International Journal of
Advanced Structures and Geotechnical Engineering
ISSN 2319-5347, Vol. 05, No. 01, January 2016

Probabilistic Slope Stability Analysis of Landslide at Abbottabad Pakistan

KHALID MAHMOOD
Department of Civil Engineering, Sarhad University of Science & Information Technology, Peshawar, Pakistan
Email: engkhan2008@gmail.com

Abstract: A permanent landslide due to seasonal stream and rainfall behind Abbottabad Medical Complex has affected residential structures. In this study original and modified slope geometry are selected for stability analysis using the geotechnical parameters evaluated from field and lab tests. Stability analysis are conducted in limit equilibrium program in coupled with saturated-unsaturated seepage analysis in finite element program. The analysis results show that the probability of failure is reduced for modified slope but may not be acceptable. The study further motivates to find additional parameters to design a safe slope for the target area by performing parametrical and sensitivity analysis study.

Keywords: *Landslide; Probabilistic slope stability; Saturated-unsaturated seepage; Abbottabad Pakistan*

Introduction:

The landslide is very common and recurrent phenomena throughout the mountainous region of Pakistan. It has been estimated that 30% of the world landslides occur in the Himalayas (Himalayan Landslide Society [HiLS]). Landslides cause substantial damage to infrastructure each year in the Abbottabad District. There are many forms of slope failures in Abbottabad such as rock falls, earth flows, toppling, plane failures, rotational slides etc. However, Earth flows and rotational slides are the two most common types of slope failures and are easily predictable by their characteristic in Abbottabad District. These kinds of landslides are common in unconsolidated strata and can be found mostly along streams. The common trigger for landslide in such soil strata is rainfall. A major landslide due to rainfall occurred in December, 2009 at along a seasonal stream behind Abbottabad Medical Complex. The near residential structures were badly affected. According to metrological data for last six decades the average rainfall in Abbottabad is 134 mm in the Month of March. However the month of March, 2014 received approximately 39.3 mm rainfall on five different dates that was more than the average rainfall. This condition resulted in numerous slope failures in the form of mudslides along the stream downward and thus further affected residential structures at target site. Figure. 1 show the landslide area of target site and residential structures effected.

Figure 1 *Landslide area of target site and residential structures effected*

Landslide is a complex phenomenon that take least the factors i.e., geometry of slope, soil strength parameters, groundwater condition, most suitable soil constrictive model and the most appropriate use of right numerical program, and the external destabilizing forces to define the failure plan.

The present research study takes into account soil shear strength parameters, hydraulic parameters and average slope geometry to find the stability of the target site slope in term of geometry.

Landslide at Abbottabad:

The landslide location is at an aerial distance of about 0.8Km from main Karakorum Highway near Officer Colony Abbottabad. The location of landslide on Google Earth is shown in Figure. 2.

***Figure 2** Location of landslide on Google Earth*

Geology of the area:

The Abbottabad Formation is named by Mark and Ali (1961) for a set of predominantly dolomitic rocks with subordinate siliceous and argillaceous rocks from the Sirban Hill, Abbottabad. Ali (1962) and Ali et al., (1964) included similar lithologies exposed in the southern Tanawal region west of Abbottabad into the Abbottabad Formation. The base of Abbottabad Formation at Aluli is arenaceous, comprising (bottom to top) ~80 m thick quartzite, followed by ~40 m thick conglomerate. Rest of the Abbottabad Formation exposed in the Aluli Syncline is predominantly dolomite. The basal dolomite is ~300 m thick that has cherty dolomite at the base and top (~50 m each). Followed by a siltstone (with a minor bed of conglomerate) for a thickness of ~50 m, the cherty dolomite reappears for a thickness of over 200 m. A 50 m dark-grey limestone bed separates these cherty dolomites from the topmost dolomites.

The quaternary deposits are present in Abbottabad Formation in the form of terraces and plains. These deposits consist of clay, gravel and pebbles and are unconformably overlie the Abbottabad Formation.

