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

Evaluating the response of Rajshahi city protection embankment, Bangladesh under seismic load

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Abstract: To evaluate the stability of slope is a major concern in the field of geotechnical engineering. For simplicity and effectiveness, usually two-dimensional analysis on limit equilibrium methods (LEMs) are implement in this field. Stability of waterfront structures such as embankments, dams and natural riverside slopes are hampered due to the seismic load. The aim of this paper is to evaluate the response of the seismic load on the stability of slope of the existing Rajshahi city protection embankment by using LEM. Bishop, Spencer, Fellenious, Janbu and Morgenstern-Price methods are used for LEM. For this study, three locations are selected from Rajshahi city protection embankment and numerical models are prepared following the in-situ dimensions of slopes for LEM based studies. Soli properties are obtained from the laboratory tests. The geometric models of the cross-section of the selected locations are prepared with the help of GEO5, a tool for analyzing the LEM based slope stability problems. The material properties are assigned and the numerical analysis are carried out by using GEO5. From the analysis, it is noted that the factor of safety of slopes decreases with the increase of horizontal seismic coefficient, K_h. Horizontal seismic coefficient affects the stability of slope severely than the vertical seismic coefficient, K_v. From the analysis, it is also observed that the factor of safety of theslope of the existing Rajshahi city protection embankment is critically stable up to the value of K_h =0.25 and K_v =0.125(equivalent to 10 for Modified Mercalli intensity scale and 7-8 for Richter scale) at present under the seismic load.

Keywords: *Slope stability, Seismic coefficients, Factor of safety, LEM, Embankment.*

1. Introduction:

Slope stability is an immensely 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 are finding endangered areas, analysis of potential failure mechanisms, determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with regard 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].

Due to change in geometry, external forces and loss of shear strength, the natural slopes that have been stable for many years may suddenly collapse [5]. Earthquake is the greatest threat to the long term stability of slopes, particularly in earthquake active zone [6]. Earthquake prompts ground shaking that causes failure to slopes which were marginally stable before earthquake. For this reasons, the appropriateestimation of the stability of slope becomes the primary concern.

There are different methods such as pseudo-static method, Newmark's sliding block method and numerical techniques for the analysis of slope stability considering the effect of earthquake.Newmark[7] studied the effect of earthquakes on dams and embankments based on Newmark'sdisplacement-type analysis. Field observations indicate that the pseudo-static method can be useful in evaluating the performance of embankments constructed of soils that do not lose significant strength during earthquakes. Such soils include clays, clayey soils, dry or moist cohesion less soils, and dense cohesion less soils [8]. For this study, the pseudo-static method is used in which the earthquake loading is represented by a horizontal static force. This horizontal static force is computed by multiplying the weight of structure by the seismic coefficient. The advantage of this method lies in its simplicity. There are several studies reported in the literature that considered the effect of earthquake in the stability of slopes. For example, a parametric study on the choice of the seismic coefficient in a more rational way to investigate the effect of earthquake for pseudostatic analysis is carried out by Sazzad et al.[9]. Similar studies have been carried out to study the effect of bedrock inclination on the seismic slope stability [10-11].The stability of slopes under seismic load hasbeen analyzed by using analytical and numerical approaches by several authors[e.g., 12]. A study has been carried out on the effect of seismic action direction on the stability of slope and reported that the stability of slope is lower than the stability of natural condition when the direction of horizontal earthquake inertia force outside toward slope [13].

Rajshahi city protection embankment is situated on the southern boundary of Rajshahi city of Bangladesh. The 15km long costly embankment structure on the Padma River serves as an important infrastructural protection to this city. The embankment material consists of sands 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 increased the river water level above the danger level in 1988 and 1998 which made the situation worst.A fault line is situated under Rajshahi city area. So, a serious earthquake is likely to take place anytime and can cause serious damage to the city infrastructure as well as city protection embankment. From the history of earthquake, it has been observed that the earthquake of July 5, 2008 caused damage to several buildings and scared the inhabitants of this city.

There are some research works that have been carried out only to evaluate the factor of safety of Rajshahi city protection embankment with the present of water [e.g., 14]. And also a research wascarried outabout the potential seepage analysis of Rajshahi city protection embankment [15]. Although seismic load can hamper the stability of slopes of Rajshahi city protection embankment, it has not given emphasis on the previous studies and no research work is yet to be carried out to evaluate the factor of safety of the existing Rajshahi city protection embankment due to earthquake.

