International Journal of
Advanced Structures and Geotechnical Engineering
ISSN 2319-5347, Vol. 05, No. 02, April 2016

Response of Rajshahi city protection embankment, Bangladesh due to the variation of water-level by FEM

MD. MAHMUD SAZZAD, FAYSAL IBNA RAHMAN, MD. SAMDANI AZAD
Department of Civil Engineering, Rajshahi University of Engineering & Technology, Bangladesh
Email: mmsruet@gmail.com, ovi_faysal@yahoo.com, samdani.civil.ruet@gmail.com

Abstract: Stability of waterfront structures such as embankments, dams and natural riverside slopes are often hampered due to the increase in water level in the river or reservoir. The aim of this paper is to evaluate the response of the Rajshahi city protection embankment due to the increase in water level during flood on the stability of slope by using finite element method (FEM). Mohr Coulomb model is used to characterize the soil for FEM. For this study, three locations are selected from Rajshahi city protection embankment, soils are collected from these locations and the soil properties are determined. The numerical models are prepared following the in-situ dimensions of slopes. The geometric models (i.e. the cross-section of the selected locations) are incorporated in the GEO5. The material properties are assigned and the numerical analysis has been carried out by using GEO5. The numerical results are computed by increasing the level of water considering three types of phreatic angle. From the study, it is noted that the variation of water level affects the factor of safety of slopes. The factor of safety decreases with the increase of the water level up to a specific height of slope (referred to as critical pool level) and then the factor of safety increases with the increase of the water level. Factor of safety varies from 4.19 to 1.52 for the selected sections of Rajshahi city protection embankment due to the variation of water level and the factor safety of critical pool level indicates the lowest factor of safety which occurs at 35% to 45% of the highest water level.

Keywords: *Embankment, FEM, Factor of safety, Slope stability, Water-level.*

Introduction:

Slope stability is an enormously important consideration in the design and construction of embankments, earth dams, bridge abutments, retaining walls and various other civil engineering structures. In construction areas, the slope may fail due to rainfall, increase in ground water table, seismic load and change in stress condition. Slope stability is the resistance of inclined surface to failure by sliding or collapsing. The main objectives of slope stability analysis include finding endangered areas, analysis of potential failure mechanisms, determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with respect to safety, reliability and economics, designing possible remedial measures, e.g. barriers and stabilization. Due to its engineering significance, it has drawn attentions to many researchers and numerous research works have been reported in the literature [1-4].

Fluctuation of external water level is one of the important factors influencing the waterfront slopes and adjacent land areas. Sources of such fluctuations may include flood water-level variations [5-6], variations caused by wind waves [7], variations caused by other weather-related events such as heavy rainstorms or snow melting, and combinations of various phenomena [8]. Besides, the natural phenomena (including time-dependent soil degradation in terms of e.g. weathering and structural changes), processes caused and driven by human activities are also influencing the stability of waterfront slopes. In slopes stability studies, water is a critical issue that can have devastating effect in the short or long term stability of slopes. Conventionally, the limit equilibrium method (LEM) is used to calculate the factor of safety of slope [9-10]. However, this method needs many pre-assumptions. With the advances of computer technology, the numerical approach such as the finite element method (FEM) has been implemented in the stability analysis of slope [1, 11]. The key advantage of FEM is that it does not require any prior assumption. Moreover, complex shapes of slopes can be easily considered.

Rajshahi city protection embankment is situated on the southern boundary of Rajshahi city of Bangladesh. The 15 km long costly embankment structure on the Padma River serves as an important infrastructural protection to this city. The embankment material consists of sand with silt and clay. Weathering, soil erosion and man-made activities in and around the embankment have been noticeably intense. The heavy monsoonal rainfalls on the upstream catchment sometimes increase the river water level above the danger level. Few research works have already been carried out considering several factors on the stability of this embankment. For example, a research was carried out by Monir and Khan [12] about the potential seepage of Rajshahi city protection embankment. However, there is no study reported in the literature that considered the variation of water level to evaluate the factor of safety of the Rajshahi city protection embankment using FEM even though the existing embankment is subjected to soil erosion and different man-made activities and the stability of the slope is questionable, in particular, due to the variation of water level during rainy season.

In this paper, three slope locations out of many worst locations from Rajshahi city protection embankment have been considered. From these locations, the soil has been collected and its properties have been determined in the geotechnical laboratory. The in situ dimensions of the slopes at the selected locations of Rajshahi city protection embankment have been measured by conventional methods. Then three numerical models are incorporated in GEO5 [14] following the in situ dimensions of the slope of Rajshahi city protection embankment and the soil properties are assigned. Numerical analysis has been carried out by FEM considering the Mohr Coulomb material model to evaluate the factor of safety of the existing slope of Rajshahi city protection embankment subject to the variations of water level.

