International Journal of Scientific & Engineering Research, Volume 6, Issue 10, October-2015 96
ISSN 2229-5518

The effect of cohesion and level of groundwater on the slope instability using finite element method

Ashkan GHolipoor Noroozi, Alborz Hajiannia

Abstract— Slope stability analysis is one of the most important topics in geotechnical engineering. Slope stability can be analyzed using one or more methods. Analytical and numerical methods are available but numerical methods are quickly, reliable, accurately and so we able to perform parametric and comprehensive study of slope stability with complex boundary conditions. In this research numerical analysis by finite element software PLAXIS version 8.5 showed that the slope angle and rainfall has the most influence in the safety factor analysis. Also for layered slope variable cohesion or friction angle for each layer has been investigated. The analysis has been done using Mohr-Coulomb constitutive model. The slope stability analyses are performed to assess the safe and economic design of human-made or natural slopes (e.g. embankments, road cuts, open-pit mining, excavations, and landfills). In the assessment of slopes, engineers primarily use factor of safety values to determine how close or far slopes are from failure. When this ratio is greater than 1, resistive shear strength is greater than driving shear stress and the slope is considered stable. When this ratio is close to 1, shear strength is nearly equal to shear stress and the slope is close to failure, if FS is less than 1 the slope should have already failed. Thus, for this research the critical safety factor is considered 1. This means that in parametric study, change in the value of soil cohesion continues until the FS is equal to 1.

keywords— Slope stability, finite element method, safety factor, rainfall.

1 INTRODUCTION

The slope stability analyses are performed to assess the safe and economic design of human-made or natural slopes (e.g. embankments, road cuts, open-pit mining, excavations, and landfills). In the assessment of slopes, engineers primarily use factor of safety values to determine how close or far slopes are from failure. When this ratio is greater than 1, resistive shear strength is greater than driving shear stress and the slope is considered stable. When this ratio is close to 1, shear strength is nearly equal to shear stress and the slope is close to failure, if FS is less than 1 the slope should have already failed. Limit equilibrium types of analysis for assessing the stability of earth slopes have been in use in geotechnical engineering for many decades. The software code, PLAXIS allows geotechnical engineers to carry out finite element slope stability analysis of existing natural slopes, unreinforced man-made slopes, or slopes with soil reinforcement.

Petterson In 1955 presented the stability analysis of the Stigberg Quay in Gothenberg, Sweden where the slip surface was taken to be circular and the sliding mass was divided into slices. Fellenius introduced the Ordinary or Swedish method of slices. Janbu in 1954 and Bishop in 1955 developed advances in the method.

Several attempts have also been made by various researchers for probabilistic slope stability analysis by both finite element as well as linear equilibrium methods. The earliest papers appeared in the early 1970s [Alonso; 1976, Tang et al; 1976, Vanmarcke; 1977] and have continued steadily [Christian; 1996, Duncan ; 2000, Hassan an Wolff; 2000] More recently some workers have produced a detailed review of the literature on this topic, and also noted that the geotechnical engineering was slow to adopt probabilistic approaches to geotechnical designing, especially in traditional problems such as slopes and foundations [El-Ramly et al; 2002, Griffiths and Fenton; 2004].

The soil mass above a trial failure surface is divided into slices by vertical planes. Each slice is taken as having a straight line base. The Factor of Safety of each slice is assumed to be the same, implying mutual support between the slices, i.e. there must be forces acting between the slices. Figure 1 shows a typical sliding mass discredited into slices and the possible forces on the slice.

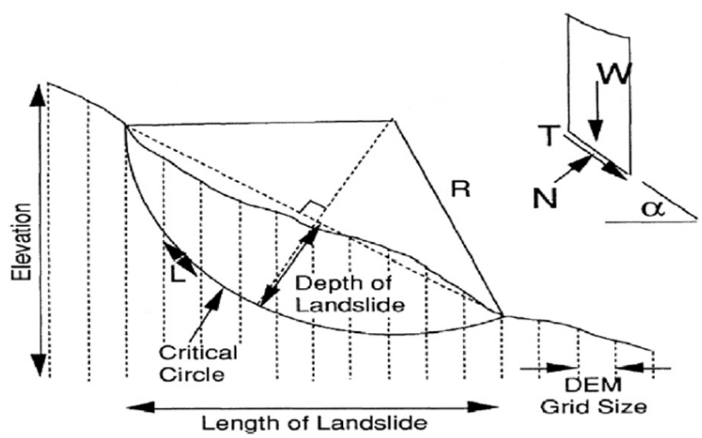


Figure 1 - Slice discretization and slice forces in a sliding mass [Rabie; 2014]