In this paper, three of the worst slope locations from Rajshahi city protection embankmenthave been considered. The soil has been collected from these locations andthe propertiesof soil have been determined at laboratory. The dimension of the slope at the selected locations have been measured by conventional methods. Three numerical models have beenprepared using GEO5 [16]. All the analysis have been carried out by LEM for Bishop, Spencer, Fellenious, Janbu and Morgensterm-Price methods and the results are reported in the following sections.

2. Analysis Technique:

2.1 Limit Equilibrium Methods:

Several limit equilibrium methods (LEMs) have been developed for slope stability analysis. Fellenius [17] introduced the first method, referred to as the Ordinary or the Swedish method, for a circular slip surface. Bishop [20] advanced the first method introducing a new relationship for the base normal force. Hence, the equations for the factor of safety become non-linear. At the same time, Janbu[21] developeda simplified method for non-circular failure surfaces, dividing a potential mass into several vertical slices.Janbu[4] proposed the generalized procedure by further development of the simplified method. Later, Morgenstern-Price [2], Spencer [18]and several others made further contributions with different assumptions for the inter-slice forces.All limit equilibrium methods (LEMs) are based on certain assumptions for the inter-slice normal and shear forces, and the basic difference among the methods lies in how these forces are determined or assumed. In addition to this, the shape of assumed slip surface and the equilibrium conditions for calculation of the factor of safety are among the others.

2.2 Load-based Seismic Slope StabilityAnalysis:

In load-based technique, the earthquake load is represented by a horizontal static force that is equal to the weight of soil multiplied by the seismic coefficient. This technique is the earliest techniques for seismic slope stability analysis. In earthquake prone areas, horizontal and vertical pseudo-static (seismic) coefficients, K_h and K_v, respectively, are used to compute the horizontal and vertical forces caused by a potential earthquake. These forces are in turn added to the overall limit equilibrium computation for the individual slice composing the failure surface and the factor of safety is computed [19].

The relation among horizontal seismic coefficient, Modified Mercalli intensity scale and Richter scale is given in Table 1.The difference between Modified Mercalli intensity scale and Ricter scale is that the ModifiedMercalli intensity scale is used for measuring the effects of an earthquake while Richter scale is used for measuring the energy released from an earthquake.

3. Geometry of the Numerical Model:

For this study, soil is collected from three of the worst locations of Rajshahi city protection embankment. These places are:Jahajghat, Shahidminar (Talaimari) andPonchoboti (I-baad). Dimensions of these slopes are determinate by conventional method. All dimensions in Figures. 1, 2 and 3are in meter.

***Table 1**: Relation among horizontal seismic coefficient, ModifiedMercalli intensity scale and Richter scale [20-21]*

K_h	Earthquake intensity in ModifiedMercalli intensity scale	Earthquake intensity in Richter scale
0	0	0
0.005	5	4-5
0.01	6	5-6
0.03	7	6
0.05	8	6-7
0.1	9	7
0.25	10	7-8
0.4	10<x<11	7-8
0.5	11	8

4. Soil Properties:

Soil properties, used for the stability analysis, have been determined at the laboratory. The shear strength properties of soil (i.e., cohesion, c and angle of internal friction, ϕ) are determined by direct shear test and dry unit weight is determined by in-situ density determination test. The results from laboratory tests are given in Table 2.

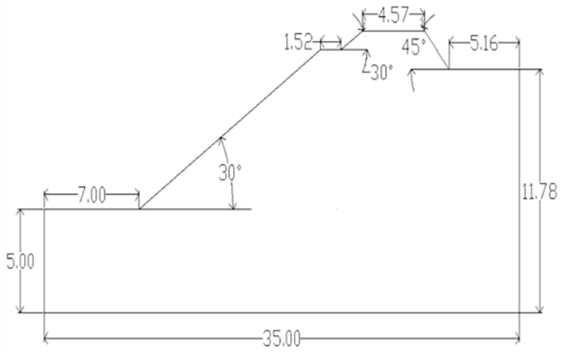

Figure 1: *Geometric model of slope at Jahajghat location of Rajshahi city protection embankment, Bangladesh*