Finite Element Method (FEM):

Finite element method (FEM) has been used by many engineers for approximate solution of problems in stress analysis, fluid flow, heat transfer, and other areas. FEM is a numerical technique for finding approximate solutions to boundary value problems. In FEM, the actual continuum or body of a matter is divided into smaller and a regular subdivision knows as finite elements. These elements are considered to be interconnected at specified joints called nodes. The nodes lay on the element boundaries where adjacent elements are considered to be connected. Basic concept of FEM includes accurate representation of complex geometry, inclusion of dissimilar material properties and easy representation of the total solution and capture of local effects.

1 Mohr-Coulomb model

In FEM analysis using Mohr-Coulomb material model requires parameters comprising of angle of internal friction and cohesion, modulus of elasticity and poison's ratio. The first two parameters are adopted to define the yield condition. The angle of dilation must be specified. The failure surface of Mohr-Coulomb model can be expressed as follows:

$$\tau = \sigma \tan\phi + c \qquad (1)$$

Where, τ represents the shear stress, σ represents the normal stress, ϕ represents the angle of internal friction (slope of the failure envelope) and c represents the cohesion (the intercept of the failure envelope with the τ axis). The Mohr-Coulomb yield surface is represented as a non-uniform hexagonal cone in the principal stress space.

Geometry of the numerical model:

For this study, soil samples are collected from three critical locations of Rajshahi city protection embankment. The selected sites are – Jahajghat, Shohidminar (Talaimari), Ponchoboti (I-baad). Dimensions of the corresponding slopes have been measured by the conventional method. Geometric models of slope at Jahajghat, Shohidminar (Talaimari), Ponchoboti (I-baad) locations of Rajshahi city protection embankment, Bangladesh are depicted in Figs. 1, 2 and 3, respectively, where the dimensions are given in meter.

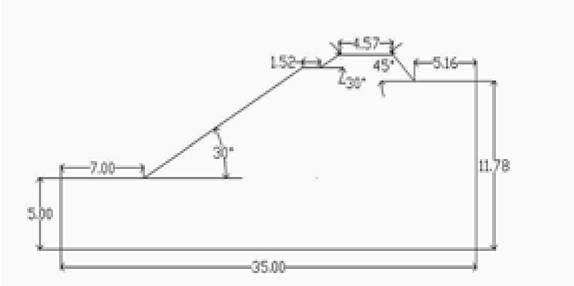

Figure 1*: Geometric model of slope at Jahajghat location of Rajshahi city protection embankment, Bangladesh*

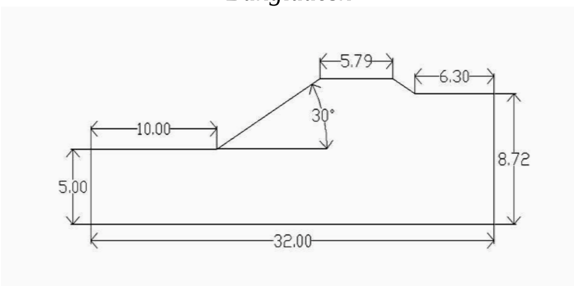

Figure 2*: Geometric model of slope at Shohidminar location of Rajshahi city protection embankment, Bangladesh*

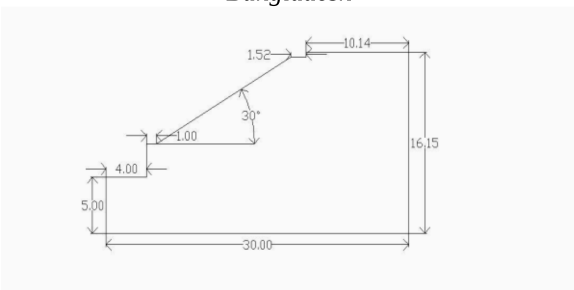

Figure 3*: Geometric model of slope at Ponchoboti location of Rajshahi city protection embankment, Bangladesh*

Since the objective of this study includes the investigation of the effect of the variation of water level on the stability of existing Rajshahi city protection embankment, the stability of the slope without the presence of water has been assessed first and then, water level has been taken into consideration. Factor of safety of slopes both considering the water and without considering the water have been evaluated for the same models (generated from the selected sites) by FEM. For the presence of water, three types of phreatic line conditions have been studied. They are –

i. Constant phreatic line of water with 5 degree downward inclination
ii. Constant straight phreatic line of water
iii. Constant phreatic line of water with 5 degree upward inclination

These are appraised with the water level in all cases of analysis. Geometric models of slope at Shohidminar location of Rajshahi city protection embankment, Bangladesh considering phreatic line with 5 degree downward inclination, straight phreatic line and phreatic line of 5 degree upward inclination are depicted in Figs. 4, 5 and 6, respectively, as instance. Mesh geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh is also depicted in Fig. 7, as instance.