2 DEFINITION OF THE PROBLEM

Consider a two dimensional soil slope with two different horizontal layers as shown in Figure 2. Each layer is defined by means of its thickness Hi, cohesion ci, angle of internal friction Φi and unit weight ci; where i=1 and 2. The sloping surface is inclined at an angle β with horizontal. It is to determine the critical height (Hc) of the slope so that the sloping mass is on

• *Co-Author name is Ashkan GHolipoor Noroozi, MSc, Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran. e-mail: ashkan.gholipour@yahoo.com.*
• *Alborz Hajiannia is Assistant Professor, Department of Civil Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.*

ISSN 2229-5518

the verge of collapse (shear failure).

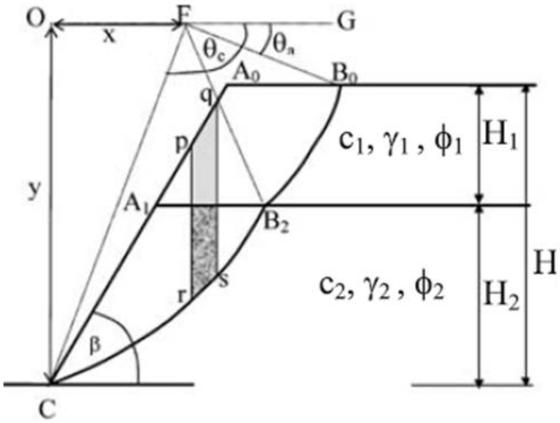


Figure 2- two dimensional soil slope with two different horizontal layers[Kumar; 2006]

The expression for computing the rate of dissipation of total internal energy along the periphery (L) of the rupture surface in the presence of pore water is provided below:

$$\dot{E}_{\text{Total}} = \int_{L} V(c\cos\phi - u\sin\phi)dl \qquad (1)$$

In the above expression, *V* is the velocity jump at any point on the rupture surface, *c* and *Φ* are the values of soil cohesion and angle of internal friction relevant at the same point, *u* is magnitude of pore water pressure and *dl* is the infinitesimal length of the element along the rupture surface. If value of the pore water coefficient (r_u) is defined at a point then the magnitude of the pore water pressure can be computed with the help of the following expression:

$$u = r_u \frac{\sum \Delta W}{dl} \qquad (2)$$

$DW = DW_1 + DW_2$ for Figure 3; DW_1 and DW_2 are the respective total weights (per unit length since the problem is two dimensional) of the elements abqp and abrs, respectively.

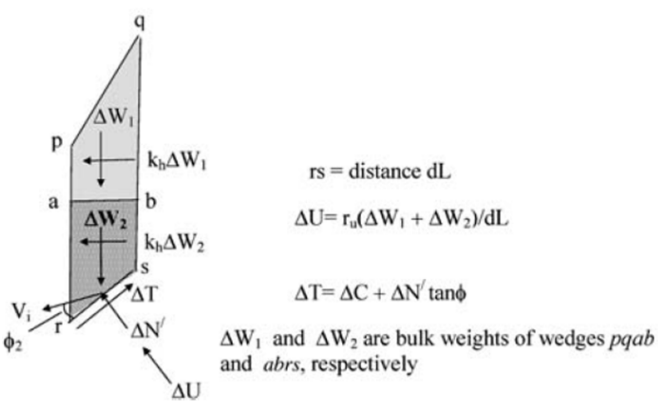


Figure3- the respective total weights of slope [Kumar; 2006]

Therefore, on the basis of Equations (1) and (2), for a chosen rupture mechanism, the rate of total work done by the body forces (including those by the surface traction if any) and the rate of dissipation of total internal energy can be determined. For a slope to be in critical state of failure, the condition ($E_{Total}= w_{Total}$) needs to be satisfied. For the chosen values of Θ_a, Θ_c (or x and y) and β, this condition can only be satisfied for a particular value of *H*. This value of *H* can be numerically determined by trial and error so that the value of ($E_{Total}- W_{Total}$) becomes almost equal to zero. After determining the magnitude of H for which the condition ($E_{Total}= W_{Total}$) is satisfied, the values of the parameters Θa and Θc can then be independently varied so as to determine the minimum value of *H* (*H* = *Hcr*) for a given slope inclination β. On this basis, using the upper bound limit analysis, the value of Hcr can, therefore, be computed for a given geometry of the slope.