Geotechnical Parameters:

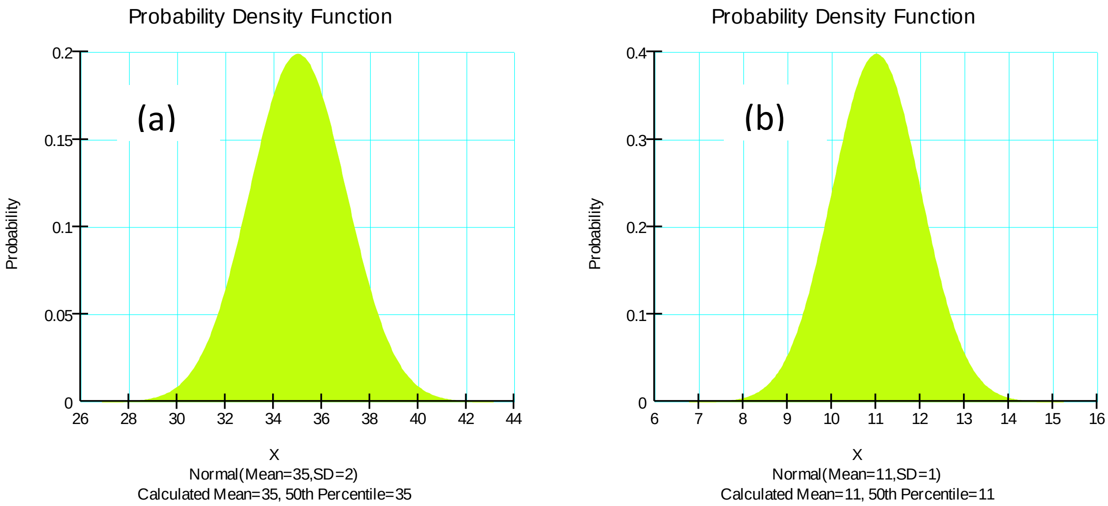
By visual inspection the soil along the slide is homogeneous. The disturbed soil samples were however collected at different location along the section of slope. The grain size distribution, hydrometer analysis and Atterberg limit tests were conducted to find the soil type according to USCS. The shear strength parameters were evaluated on remolded samples of field conditions in direct simple shear apparatus. Because of landslide there is shear failure in soil that may also cause volumetric change and thus unit weight change. The field density were calculated for both failed slope and at another location where the soil was stable using core cutter method. The shear strength parameter i.e., effective cohesion and friction angle were evaluated using direct simple shear test. The hydraulic conductivity was calculated using falling head method. The stability and seepage analysis parameters are shown in Table. 1.

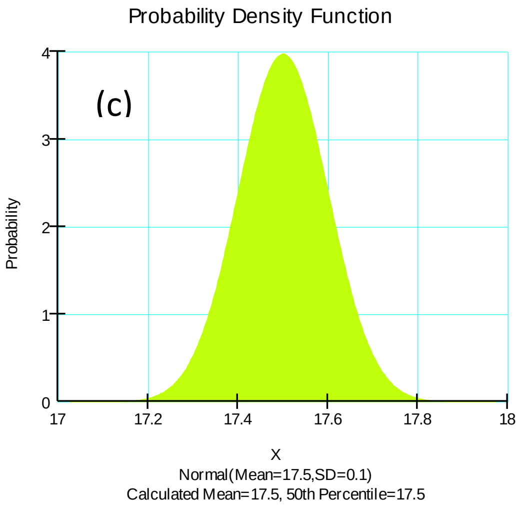
In order to define the stability results in terms of probability of failure, the soil slope is considered statistically homogeneous with a mean value and standard deviation for the shear strength parameters. The previous research such as (Lumb 1970, Grivas, 1981, Kim, 2001, Mahmood et al., 2013) shows that the COV of c' is greater than φ'. Kim (2001) reported that the COVs of c' ranges from 0.18 to 0.63 and that of φ' is in the range of 0.037 to 0.29. This study assumes the COV for c' and φ' as 0.2 and 0.1 respectively. Furthermore the COV of unit weight is assumed as 0.01.

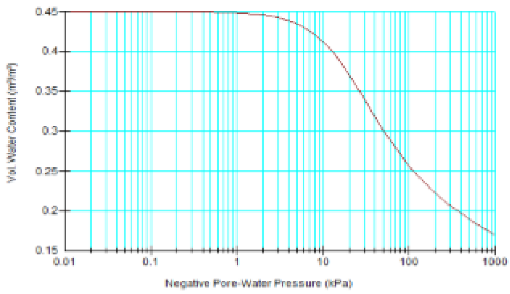
Table. 1 the mean and standard deviation of parameters needed for stability and seepage analysis. Figure. 3 shows the probability density functions used in the stability analysis.

