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Evaluation of the Response of Rajshahi City Protection Embankment, Bangladesh under Variation of Water-Level by LEM

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Abstract: In the field of geotechnical engineering, to evaluate the stability of slope is a major concern. Stability of waterfront structures such as embankments, dams and natural riverside slopes are hampered due to the variation of water level. Due to the fluid nature, water can easily move into the soil pores. This reduces the effective stress and soil strength that can have devastating effects on the stability of earth slopes. The aim of this paper is to evaluate the response of the variation of water level on the stability of slope of existing Rajshahi city protection embankment by using limit element method (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 for LEM based studies. Soli properties are obtained from laboratory test. The geometric models are incorporated in the GEO5, a tool for analyzing for LEM based slope stability problems. The material properties are assigned and the numerical analysis are carried out by using GEO5. The level of water is varied and the numerical results are computed considering three types of phreatic angle. From the study, it is noted that the variation of water level effects the factor of safety of slopes. The factor of safety decreases with the increase of the water level up to the critical point and then the factor of safety increases with the increase of the water level. Factor of safety varies 4.15 to 1.72 for incorporating model and factor safety of critical pool level indicates lowest factor of safety which occurs 35% to 45% of the highest water level in the slope range.

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

1. 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 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].

Fluctuation of external water levels is one important factor influencing waterfront slopes and adjacent land areas. Sources of such fluctuations may e.g. include tidal 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 (also 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.

Due to the fluid nature, water can easily move into the soil pores. This reduces the effective stress and soil strength that can have devastating effects on the stability of earth slopes. Hence, in slopes stability studies, water is a critical issue that ignoring it can be have devastating effects in the short or long term. Conventionally, the limit equilibrium method is used to calculate the factor of safety for slope [9, 10]. However, this method needs many pre-assumptions.

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 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 sometimes increase the river water level above the danger level in 1988 and 1998 which made the situation worst.

There are some research works have been carried out only to evaluate the factor of safety of Rajshahi city protection embankment with present of fixed water level by LEM [12]. And also a research was carried out by Monir and Khan about potential seepage analysis of Rajshahi city protection embankment [13]. Effect of variation of water level plays a vital role to evaluate the factor of safety of soil slope. But there is no research yet to be done to evaluate the factor of safety of the existing the Rajshahi city protection embankment due to variation of water.

In this paper, three worst slope locations from Rajshahi city protection embankment have been considered. From those locations, the soil has been collected and determined the soli properties at laboratory as well as dimension of those selected slopes have been measured by conventional methods. Then three numerical models are incorporated in GEO5 [16] software with their determinate soil properties. All the analysis have been carried out by finite element method. Mohr Coulomb material model is used for LEM.

2. Analysis Technique:

2.1 Limit Euilibrium Methods:

Several limit equilibrium methods (LEM) have been developed for slope stability analysis. Fellenius (1936) introduced the first method, referred to as the Ordinary or the Swedish method, for a circular slip surface. Bishop (1955) 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 (1954) developed a simplified method for non-circular failure surfaces, dividing a potential mass into several vertical slices. Janbu (1973) proposed the generalized procedure by further development of the simplified method. Later, Morgenstern-Price (1965), Spencer (1967), Sarma (1973) and several others made future contributions with different assumptions for the interslice forces. All limit equilibrium methods (LEM) are based on certain assumptions for the interslice normal (E) and shear forces (T), and the basic difference among the methods 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 FOS are among the others.

2.1.1 Fellenius method:

The simplest method of slices assumes only the overall moment equation of equilibrium written with respect to the center of the slip surface. The shear and normal forces between blocks are neglected. The factor of safety FS follows directly from the following expression:

$$FS = \frac{1}{\sum \sin\alpha}\sum[cl + 9N - ul)\tan\varphi] \qquad (1)$$

where:
u = pore pressure within block
c, φ= effective values of soil parameters
W =block weight
N =normal force on the segment of the slip surface
α=inclination of the segment of the slip surface
l = length of the segment of the slip surface