3 NUMERICAL MODELING

The finite element program Plaxis v8 was used to develop a numerical model of a reference problem to study on slope. With PLAXIS, both simple and complex problems can be analyzed for a variety of slip surface shapes, pore-water pressure conditions, soil properties, analysis methods and loading conditions. Using finite element, PLAXIS can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure conditions using a large selection of soil models. This program has been used to analyse several slope stability problems including the influence of layering and free surface on slope and dam stability (Griffiths and Lane, 1999). The program computes the factor of safety (FOS) of the slope by using the nonconvergence solution, coupled with a sudden increase in nodal displacements as an indication of failure conditions (Griffiths and Lane, 1999). Properties of different materials are shown in Table 1. A plane strain analysis was carried out using Mohr-Coulomb criterion. A drained behavior was assumed for all materials.

Table 1- Properties of soil

	γ_{sat} (KN/m^3)	γ_{unsat} (KN/m^3)	υ	E (KN/m^2)	C (KN/m^2)	Φ (^{0})
Layer1	22	20.2	0.2	4000	11	25
Layer2	21	19	0.25	5000	12	30

3- 1 PARAMETRIC STUDY FOR TWO LAYERS OF SOIL:

After the modeling section with two layers of soil, the confidence in the dry and saturation state are as follows:

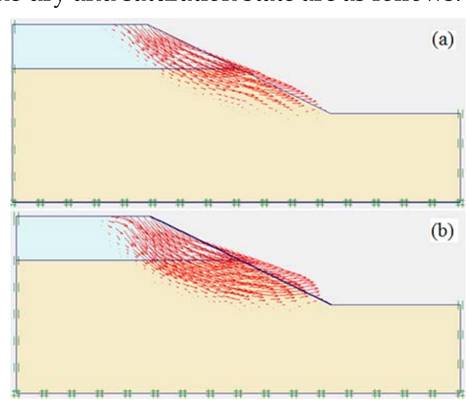


Figure4 – total displacement in (a) dry state; FS=1.626, (b) saturation state; FS=0.8644

So as you can see, the presence of water and rainfall is one of

ISSN 2229-5518

the main reasons for the instability of the slope. At this stage, with change the level of underground water, the study will be discussed.

3- 1-1 CHANGE IN UNDERGROUND WATER LEVEL:

In this section, by reducing groundwater levels and the calculation of software will get the following results:

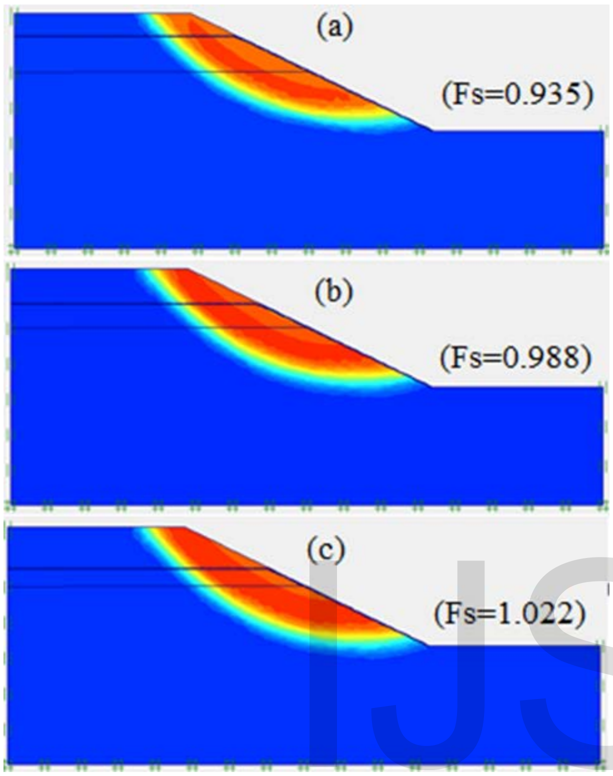


Figure 5- Total displacement in the desired section for the level of underground water to height of 4,6 and 7 meters.

According to the above figures and other results, the following will conclude. As the chart suggests, the critical height of ground water level is 7 meters below ground level. That, the reduction of the height causing the safety factor will be reduced to below 1.

