a series of simplified probabilistic slope stability design charts that having feature to estimate the factor of safety and probability of failure using the random variability of soil properties expressed by the coefficient of variation (COV) as inputs in the same chart[9]. These probabilistic design charts were produced using Monte Carlo simulations in SVSlope software package[10]. The slope stability analysis in SVSlope is based on limit equilibrium method (LEM). The probabilistic slope stability design charts proposed by Javankhoshdel and Bathurst were produced for two ranges of coefficient of variation of cohesion (COV_c) and coefficient of variation of friction angle (COV_φ) which were given as. $COV_c = COV_\varphi = 0.1$, and $COV_c = 0.5$, $COV_\varphi = 0.2$. Those values were selected based on the suggestions given in the research conducted by Phoon and Kulhawy[11].

Since design charts are relatively new method to conduct probabilistic slope stability analysis rather than FEM that has been widely used. Therefore, it is important to assess the validation of this method. In this paper, the results of probabilistic slope stability analysis obtained from FEM were compared to design charts. Then, statistical analysis is performed to evaluate the correlation of both methods.

2. Experimental Details

The 5 m high slope models with six different slope angles ($\alpha = 30^o, 40^o, 50^o, 60^o, 70^o, 80^o$, and 90^o) were used in probabilistic slope stability analysis using FEM and design charts. In FEM modeling, triangular plain strain elements having six nodes were used and fixed boundary condition has been applied along the lateral sides and at the base of the slope models. Figure 1 shows the geometry, boundary condition and FEM mesh for slope model. The fixed soil mechanical properties assigned to all slope models were: mean unit weight $\mu_\gamma = 17$ kN/ m^3, mean cohesion $\mu_c = 7.2$ kPa, Young's modulus E = 50000 kPa and Poisson's ratio $\upsilon = 0.4$. Furthermore, three different mean friction angles ($\mu_\varphi = 20^o$, 30^o and 40^o) were chosen based on the values available in design charts.

The probabilistic slope stability analysis for each slope model was conducted using FEM and design charts. Rocscience Phase[2] 8.0 was employed in FEM analysis. The probabilistic analysis approach used in this software is Rosenblueth's Point Estimate Method. The required input parameters to perform probabilistic slope stability analysis using the design charts proposed by Javankhoshdel and Bathurst are α and μ_c / (μ_γHtanμ_c) where H is the height of the slope model. Simply entering the input parameters then mean factor of savety (FS_{mean}), the probability of failure (P_f) for $COV_c = COV_\varphi = 0.1$, and the probability of failure (P_f) for $COV_c = 0.5$, $COV\varphi = 0.2$ can be easily obtained. Finally, the statistical analysis was conducted using Microsoft Excel to compare the results obtained from FEM and design charts by using the statictical parameters of coefficient of determination (R-squared) and standard error.

3. Results and Discussion

Figure 2 shows the comparison of probabilistic slope stability analysis using FEM and design chart of slope model with $\alpha = 60^o$ and $\mu_\varphi = 30^o$ for $COV_c = 0.5$, $COV_\varphi = 0.2$. The FS_{mean} obtained from design chart is 1.15. This result is close enough compared to the FS_{mean} obtained from FEM which is 1.16. The result of P_f for $COV_c = 0.5$, $COV\varphi = 0.2$ obtained from design chart is 37%. This value is slightly higher than the P_f for $COV_c = 0.5$, $COV\varphi = 0.2$ obtained from FEM which is 32.96%.

The comparison of FSmean, P_f for $COV_c = COV_\varphi = 0.1$ and P_f for $COV_c = 0.5$, $COV\varphi = 0.2$ obtained from FEM and design charts for all slope models are shown in Figure 3, Figure 4 and Figure 5 respectively. In general, the mean safety factors obtained from both methods do not show significant difference. Meanwhile, the P_f for $COV_c = COV_\varphi = 0.1$ and P_f for $COV_c = 0.5$, $COV\varphi = 0.2$ obtained from both methods indicate that for some slope models the probability of failures obtained from design charts are slightly higher than FEM. This might be happened since the method for probabilistic analysis in design chart is based on Monte Carlo simulation which is different with the method used in FEM that is Rosenblueth's Point Estimate Method.

