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Effect of Area Development on the Stability of Cut Slopes

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Abstract

Many natural slopes were subjected to change in geometry in order to make room for construction of infrastructures. This paper presents stability analysis of a natural slope subjected to cutting to make room for the development of factories in an industrial site. The analysis was performed for the most critical slope section and analysis was made in comparison to the case presented in literature. Data required for slope stability analysis were retrieved from relevant project report. The result shows that the stability of the slope decreases due to slope excavation and stabilization should be done in order to limit further reduction of shear strength due to yielding of soil mass. Analysis using circular failure surface such as Simplified Bishop is simple and is usually suitable for analysis of existing slope where there is no indication of incipient failure. However, pre-defined failure surface in Morgensten Price method is more useful if failure surface could be predicted based on slope assessment or when rectification work has been applied.

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Keywords: slope geometry, area development,safety factor, yielding; slope stabilization.

1. Introduction

Slope failure is the most frequent disaster faced by many countries, especially when slopes are cut extensively for area development. Most failures of man-made slope are caused by design errors which include geometric design i.e. slope inclination, slope height and inability to estimate the load and the soil resistance. During excavation work of natural slopes, the slope face may deform and results in the reduction of shear strength, and this can lead to slope failure [1]. The movement may continue if no remedial work was implemented on the cut slope.

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A case of long term slope failure was presented in [2] where a natural slope of 1V:2½ H (case 1) was excavated to make room for a development of a railway construction. The resulting slope was 1V: 2H (case 2). Thirty years after the construction of the railway, the slope was trimmed back to a slope of 1V:1½ H for further area development (case 3). The slope failed five years after the latter modification. This case study indicated that after the second cutting without any remediation work, the shear strength of the soil decreases gradually due to creep.

This paper presents stability analysis performed for similar case as presented in [2] book except that a rectification work was implemented on the slope. A natural slope was subjected to cutting in order to make room for the development of factories in an industrial site in Johor Bahru [3]. The most critical section was selected for this study. The stability analysis was performed on original slope and two possible angle of excavation. Stabilization method was selected based on the condition of the slope as to not induce long term movement of the slope face. Data required for these analyses were retrieved from relevant project report.

2. Limit Equlibrium Method (LEM)

In general, cut slope is designed based on Limit Equilibrium Method (LEM) in which the stability is calculated based on a set of data obtained from laboratory test. The method treats the soil as rigid plastic material in which the soil is assumed not to deform as long as the driving stress is less than the soil strength. The method does not take into account the change in soil strength when the soil deform during excavation or long time after it is formed. In reality, the variation of soil strength is the dominant factor in the slope stability analysis [4]. The biggest problem involved in the use of limit equilibrium method is that failure occurs at a prescribed failure surface. In limit equilibrium method, the stability of slopes in soil is defined as the ratio between the available shearing resistance along a potential failure surface and the shear stress on the surface. Thus, a factor of safety can be defined as a ratio of available shear resistance (σ) to shear stress (τ) on the failure plane:

$$FS = \frac{\sigma}{\tau} \quad (1)$$

When failure occurs, the sum of all the shear stresses along the slip surface exactly equals the available strength of the soil, and the factor of safety is equal to one. [5] mentioned that two conditions which bring the soil instability is through a decrease in the shear strength of the soil (internal factors e.g. ground water level) and an increase in the shear stress required for equilibrium (external factors e.g. applied load). Hence, slide is a result of failure of soil mass located beneath a slope and resisting shear strengths and mobilized shear forces along the slip surface control it.

The minimum factor of safety required for a man made slope differs from that required for natural ones due to the uncertainty related to the material properties and construction process. A global factor of safety for natural slope between 1.25 and 1.40 is considered [6], but for the design purpose, higher safety factor of 1.5 to 2.0 is required [7]. [8] which was adopted in BS standard (2009) suggested the use of partial safety factors in which shear strength parameters should be divided by 1.6 and 1.25 respectively. A factor of unity is appropriate for the self-weight of the soil and for pore water pressures but variable loads on the soil surface adjacent to the slope should be multiplied by a factor of 1.30. This shows that the variation in the shear strength of soil should be considered in the analysis.

3. Methodology

The study reanalyzes the case of effect of area development slope stability as presented in literature. The first is the study on case presented in [2] whereby the slope was not stabilized after excavation and failed after a few years of development. The second case was presented in [3] whereby the slope was stabilized to prevent further movement of slope face. Analysis was performed using Limit Equilibrium program SLOPE/W [9]. Analysis and discussion of the first case was used in the selection of slope stabilization to be used for Case 2.