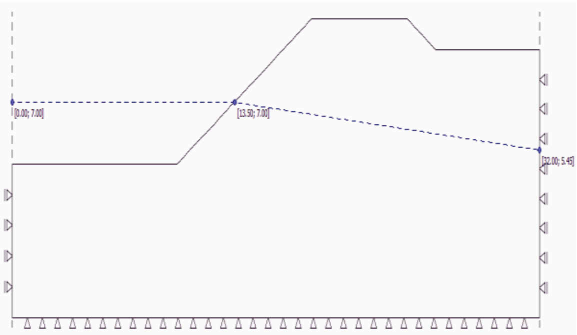

***Figure 4**: Geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh, considering phreatic line with 5 degree downward inclination*

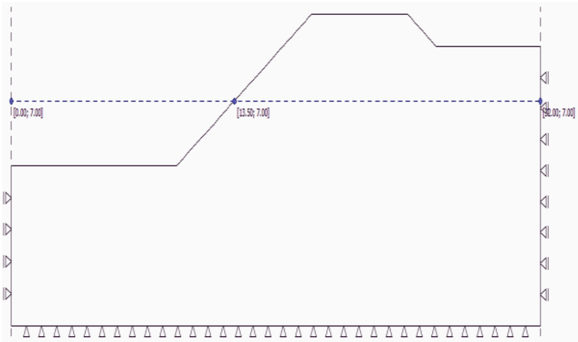

***Figure 5**: Geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh, considering straight phreatic line*

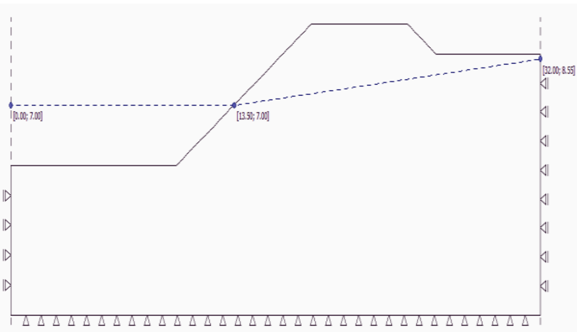

***Figure 6**: Geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh, considering phreatic line with 5 degree upward inclination*

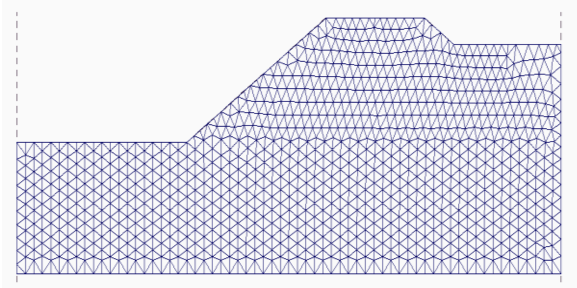

***Figure 7**: Mesh geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh*

All interpretations have been done considering 6-node triangle element with 0.5 meter mesh size by FEM arrogating Mohr-Coulomb model. This is due to the fact that 6-node triangle elements consisting of 0.5 meter mesh size give the optimum result [14].

Soil properties:

Soil properties, considered for the consecutive models for the stability analysis, have been deduced by laboratory tests. The shear strength parameters of soil (i.e. cohesion, c and angle of internal friction, ϕ) are determined by direct shear test and unit weight has been determined by in-situ density determination test. The results obtained from laboratory test are accorded in Table 1.

Table *1*: Properties of soil

Location	Dry unit weight, γ (kN/m^3)	c (kN/m^2)	ϕ ($^\circ$)
Jahaj ghat	15.30	12	34
Shahid minar (Talaimari)	15.05	11	33
Ponchoboty (I -baad)	15.53	14	33

1 Stability analysis of embankment without present of water

For this study, three locations of Rajshahi city protection embankment have been considered to evaluate the factor of safety of existing Rajshahi city protection embankment. GEO5 [16] is used for these analysis. From Fig 8, it has been observed that present condition of Rajshahi city protection embankment is satisfactory and all analyses indicate that factor of safety is greater then 1.5 without the presence of water.