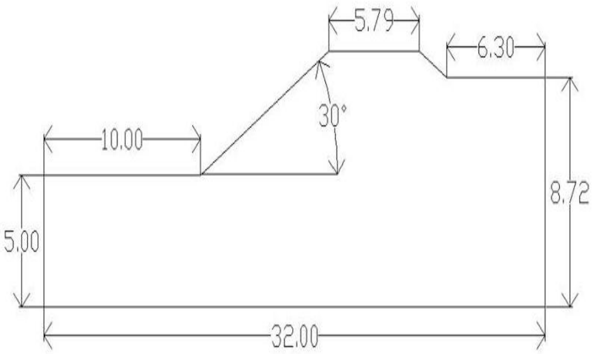

Figure 2*: Geometric model of slope at Shahidminar location of Rajshahi city protection embankment, Bangladesh*

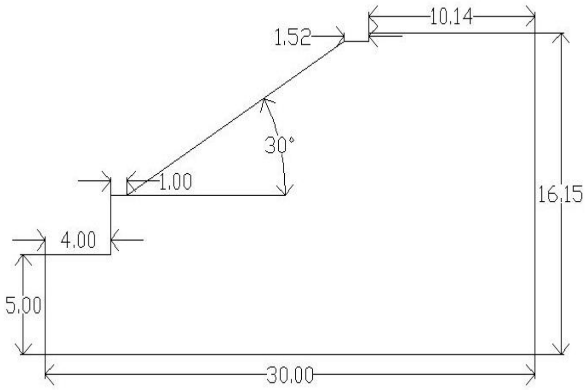

Figure 3*: Geometric model of slope at Ponchoboti location of Rajshahi city protection embankment, Bangladesh*

5. Stability Analysis of Slope of Rajshahi City Protection Embankment without Considering Earthquake:

For this study, three locations of Rajshahi city protection embankment have been considered to evaluate the factor of safety of the existing Rajshahi city protection embankment. GEO5 [16] is used for these analysis. The factor of safety of slopes at three locations of Rajshahi city protection embankment is given in Table 3. From Table 3, it is observed that the factor of safety is well above 1.5 regardless of the methods used for the analysis which confirms the stable condition of Rajshahi city protection embankment without considering any earthquake.

Table 2: *Properties of soil at different loations of Rajshahi city protection embankment, Bangladesh*

Location	Dryunit weight, γ (kN/m^3)	Cohesion, c (kN/m^2)	Angle of internal friction, ϕ (°)
Jahajghat	15.30	12	34
Shahidminar (Talaimari)	15.05	11	33
Ponchoboti (I -baad)	15.53	14	33

Table 3*: Factor of safety of slopes at different locations of Rajshahi city protection embankment*

Location	Bishop	Fellenious	Spencer	Janbu	Morgenster -price
Jahajghat	2.32	2.20	2.31	2.31	2.31
Shahid-minar	2.79	2.64	2.78	2.78	2.78
Poncho-boti	1.82	1.79	1.83	1.87	1.83

Note also that Fellenious method depicts a bit lower factor of safety than Bishop, Spencer, Janbu and Morgensterm-Price methods. It is due to the fact that Fellenious method neglectsthe normal and shear forces between the blocks and calculates the moment about the center of slip surface.Among the three locations, Ponchobotiyields the lowest factor of safety.

6.Stability Analysis of Slopes of Rajshahi City Protection Embankment Considering Earthquake:

The stability ofthe existing Rajshahi city protection embankment is analyzed using GEO5[16] considering the effect of earthquake. Here, the effect of earthquake is evaluated using suitable seismic coefficients. To evaluate the stability of slope under seismic load, analyses have beencarried out considering the ratio of vertical seismic coefficient, K_v and horizontal coefficient, K_h (i.e., K_v / K_h) to be0.5 and the results are reported in Tables 4, 6 and 8, respectively, for Jahajghat, Shahidminar and Ponchoboti of Rajshahi city protection embankment. The results for K_v / K_h equal to 1.0 are reported in Tables 5, 7 and 9, respectively, for Jahajghat, Shahidminar and Ponchobotiof Rajshahi city protection embankment.