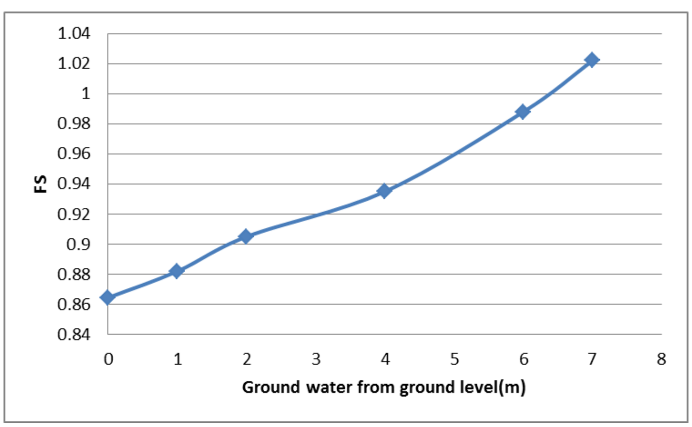


Figure 6 - slope safety factor variations against changing the Ground water from ground level

3- 1-2 CHANGE IN COHESION OF SOIL LAYERS:

In this section, initially we changed the cohesion of top layer. And safety factor in the results obtained.

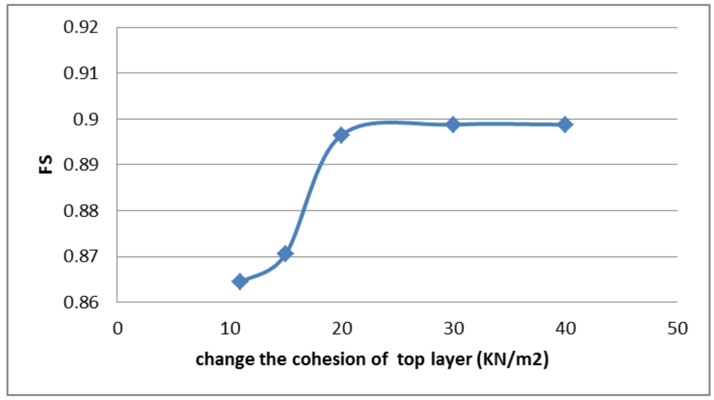


Figure 7 - slope safety factor variations against changing the cohesion of upper layer

As is known from the above; in saturated state, when the bottom layer cohesion is 12 Kn / m^2 with changing the cohesion of the top layer, the amount of safety factor arrives to 0.898 and more changes will not occur. The bottom layer cohesion to change and safety factor in the results obtained. Then the bottom layer cohesion changed and the results of safety factor obtained according to Figure 8.

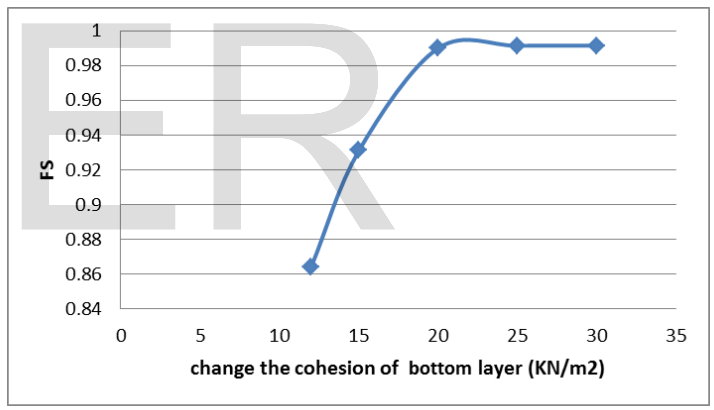
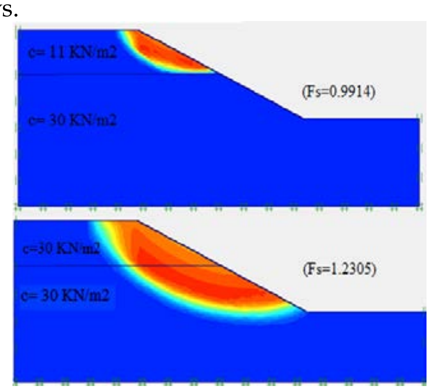


Figure 8 - slope safety factor variations against changing the cohesion of bottom layer

Then, with fixed bottom layer cohesion to 30 Kn /m^2, the cohesion variations of the top layer is done and the results will be as follows.