Table. 1 Stability and seepage analysis parameters

Stability/Seepage Parameters	Mean Value	Standard Deviation
Effective unit weight, $\gamma'(kN.m^{-3})$	17.5	0.1
Mean effective cohesion, $c'\ (kPa)$	35	2
Mean effective friction angle, $\varphi'(°)$	11	1
Saturated hydraulic conductivity $k_s(m.s^{-1})$	1×10^{-8}	Constant







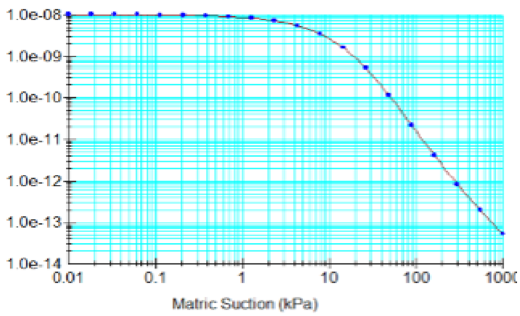


Figure 3 *Probability density function (a) cohesion; (b) friction angle; (c) unit weight*

Figure 4 *(a) SWCC and hydraulic conductivity curve for seepage analysis*

In saturated zone the coefficient of permeability is equal to the saturated hydraulic conductivity of soil. In unsaturated soil the hydraulic conductivity is a function of degree of saturation. This function is most often established from soil water characteristic curve (SWCC). The SWCC and hydraulic conductivity curves used in this study are given in Fig. 4a and 4b.

Example Problem:

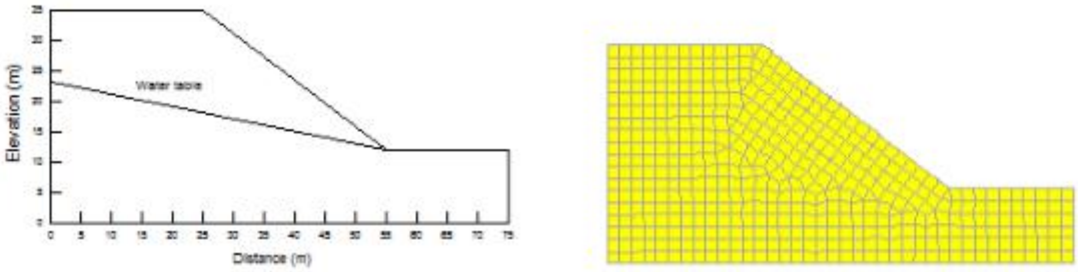
Geometry and Finite Element Model

The steady state seepage and stability analyses are carried out first on the existing slope geometry and groundwater condition. The initial condition is established through steady state seepage analyses in Finite Element Program Seep/W. The Mohr Coulomb failure criterion (Eq. 1) is used to evaluate the factor of safety of slope in limit equilibrium program Slope/W.

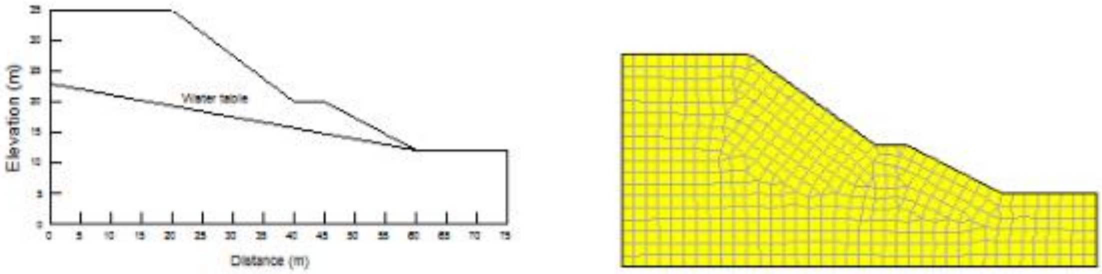
$$\tau = c' + (\sigma_n - u_a) tan\varphi' \qquad (1)$$

where c' and φ' are the effective cohesion and friction angle respectively, $(\sigma_n - u_w)$ is the effective stress