4. Effect of changing geometry, creep and tension crack

The study started with discussion on a case presented in [2] where a natural slope of 1V:$2^{1/2}$ H was excavated to make room for a development of a railway construction. The resulting slope was 1V:2H. Thirty years after the construction of the railway, the slope was trimmed back to a slope of 1V:1$^{1/2}$ H for further area development. The slope failed five years after the latter modification. The soil consisted of a firm, homogeneous, intact lightly over consolidated clay with some thin layers of silts and sand. The properties of the soil, obtained from a series of consolidated undrained triaxial test with pore water pressure measurement, are c'= (10 ± 2.2) kN/m^2 and ϕ'= 27° ± 2 (tan ϕ'= 0.512 ± 0.038). The lowest value of internal friction angle was 22°. Back-analysis, performed after failure using Bishop routine method and average shear strength parameters, yield in an average FS of 1.05 considering actual failure circle or 1.01 considering critical failure circle (Figure 1).

Further analysis was performed in this study to evaluate the effect of each activities and conditions to the stability of the slope. Limit equilibrium analysis (LEA) was performed by SLOPE/W for which Simplified Bishop and Morgensten & Price's (M-P) method were utilized. The simplified Bishop method was selected to show that the critical failure surface generated by computer program is not always represent actual failure plane. The M-P method was selected due to its ability to satisfy all equilibrium conditions and the possibility of assigning predefined failure surface. [5] have shown that the method give accurate results for any conditions except when numerical problems arise.

The highest shear strength parameters (c′ = 12.2 kN/m^2 , ϕ'= 29°) were used for calculation of slope stability in the original condition, after the first cutting and after the second cutting. Lowest shear strength properties (c′ = 7.8 kN/m^2 , ϕ'= 22°) were used for condition at failure i.e. five years after the second excavation. In the simplified Bischop method, the program defines the most critical circular failure surface for each case except for the case where tension crack has developed at the crest. For M-P method, all cases were analyzed for pre-defined failure surface as indicated in [2] (Fig. 1). Analyses show that both Simplified Bishop and M-P methods show a clear decrease FOS as the results of the in change in slope inclination. Both methods show a reduction of factor of safety from 1.95 (original condition) to 1.67 (after the first cutting), and 1.39 (after the second cutting). In fact, the slope can be considered as stable after the second cutting (FS > 1.3) however, tension cracks has developed at the crest and the soil properties may have changed due to continued movement of the slope face. By considering the residual strength and the presence of tension crack, Simplified Bishop Method gives FS of 0.99 while M-P method gives 1.02. These values are almost similar to back-calculation by [2] considering actual failure plane (1.05) and considering critical failure plane (1.01) as shown in Figure 1.

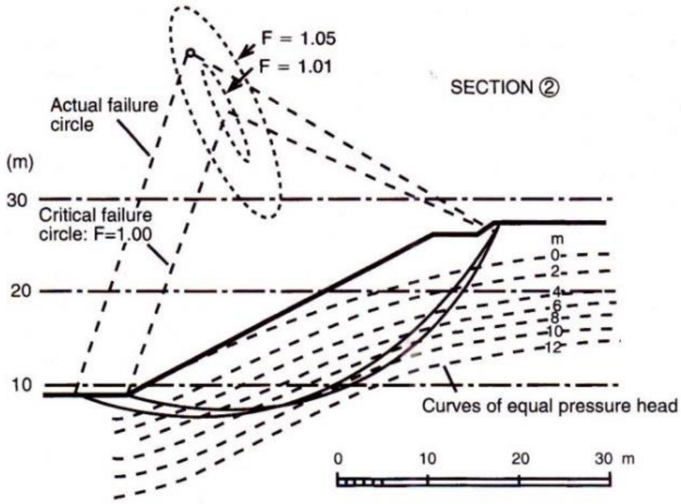
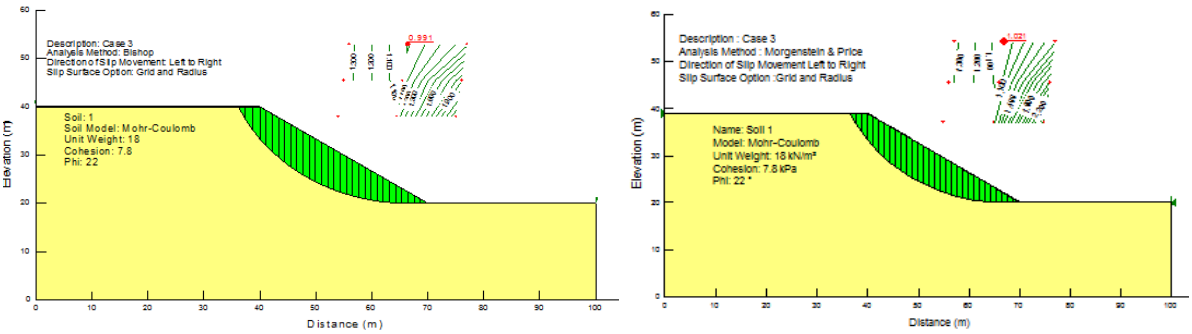