From the analysis, it is found that Fellenious method yields the lowest factor of safety regardless of the value of K_v / K_h and the location considered. Among the three locations considered in the present study, Ponchoboti gives the lowest factor of safety (see Fig. 4 as well). The study shows that the slope of Rajshahi city protection embankment is safe up to horizontal seismic coefficient of 0.1 and vertical seismic coefficient 0.05(which is equivalent to 9for ModifiedMercalli intensity scaleand 7 for Richter scale) under seismic load and critically stable up to horizontal seismic coefficient of 0.25 and vertical seismic coefficient 0.125 (which is equivalent to 10 for Modified Mercalli intensity scale and 7-8 for Richter scale) under seismic load.Note also that thefactor of safety decreases with the increase of the horizontal seismic load coefficient K_h and little influence is noticed by increasing the vertical seismic load coefficient K_v. So, it can be concluded that the effect of horizontal seismic coefficient is more severe than that of vertical seismic coefficient (shown in Fig.5 as well).

Table 4: *Evaluating the factor of safety at Jahajghat location for seismic loadconsidering K_v / K_h =0.5*

K_h	K_v	Bishop	Fellenious	Spencer	Janbu	Morgenster-price
0	0	2.32	2.20	2.31	2.31	2.31
0.005	0.0025	2.28	2.18	2.28	2.27	2.28
0.01	0.005	2.27	2.16	2.27	2.26	2.27
0.03	0.015	2.19	2.08	2.19	2.18	2.19
0.05	.025	2.10	1.99	2.10	2.09	2.09
0.1	0.05	1.90	1.80	1.90	1.90	1.90
0.25	0.125	1.41	1.34	1.42	1.41	1.41
0.4	0.20	1.03	0.97	1.03	1.02	1.03
0.5	0.25	0.86	0.83	0.85	0.85	0.85

Table 5: *Evaluating the factor of safety at Jahajghat location for seismic loadconsidering K_v / K_h =1*

K_h	K_v	Bishop	Fellenious	Spencer	Janbu	Morgenster-price
0	0	2.32	2.20	2.31	2.31	2.31
0.005	0.005	2.30	2.19	2.30	2.28	2.30
0.01	0.01	2.28	2.18	2.29	2.27	2.28
0.03	0.03	2.20	2.09	2.24	2.23	2.23
0.05	0.05	2.11	2.00	2.11	2.11	2.11
0.1	0.1	1.92	1.82	1.92	1.91	1.92
0.25	0.25	1.43	1.36	1.44	1.44	1.43
0.4	0.4	1.09	1.03	1.10	1.10	1.10
0.5	0.5	0.90	0.85	0.95	0.93	0.91

Table 6: *Evaluating the factor of safety at Shahidminar location for seismic load considering K_v / K_h =0.5*

K_h	K_v	Bishop	Fellenious	Spencer	Janbu	Morgenster-price
0	0	2.79	2.64	2.78	2.78	2.78
0.005	0.0025	2.76	2.60	2.76	2.76	2.77
0.01	0.005	2.69	2.56	2.69	2.68	2.68
0.03	0.015	2.63	2.49	2.63	2.63	2.63
0.05	.025	2.54	2.41	2.53	2.53	2.53
0.1	0.05	2.32	2.20	2.32	2.32	2.32
0.25	0.125	1.74	1.63	1.73	1.74	1.73
0.4	0.20	1.17	1.12	1.17	1.17	1.17
0.5	0.25	0.95	0.84	0.95	0.95	0.94

Table 7: *Evaluating the factor of safety at Shahidminar location for seismic load considering K_v / K_h =1*

K_h	K_v	Bishop	Fellenious	Spencer	Janbu	Morgenster-price
0	0	2.79	2.64	2.78	2.78	2.78
0.005	0.005	2.77	2.62	2.76	2.76	2.76
0.01	0.01	2.74	2.59	2.73	2.73	2.73
0.03	0.03	2.65	2.51	2.64	2.64	2.64
0.05	0.05	2.56	2.43	2.56	2.56	2.56
0.1	0.1	2.35	2.23	2.35	2.34	2.35
0.25	0.25	1.77	1.69	1.78	1.80	1.78
0.4	0.4	1.26	1.18	1.33	1.33	1.33
0.5	0.5	0.99	0.89	1.03	1.03	1.03