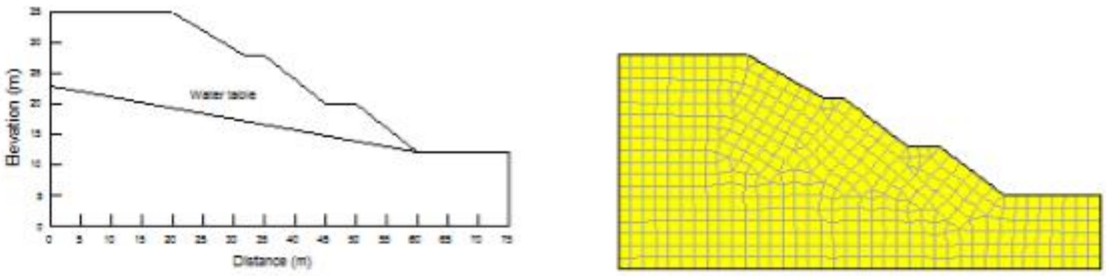
The finite element seepage model shown in Fig. 5 consists of 521 nodes and 475 quads and triangular elements for original slope (Fig. 5a).



(a)



(b)

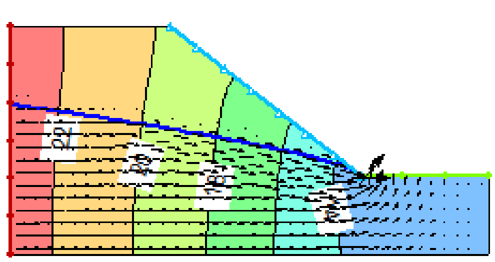


(c)

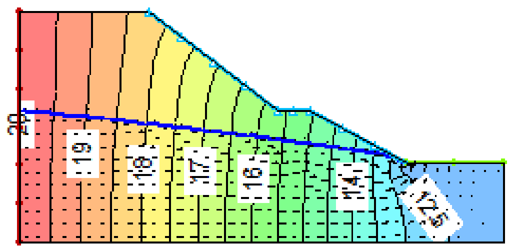
***Figure** 5 **(a)** Geometry and **(b)** Finite element model of original slope used in numerical analysis*

Results and Discussion:

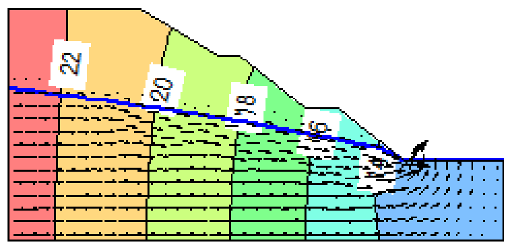
The steady state seepage analysis under the specified hydraulic head conditions is carried out. The steady-state condition is based on the assumption that evapotranspiration from the ground surface is negligible. Figure. 6 shows the equipotential and flow vectors of ground water



(a)



(b)



(c)

***Figure. 6** Equipotential and flow lines (a) orignal slope; (b) modified slope 1 and (c) modified slope 2*

Figure. 6 shows that groundwater seeps into the toe of slope. Furthermore it also shows that the velocity vector is almost zero above the water table. This is because the hydraulic conductivity drops in the unsaturated zone. The saturated-unsaturated seepage analysis are further used in stability analysis.

The factor of safety of slope is evaluated using the Morgenstern–Price method with the same grid and radius for the critical slip surface. The probability of failure is evaluated using 2000 Monte Carlo simulations. The probability density function of factor of safety is shown in Fig.6 for original slope. In the limit equilibrium program the reliability index is evaluated from Fig. 6 as

$$\beta = \frac{(\mu_F - 1)}{\sigma_F} \qquad (2)$$

Where β is the reliability index and u_F is the mean factor of safety with standard deviation σ_F of the probability density function.