Fig.1. Slip plane generated from back-analysis of slope failure using Bishop routine method [2]

The results presented by this analysis indicated that the stability of a slope is influenced by several factors. First, slope angle (β) have a significant influence on deformation or the total displacements at the slope face, hence on the slope stability. Therefore, the analysis of a cut slope should also consider the deformation occurred at the slope face because if the displacement of soil particle has mobilized large strain in the soil mass, then residual strength parameters may have to be used in the analysis.

Second, the construction consequence induced the mean total stresses decrease due to removal of soil from the excavation as the maximum shear stress increases until it reaches the failure stress. The zone of failure increases in extent as the excavation becomes steeper. The activity will decrease the shear strength of soil to resist from failure in the long term period. As a result there will be a slip and sliding along the toe of the slope, hence the selected stabilization method should protect the toe of the slope from movement.



(a) Simplified Bishop's method (b) Morgensten and Price

Fig. 2. LEM analysis for slip circle at failure condition using SLOPE/W

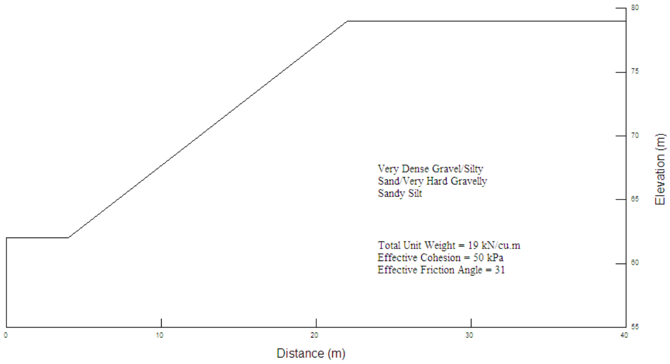
[5] suggested based on their study, that undisturbed peak strength cannot represent the field strength when evaluating the stability of cut slope. The analysis shows that there is a significant decrease in factor of safety on Case 4 when residual strength parameters are used in the analysis. This indicates that the displacement or strain increases at constant stresses after reaching the yield point and give a factor of safety close to one. This is the case of slope, especially in clay soil, subjected to movement and fail after a long period of time where the residual strength remains to resists the sliding. Furthermore, the presence of tension crack is usually specified as the starting point of failure plane which progressing to the toe. Thus protecting the crest from development of tension crack is important when considering stabilization of excavated slope.

5. Effect of changing geometry and rectification work

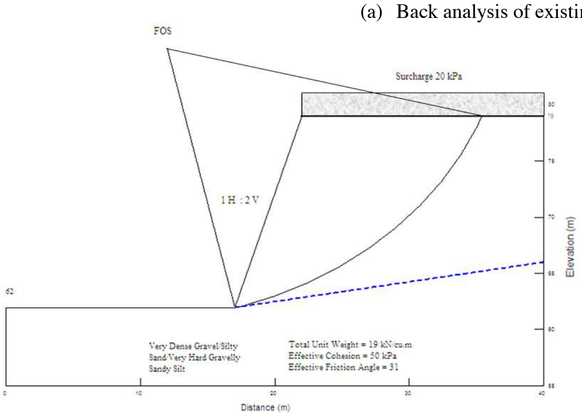
The second case was presented in [3] where a slope was subjected to cutting to make room for construction of factories in an industrial area in Johor Bahru. A critical section was selected and a cross-section of the slope before and after development was defined as shown in Figure 2. The original slope was about 18 m to 20 m high formed an angle of about 43° to the horizontal. The slope was formed by very dense silty sand and or very hard sandy silt materials. Laboratory tests indicated that the soil has a unit weight of 19 kN/m^2 and effective shear strength parameters of c'= 50 kN/m^2 and ϕ'= 31°. These hard materials do not encourage vegetation to grow, thus slope remained barren with little vegetation. Ground water table was very deep.