Two statistical parameters including R-squared and standard error are used to assess the correlation of the results obtained from both methods. Based on the statistical analysis, the following data are obtained: R-squared of FS_{mean}, P_f for $COV_c = COV_\varphi = 0.1$ and P_f for $COV_c = 0.5$, $COV_\varphi = 0.2$ are 0.9915, 0.9924, 0.9865, respectively. Moreover, standard error of FS_{mean}, P_f for $COV_c = COV_\varphi = 0{,}1$ and P_f for $COV_c = 0.5$, $COV_\varphi = 0.2$ are 0.005, 4.134, 4.664, respectively. These results indicate that results of probabilistic slope stability analysis obtained from FEM and design charts are having strong correlation in the analysis of simple slopes.

4. Conclusion

In this study, a comparative study of probabilistic slope stability analysis using FEM and design charts is conducted. In general, the results of simulation indicate that FS_{mean} and P_f for $COV_c = COV_\varphi= 0.1$ and $COV_c = 0.5$, $COV_\varphi = 0.2$ obtained from FEM resemble to the results obtained from design charts. The statistical analysis indicates that results obtained from both methods are having strong correlation. This result also confirms that the design charts are valid. Eventually, for simple cases, the use of design charts is more convenient rather than FEM since the steps of slope modeling and running the simulation are not necessary. Therefore, for probabilistic slope stability analysis of slopes with simple geometry, isotropic, and homogeneous soil properties, the use of design charts is more recommended.

References

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Figure Caption

Figure 1. Geometry, boundary condition and FEM mesh for slope model.

Figure 2. Comparison of probabilistic slope stability analysis using FEM and design chart of slope model with $\alpha = 60^o$ and $\mu_\varphi = 30^o$ for $COV_c = 0.5$, $COV_\varphi = 0.2$.

Figure 3. Comparison of FS_{mean} obtained from FEM and design charts.

Figure 4. Comparison of P_f for $COV_c = COV_\varphi = 0.1$ obtained from FEM and design charts.

Figure 5. Comparison of P_f for $COV_c = 0.5$, $COV_\varphi = 0.2$ obtained from FEM and design charts.

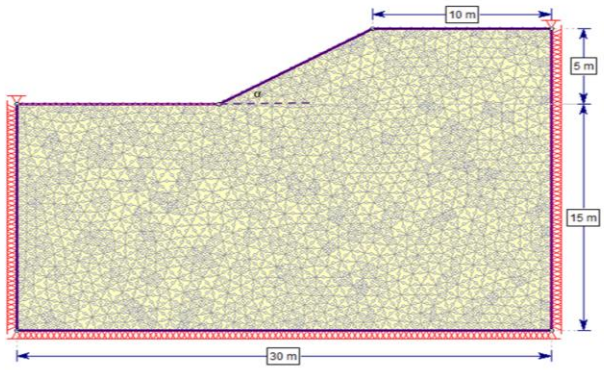

Figure 1. Hutama et al.

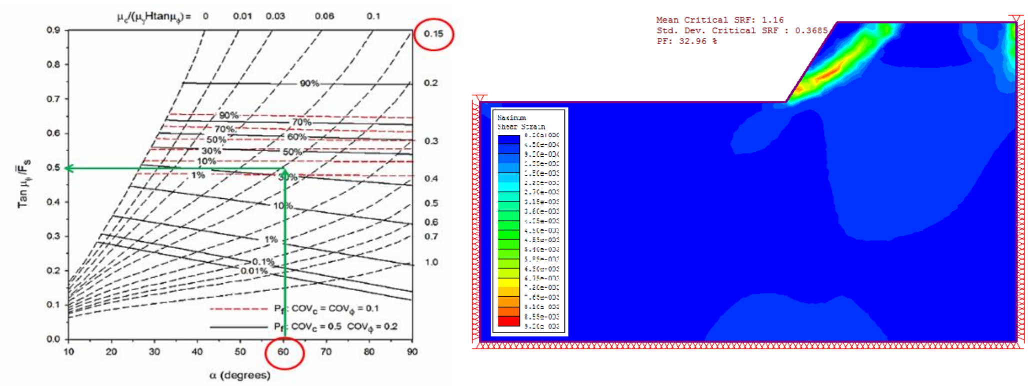

Figure 2. Hutama et al.