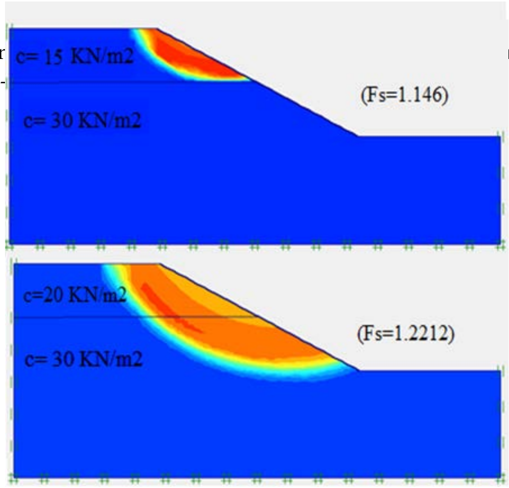


Figure 9 - Total displacement in the desired section for various cohesion

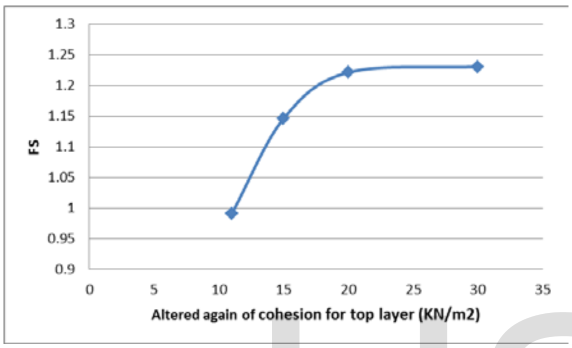


Figure 10 - slope safety factor variations against Altered again of cohesion for top layer

4 Conclusion

Significant works by numerous authors have been done with regards to stability of slopes. Various methodologies used by them have been assimilated in the comprehensive review and discussed briefly with regards to the time span. A case study of a slope from Kiasar, Iran has been studied using finite element method. Therefore, On the basis of literature survey carried out following concluding remarks are made:

1- the presence of water and rainfall is one of the main reasons for the instability of the slope
2- the critical height of ground water level is 7 meters below ground level. That, the reduction of the height causing the safety factor will be reduced to below 1.
3- in saturated state, when the bottom layer cohesion is 12 Kn / m^2 with changing the cohesion of the top layer, the amount of safety factor arrives to 0.898 and more changes will not occur.

References

[1] A.W Bishop, "The use of the slip circle for the stability analysis of slopes", Géotechnique, 5(1):7–17, 1955.
[2] Alonso, E.E. "Risk analysis of slopes and its application to slopes in Canadian sensitive clays‖", Geotechnique, 26, pp453-472, 1976.
[3] Christian, J.T. "Reliability methods for stability of existing slopes" (In C.D. Shackelford et al, editor), Uncertainty in the geologic environment: From theory to practice, ASCE , GSP 58, pp409–419, 1996.
[4] Duncan, J. M. "Factors of safety and reliability in geotechnical engineering", J Geotech Geoenv Eng, ASCE, 126(4), pp307–316, 2000.
[5] El-Ramly, H., Morgenstern, N.R., and Cruden, D.M. "Probabilistic slope stability analysis for practice", Can Geotech J, 39, pp665–683, 2002.
[6] Griffiths, D. V., Lane P. A. "Slope Stability analysis by finite elements", Geotechnique 49(3), pp387-403, 1999.
[7] Griffiths, D.V. and Fenton, G.A. "Probabilistic slope stability analysis by finite elements", J Geotech Geoenv Eng, 130(5), pp. 507–518, 2004.
[8] Hassan, A.M., and Wolff, T.F. "Effect of deterministic and probabilistic models on slope reliability index"(In D. V. Griffiths et al, editor), Slope Stability, ASCE,. GSP No. 101, pp194–208, 2000.
[9] K.E. Petterson, "The early history of circular sliding surfaces". Géotechnique, 5: 275–296, 1955.
[10] N. Janbu , "Applications of composite slip surfaces for stability analysis", In Proceedings of the European Conference on the Stability of Earth Slopes, Stockholm, Vol. 3, pp. 39–43, 1954.
[11] Rabie, M. "Comparison study between traditional and finite element methods for slopes under heavy rainfall", Housing and Building National Research Center Journal , 2014, vol.10, No. 2, pp.160–168.
[12] Tang, W.H., Yucemen, M.S., and Ang, A.H.S. "Probability based short-term design of slopes", Cand. Geotech J, 13, pp201–215, 1976.
[13] Vanmarcke, E.H. "Reliability of earth slopes", J Geotech Eng, ASCE, 103(11), pp1247–1265, 1977.
[14] W. Fellenius , "Calculation of the stability of earth dams", In Transactions, 2nd Congress on Large Dams, Washington, Vol. 4, pp. 445, 1936.
[15] Kumar, J, SAMUI, P. "Stability determination for layered soil slopes using the upper bound limit analysis", Geotechnical and Geological Engineering, 2006, vol.24, pp.1803–1819.