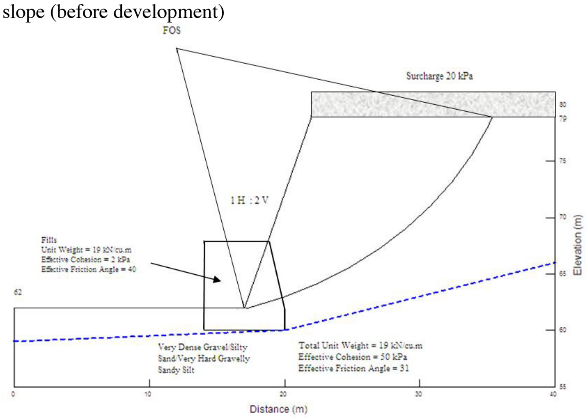
LEM analysis by Simplified Bishop method was performed in SLOPE/W to analyze the stability of the original slope. The result indicated that the original slope is stable with FS of 2.08. Preliminary analysis also indicated that the slope can stand with factor of safety of 1.51 if cut to an angle of 55°. However, the development plan requires that excavation to be made that to a slope angle of 70° at some parts of the slope. Stability analysis of the cut slope (to 70° angle) resulted in the factor of safety of 1.28. Note that the stability analysis of the new slope configurations considered a surcharge load of 20 kPa to represent some utility lines and construction at the crest

From the foregoing analysis, some rectification work was required to increase the stability of the slope and to restrict the movement of slope face after excavation. In considering the method of slope stabilization, several considerations must be made. Firstly, the slope is steep enough (> 63°) to induce a slip and sliding along the toe of the slope [10]. Thus, the selected stabilization method in this project should include the stability enhancement at the new toe by the construction of retaining wall. The excavation activity will decrease the shear strength of soil to resist from failure in the long term period, hence the selected stabilization method should protect the toe as well as the face of the slope from movement. Another concern, some utility lines were presence some 2 m away from the crest of the slope, thus cutting at the toe is expected not to results in disturbance to the crest. On the other hand, the crest should be treated so that the development of tension crack could be avoided. Figure 3 shows the rectification work implemented on the slope which consists of retaining structure (Betoflor) at the toe of the slope and shotcrete application (guniting) at the slope face. Betoflor is a patented dry build interlocking system of concrete block walling which can be constructed up to 2m high while guniting is a dry mixture of cement, sand or crushed slag, and water, sprayed over the slope face as a lightweight concrete. Treatment was also made at the crest to mitigate the development of tension crack.



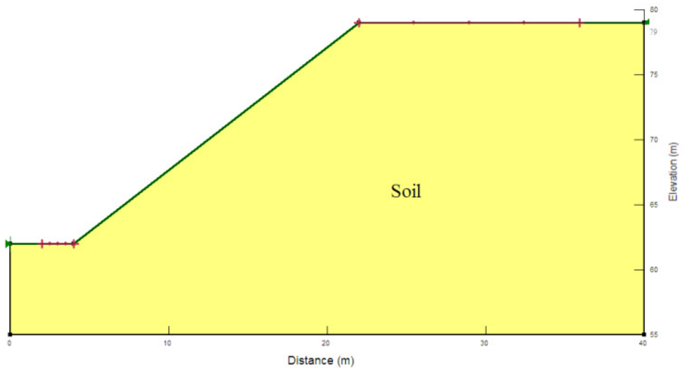
(a) Back analysis of existing slope (before development)