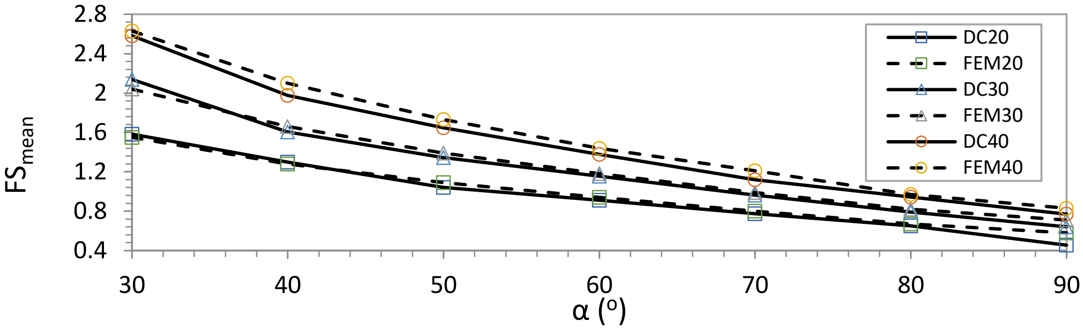

Figure 3. Hutama et al.

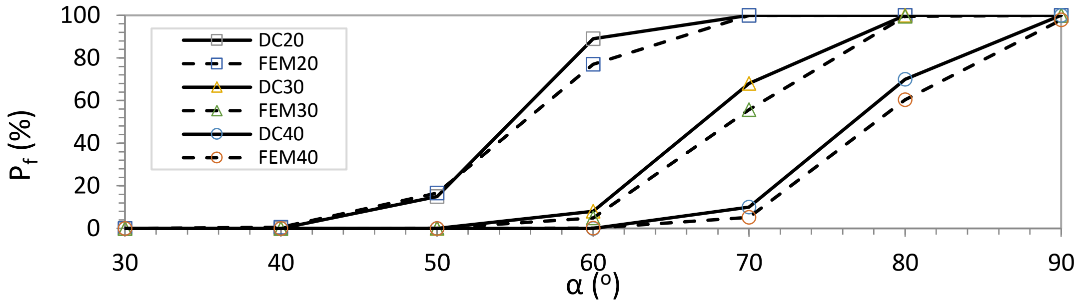

Figure 4. Hutama et al.

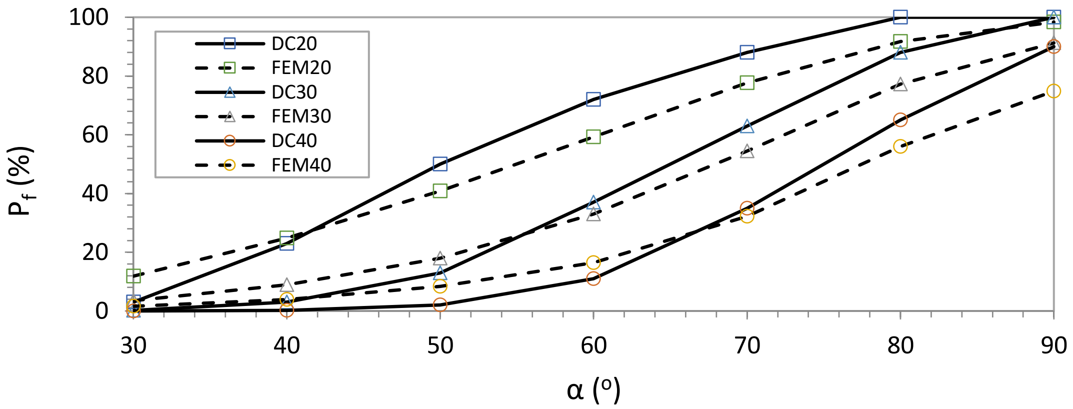

Figure 5. Hutama et al.