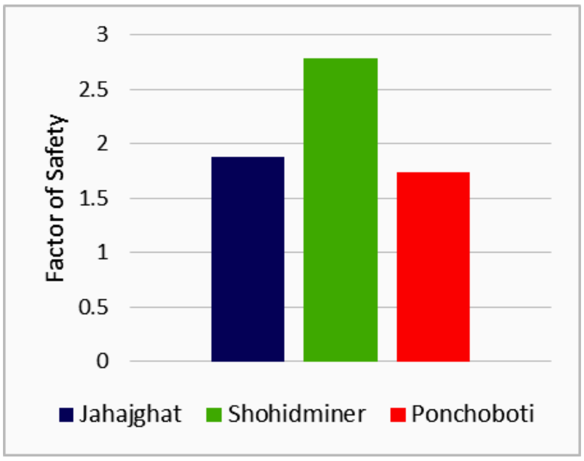

Figure 8: *Evaluating the factor of safety at Jahajghat, Shohidminer and Ponchoboti location of Rajshahi city protection embankment, Bangladesh without the present of water*

2 Stability analysis of embankment with the presence of water

The stability of existing Rajshahi city protection embankment has been analyzed using GEO5 [14] considering the effect of the variation of water level. Three phreatic line conditions have been applied for the analysis. The variation in water level of river has pronounced effect on the on the stability of slope. Table 2, 3 and 4 depict the variations in the factor of safety with the variation in water level. The stability of slope goes through a process of reducing at first and then increasing with the rise of river water level along the slope. So, the slope stability against sliding obviously increases at higher level and the water pressure provides an advantage of maintaining the slope stability against sliding.

From the analysis, it has been found that the most critical location of water is at about 35 % to 45% of height water level. The points at which the factor of safety changes from the decreasing trend to the increasing trend is referred here to be the critical pool level and the factor of safety at this height is the minimum one. With the increase of water level, horizontal thrust of water increases and pore water pressure decreases proportionally. Considering the combination of horizontal thrust for water and pore water pressure, resultant factor of safety first decrease and then increase with the rise of river water level. It is noted from the analysis that the factor of safety of slope at Ponchoboti location yields the lowest value (1.52) compared to other locations and the slope is safe even at critical pool level.

Table 2*: Evaluation of the factor of safety at Jahajghat location of Rajshahi city protection embankment, Bangladesh for variation of water level*

Water level from ground (in meter)	Factor of safety for phreatic line of water with 5 degree downward inclination	Factor of safety straight phreatic line of water	Factor of safety for phreatic line of water with 5 degree upward inclination
0	1.90	1.88	1.86
1	1.95	1.88	1.70
2	1.98	1.73	1.60
3	2.09	1.81	1.56
4	2.14	1.88	1.56
5	2.43	1.88	1.54
6	2.57	1.89	1.73
7	2.86	1.93	1.92
8	3.06	2.38	2.03
8.61	3.15	2.97	2.97

Table 3*: Evaluating the factor of safety at Shohidminar location of Rajshahi city protection embankment, Bangladesh for variation of water level*

Water level from ground (in meter)	Factor of safety for phreatic line of water with 5 degree downward inclination	Factor of safety for straight phreatic line of water	Factor of safety for phreatic line of water with 5 degree upward inclination
0	2.85	2.79	2.61
1	2.68	2.61	2.54
2	2.82	2.75	2.65
3	3.14	3.06	2.82
4	3.80	3.59	3.48
4.72	4.19	4.14	4.14

Table 4*: Evaluating the factor of safety at Ponchoboti location of Rajshahi city protection embankment, Bangladesh for variation of water level*

Water level from ground (in meter)	Factor of safety for phreatic line of water with 5 degree downward inclination	Factor of safety for straight phreatic line of water	Factor of safety for phreatic line of water with 5 degree upward inclination
0	1.74	1.74	1.69
1	1.74	1.73	1.71
2	1.78	1.71	1.67
3	1.73	1.71	1.60
4	1.75	1.69	1.52
5	1.78	1.78	1.69
6	1.90	1.78	1.69
7	2.03	1.90	1.64
8	2.09	1.93	1.90
9	2.23	2.09	1.92
10	2.38	2.35	2.03
11	2.74	2.43	2.42
11.15	3.28	2.44	2.44

From Fig. 9, it has been found that phreatic angle has great influence on the stability of slopes. Phreatic line of water with upward inclination has yielded the lowest factor of safety compared to that with downward inclination.