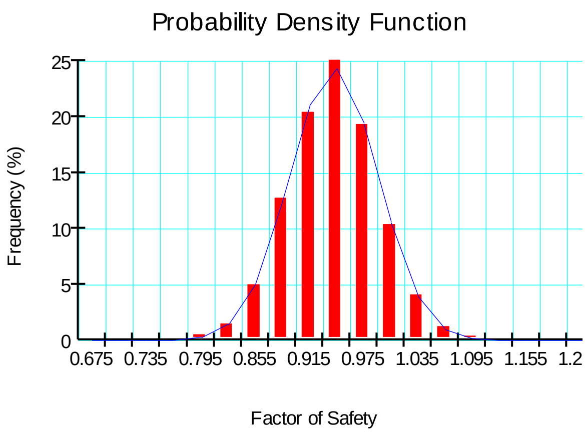


Figure. 7 *Probability density function of factor of safety for orignal slope*

The soil properties of the entire soil layer are only sampled once for each Monte Carlo simulation. The probability distribution function of the 2000 Monte Carlo factors of safety is shown in Fig. 8. The red line represents the probability of failure that shows a value of 90% for original slope (Fig. 8a). In case of modified slope (Fig. 8b and 8c) the factor of safety is above 1 and thus the probability of failure is decreased. In these cases however the depth of failure plan increases, furthermore, a FOS value just above unity may not be acceptable for most of the soil slope in geotechnical engineering and also for the present case study.

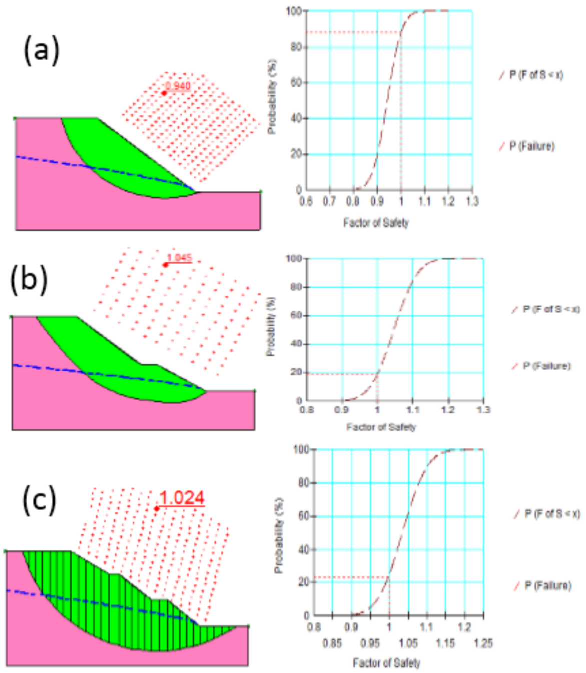


Figure. 8 *Factor of safety and probability of failure (a) orignal slope; (b) modified slope 1; (2) modified slope 2*

The present study shows that simple modification of slope geometry increases the factor of safety of slope, however there is still probability of failure. To better understand the failure mechanism and safely design the slope it is recommended to perform further parametrical and sensitivity analysis study.

Conclusions:

The numerical analyses were conducted to evaluate the factor of safety and probability of failure for a permanent landslide due to seasonal stream and rainfall behind Abbottabad Medical Complex. The analysis results showed that for the given slope parameters the original slope has a factor of safety less than unity and probability of failure 90%. The analysis results further show that the factor of safety for modified stepped slope increases above unity however there is still probability of failure. The study recommends further parametrical and sensitivity analysis study.

Acknowlegement:

This research work was supported by Sarhad University of Science and Information Technology (SUIT), Peshawar, Pakistan.

References:

[1] Ali, C.M., 1962. The Stratigraphy of South Western Tanawal Area, Hazara, West Pakistan. Geological Bulletin Punjab University, 2, 31-38.

[2] Ali, S.T., Calkins, J.A., Offield, T.W., 1964. Mineral Deposits of The Hazara District, West Pakistan. Geological Survey of Pakistan, Record, 13, 1, 38.

[3] Grivas DA (1981) How reliable are the present slope failure prediction method? Proceeding of the 10th International Conference of Soil Mechanics and Foundation Engineering, Stockholm, Sweden, 3: 427–430.

[4] Himalayan Landslide Society [HilS]; http://hils.org.np/hils/index.php/organization/background

[5] Kim JM (2001) Probabilistic approach to evaluation of earthquake induced permanent deformation of slopes. University of California Berkeley USA. Ph.D. thesis.

[6] Himalayan Landslide Society [HiLS], http://hils.org.np/hils/index.php/organization/background

[7] Lumb P (1970) Safety factors and the probability distribution of soil strength. Can Geotech J 7:225–242.

[8] Mahmood K, Ryu JH, JM Kim (2013) Effect of anisotropic conductivity on suction and reliability index of unsaturated slope exposed to uniform antecedent rainfall. Landslides 10: 15-22.

[9] Mark, P., Ali, C.M., 1961. The geology of the Abbottabad area with special reference to the Infra-Trias. Geological Bulletin of Punjab University, 2, 47-56.