Table 8*: Evaluating the factor of safety at Ponchoboti location for seismic load considering K_v / K_h =0.5*

K_h	K_v	Bishop	Fellenious	Spencer	Janbu	Morgenster-price
0	0	1.82	1.79	1.83	1.87	1.83
0.005	0.0025	1.79	1.76	1.79	1.80	1.80
0.01	0.005	1.75	1.72	1.75	1.75	1.75
0.03	0.015	1.73	1.70	1.73	1.73	1.74
0.05	.025	1.69	1.66	1.69	1.69	1.69
0.1	0.05	1.55	1.52	1.55	1.55	1.55
0.25	0.125	1.23	1.19	1.22	1.24	1.24
0.4	0.20	0.97	0.95	1.10	1.10	1.20
0.5	0.25	0.85	0.78	0.85	0.86	0.88

Table 9*: Evaluating the factor of safety at Ponchoboti location for seismic load considering K_v / K_h =1*

K_h	K_v	Bishop	Fellenious	Spencer	Janbu	Morgenster-price
0	0	1.82	1.79	1.83	1.87	1.83
0.005	0.005	1.81	1.78	1.82	1.83	1.82
0.01	0.01	1.80	1.76	1.80	1.84	1.81
0.03	0.03	1.77	1.73	1.77	1.75	1.76
0.05	0.05	1.70	1.67	1.71	1.71	1.71
0.1	0.1	1.59	1.57	1.59	1.59	1.60
0.25	0.25	1.26	1.24	1.29	1.30	1.31
0.4	0.4	1.01	0.99	1.05	1.04	1.04
0.5	0.5	0.87	0.86	0.87	0.87	0.89

7. Conclusions:

Different LEMs are used to evaluate the factor of safety of slope of the existing Rajshahi city protection embankmentunder the effect of seismic load. Some of the important points of the study are summarized as follows:

i. Factor of safety of slopesof the existing Rajshahi city protection embankmentby LEM varies from1.79 to 2.79without seismic load which indicates that the slopes are stable at present without earthquake.

ii. Factor of safety of slopes of the existing Rajshahi city protection embankmentdecreases with the increase of horizontal seismic load coefficient (K_h). Horizontal seismic load coefficient affects the stability of slopes more severely than the vertical seismic load coefficient.

iii. Fellenious method yields the lowest factor of safety regardless of the value of K_v / K_h and the location considered.

iv. The slope of Rajshahi city protection embankment is safe up to horizontal seismic coefficient of 0.1 and vertical seismic coefficient 0.05 (which is equivalent to 9 for Modified Mercalli intensity scale and 7 for Richter scale) under seismic load and critically stable up to horizontal seismic coefficient of 0.25 and vertical seismic coefficient 0.125 (which is equivalent to 10 for Modified Mercalli intensity scale and 7-8 for Richter scale) under seismic load.

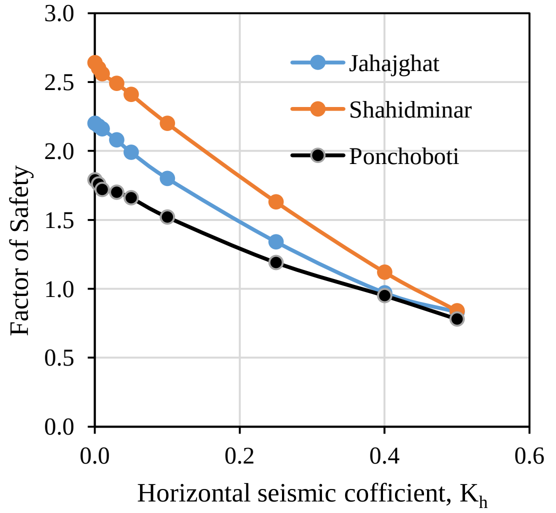

Figure4:*Factor of safety of three location for Fellenious method considering K_v / K_h =0.5*