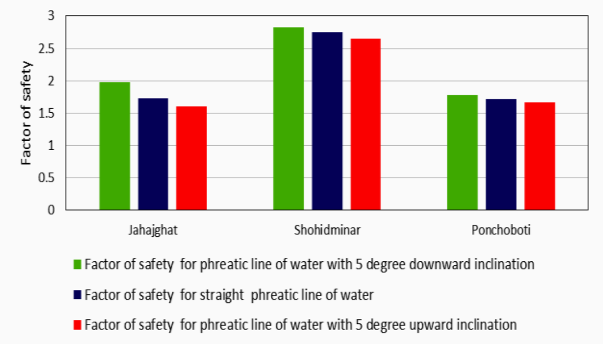

Figure 9: *Evaluating the factor of safety at Jahajghat, Shohidminer and Ponchoboti location of Rajshahi city protection embankment, Bangladesh with present of water (considering water level 2 meter above from ground level)*

Conclusion:

Mohr-Coulomb material model has been used to evaluate the factor of safety of slope of the existing Rajshahi city protection embankment due to the variation of water level. Some of the important points of the study are summarized as follows:

1. In FEM analysis, the factor of safety of slope varies from 2.79 to 1.74 without the present of water and it indicates that the slopes are stable at present without the present of water.
2. The factor of safety of slope varies from 4.19 to 1.52 with the variation of water level which indicates that the slopes are still stable at present when the variation of water level is taken into account in the FEM based analysis.
3. The slope safety factor decreases first then increase as the water level increases. The slope safety factor reaches its minimum value when the water level increases to 35% - 45% of the highest water level in the slope range. It indicates that the critical pool level for Rajshahi city protection embankment lies in the range of 35% to 45% of the highest water level in the slopes considered in the present study.
4. Phreatic line with upward inclination has yielded the lowest factor of safety compared to that with downward inclination.

It should be noted that present study has considered only three worse locations of the Rajshahi city protection embankment. Other worse locations should be considered for the enhanced evaluation of the stability of slopes of Rajshahi city protection embankment under the variation of water level.

References:

[1] He, B. and Zhang, H. *Stability analysis of slope based on finite element method*. International Journal of Engineering and Manufacturing, 3, 70-74, 2012.

[2] Morgenstern, N. R. and Price, V. E. *The analysis of the stability of general slip surfaces*. Geotechnique, 15(1), 77-93, 1965.

[3] Bishop, A.W. *The use of the slip circle in the stability analysis of slope*. *Geotechnique*, 5(1), 7-17, 1995.

[4] Janbu, N. *Slope stability computations*. Embankment Dam Engineering, Casagrande Volume, pp. 47-86, 1973.

[5] Li, L., Barry, D. A., & Pattiaratchi, C. B. (1997). "Numerical modelling of tide-induced beach water table fluctuations". Coastal Engineering, vol. 30, no. 1-2, pp. 105–123.

[6] Ward, W. H. (1945). "The Stability of Natural Slopes". The Geographical Journal, vol. 105, no. 5/6, pp. 170.

[7] Bakhtyar, R., Barry, D. A., Li, L., Jeng, D. S., & Yeganeh-Bakhtiary, A. (2009). "Modeling sediment transport in the swash zone: A review". Ocean Engineering, vol. 36, no. 9-10, pp. 767–783.

[8] Zhang, C. (2013). "Non-Tidal Water Level Variability in Lianyungang Coastal Area". Advanced Materials Research, vol. 610, pp. 2705–2708.

[9] Cala, M. and Flisiak, J. *Slope stability analysis with numerical and limit equilibrium methods.* In proceedings of the 15th International Conference on Computer Methods in Mechanics, Gliwice, Poland, pp. 1-4, 2003.

[10] Lin, H. and Cao, P. *Limit equilibrium analysis for the relationships among slope c, ϕ and slip surface*. Electronic Journal of Geotechnical Engineering, 17, 185-195, 2012.

[11] Griffiths, D.V. and Lane, P. A. *Slope stability analysis by finite elements*. *Geotechnique*, 49(3),387-403, 1999

[12] MONIR, M. M. U. and KHAN, Y. A. *Seasonal potential seepage analysis of Rajshahi city protection embankment, Rajshahi, Bangladesh*, Ninth International Symposium on River Sedimentation October 18 – 21, 2004, Yichang, China.

[13] Sazzad, M. M., Rahman, F. I., & Mamun, M. A. A. (2015)“Mesh Effect on the FEM Based Stability Analysis of Slope” *International Conference on Recent Innovation in Civil Engineering for Sustainable Development (IICSD-2015), Department of Civil Engineering DUET - Gazipur, Bangladesh.(ISBN: 978-984-91467-9-7, page:387-391).*

[14] GEO5 v19. (2016). User’s manual. *Fine software company*, Czech Republic