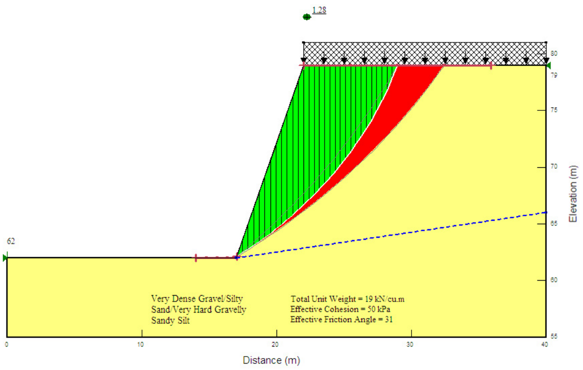


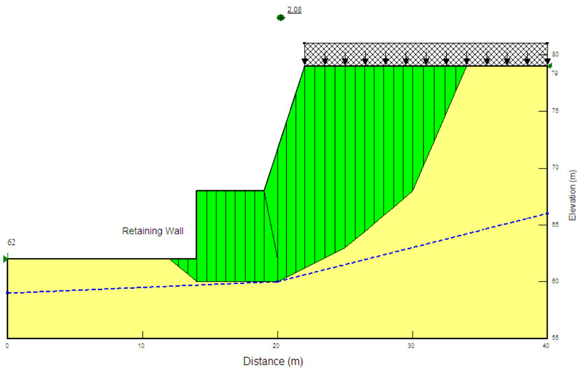
(b) Cut Slope (after development) (c) Cut slope with remedial work

Fig.3. Geometry of the slope before and after excavation as well as after stabilization



(a) Before analysis





(b) Existing cut slope with 70° to the horizontal

(c) Existing cut slope with 70° to the horizontal and six meters of retaining structure

Fig. 4. Limit equilibrium analysis by SLOPE/W

Stability analysis of stabilized slope was performed by M-P method using pre-defined failure surface considering the dimensions of retaining wall and surcharge weight at the crest. The results showed that the implementation of the selected rectification work increases the factor of safety to 2.08 for the slope angle 70^o and 2.3 for the slope angle 55^o.

Fig. 5. Slope face after stabilization [3]

6. Conclusions

This paper presents the effect of cutting on natural slope on its stability both due to the change in geometry (slope angle) as well as the change in shear strength parameters related to the strain induced by the movement of slope face. Selection of shear strength parameters in limit equilibrium method is important to predict the stability of a cut slope especially when the calculated safety factor is relatively low. Installation of instrumentation is useful for monitoring the movement of a cut slope because the failure may occur at any time after construction, in the first case is five year after the last modification.

Analysis using circular failure surface such as Simplified Bishop is simple and is usually suitable for analysis of existing slope where there is no indication of incipient failure. However, when there are some indications of developing tension crack or other movement, pre-defined failure surface considering this information could be useful for stability analysis. It is important that information obtained during site investigation should be considered in the analysis of cut slope.

Requirement and selection of slope stabilization method should consider the problems that may occur due to the excavation activities. In this study combination of retaining wall at the toe and shotcrete application at the slope face is considered suitable to limit the movement at slope face. The presence of retaining wall increases the factor of safety from 1.51 to 2.30 for slope angle 55^o and from 1.28 to 2.08 for slope angle 70^o. The placement of retaining wall at the toe strengthens the slope by changing the failure plane

References

[1] Dunnicliff, J. Geotechnical Instrumentation for Monitoring Field Performance. New York: John Wiley & Sons. 1988.

[2] Craig, R.F. *Craig's Soil Mechanic*. 7th ed. Chap. 9: Stability of Slope and Chap. 11: Case Studies. Spon Press, Taylor & Francis. 2004.

[3] Berhanuddin, M.S. Effect of Change of Geometry on Slope Stability. Final Year Project Report. Universiti Teknologi Malaysia. 2011.

[4] Jitno, H and Gofar, N. Stability and Deformation Analysis of Failed Embankments Founded on Soft Clays. Malaysian Journal of Civil Engineering. 2005. 17(1): 1-12.

[5] Duncan, J.M. and Wright, S.G. Soil Strength and Slope Stability. Canada: John Wiley & Sons. 2005.

[6] Neoh CA. Slope Stabilization and Protection for Residential Development Profile. Conference on Landslide Risk Mitigation and Hillslope Re-engineering Planning. PWTC Kuala Lumpur. 2009.

[7] Chen, C.S. & Lim, C.S. Some Case Histories of Slope Remedial Works. SSP Geotechnics Sdn. Bhd., Malaysia. Geotechnical Engineering for Disaster Prevention and Rehabilitation. Semarang 2005.

[8] Eurocode 7: Geotechnical Design – Part 1: General Rules ENV 1997-1, 1997.

[9] Geo-Slope International Ltd. SLOPE/W User's guide for Slope Stability Analysis. Version 5, Calgary, Alta., Canada. 2007.

[10] Gofar, N. and K.A. Kassim. Introduction to Geotechnical Engineering-Part I Chapter 5: Slope Stability. Pearson Education, revised edition. 2007.