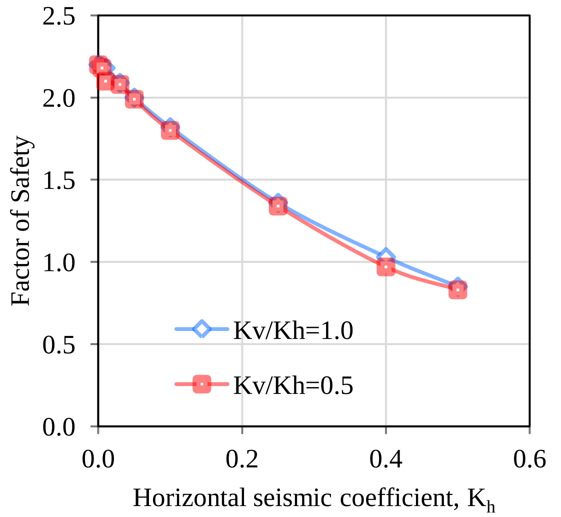

Figure 5*: Comparison of K_v / K_h =0.5 and K_v / K_h =1 for Jahajghat location considering Fellenious method*

It should however be noted that the present study has considered only three worse locations of Rajshahi city protection embankment. Other worse locations should be considered for the concrete evaluation of the stability of slopes of Rajshahi city protection embankment under seismic loads.

References:

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

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

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

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

[5] Abramson, L. W., Lee, T. S., Sharma, and Boyce, G. M. (2002). Slope Stability Concepts, Slope Stabilization and Stabilization Methods, Second edition, *John Willey & Sons, Inc*., pp. 329-461.

[6] Taylor, M. J. and Burns, S. F. (2005). Slope and seismic stability of Castle Lake Debris Dam, St. Helens, Washington, Landslide and Avalanches: *ICFL, Norway, Edr. Senneset, Flaateand Larsen*.

[7] Newmark N. M. (1965).Effects of earthquakes on dams and embankments.*Géotechnique*, 15(2), 139-160.

[8] Seed H. B. (1979).Considerations in the earthquake-resistant design of earth and rockfill dams. *Géotechnique*,29(3), 215-263.

[9] Sazzad, M. M., Mazumder, S. and Moni. M. M. (2015). Seismic stability analysis of homogeneous and layered soil by LEM. *International journal of Computer Applications*, 117(22), 12-17.

[10] Kandolkar, S. S., Aldonkar, S. S. and Savoikar, P. P. (2010). Rational Pseudo-static stability analysis of embankments.*Indian Geotechnical Conference*, India, pp. 135-138.

[11] Miraboutalebi, M., Askari, F. and Farzaneh, O. (2011). Effect of bedrock inclination on seismic slope stability according to Iran seismically data.*International Journal of Civil Engineering*, 9(4), 247-254.

[12] Chatterjee, K. and Choudhury, D. (2012). Seismic stability analysis of soil slopes using analytical and numerical approaches. *ISET Golden Jubilee Symposium.* Paper No. C005.

[13] Gao, F. and Lie, W. (2013). Study on effect of seismic action direction on slope stability. *International Efforts in Lifetime Earthquake Engineering*, pp. 656-662.

[14] Khan, Y. A. (2008). Mechanisms and causes of embankment slope failure at Talaimarilocation of the Rajshahi City Protection Embankment, Bangladesh, Vol. 11, *EGU*2009-581.

[15] MONIR,M. M. U.and Khan, Y. A. (2004).Seasional potential seepageanalysis of Rajshahi cityprotection embankment, Rajhahi, Bangladesh,*Ninth International Symposium on River Sedimentation*October 18 – 21, Yichang, China.

[16] GEO5 v19. (2015). User's manual. *Fine software company*, Czech Republic

[17] Fellenius, W. (1936). Calculation of the stability of earth dams.*Proc. of the 2nd congress on large dams*, Washington, *D.C.*, 4, U.S. Government Printing Office.

[18] Spencer, E. (1967). A method of analysis of the stability of embankments assuming parallel interslice forces.*Geotechnique*, 17(1): 11–26.

[19] Tan, D. 2006. Seismic slope safety – Determination of critical slip surface using acceptability criteria.*Doctoral thesis* at Imperial College University of London.

[20] Bishop, A.W. (1955). The use of the slip circle in the stability analysis of slope. *Geotechnique*, 5(1), 7-17.

[21] Janbu, N. (1954). Application of composite slip surface for stability analysis. European Conference on StabilityAnalysis, Stockholm, Sweden.