2.1.2 Bishop method:

Bishop's simplified method is very common in practice for circular shear surface. This method considers the interslice normal forces but neglects the interslice shear forces (Abramson et al. 2002). It further satisfies vertical force equilibrium to determine the effective base normal force (N), which is given by

$$N = \frac{1}{m_a}\sum(W - \frac{cl\sin\alpha}{F} - ul\cos\alpha \qquad (2)$$

where,

$$m_a = (1 + \tan\alpha\frac{\tan\varphi}{F}) \qquad (3)$$

where:
u = pore pressure within block
c, φ= effective values of soil parameters
W =block weight
N =normal force on the segment of the slip surface
α=inclination of the segment of the slip surface
l = length of the segment of the slip surface

2.1.3 Janbu method

Janbu method assumes non-zero forces between blocks. Method satisfies the force equations of equilibrium in the horizontal and vertical directions for all blocks and the moment equation of equilibrium for all but the last (uppermost) slice. Assumption of this method is choice of position of forces acting between the blocks. The factor of safety FS is found through the iteration of forces acting between blocks and then inclinations of these forces are calculated.

2.1.4 Morgenstern-Price method

The Morgenstern- Price method (M-PM) also satisfies both force and moment equilibriums and assumes the interslice force function. According to M-PM (1965), the interslice force inclination can vary with an arbitrary function (f(x)) as:

$$T = f(x)\lambda E \qquad (4)$$

where,
f(x) = interslice force function that varies continuously along the slip surface,
λ = scale factor of the assumed function.

The method suggests assuming any type of force function, for example half-sine, trapezoidal or user defined. The relationships for the base normal force (N) and interslice forces (E, T) are the same as given in JGM. For a given force function, the interslice forces are computed by iteration procedure until, F_f is equals to F_m in Esq. (5) and (6) (Nash 1987).

$$F_f = \frac{\sum[\{cl + (N - ul)\tan\varphi\}\sec\alpha]}{\sum\{W - (T_2 - T_1)\}\tan\alpha + \sum(E_2 - E_1)}$$

$$F_m = \frac{\sum\{cl + (N - ul)\tan\varphi\}}{\sum W\sin\alpha}$$

2.1.5 Spencer's method:

Spencer's method (SM) is the same as M-PM except the assumption made for interslice forces. A constant inclination is assumed for interslice forces and the FOS is computed for both equilibriums (Spencer 1967). According to this method, the interslice shear force is related to:

$$T = E\tan\vartheta$$

3. Geometry of the numerical model:

For this study, soil are collected from three worst condition of Rajshahi city protection embankment. Those places are – Jahajghat, Shahidminar (Talaimari), Ponchoboti (I-baad). Dimensions of those slopes are determinate by conventional method. All dimensions are given in meter in Fig 1, 2 and 3.

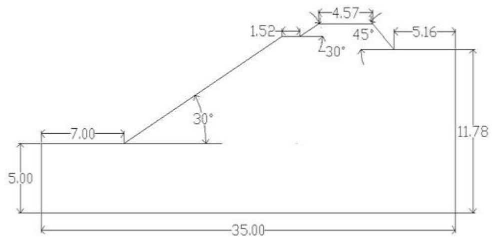

Figure 1: Geometric model of slope at Jahajghat location of Rajshahi city protection embankment, Bangladesh

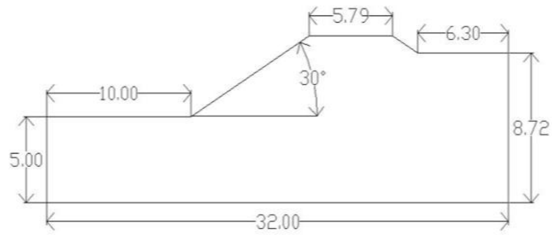

Figure 2: Geometric model of slope at Shahidminar location of Rajshahi city protection embankment, Bangladesh

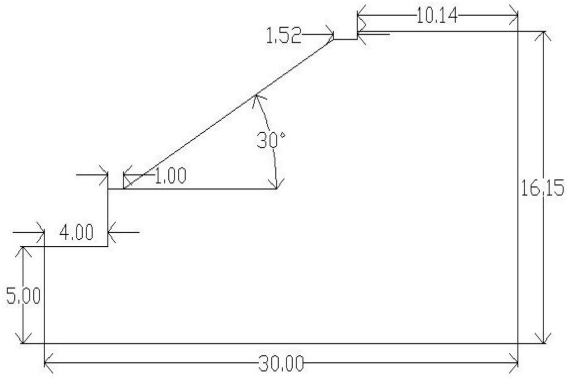

Figure 3: Geometric model of slope at Ponchoboti location of Rajshahi city protection embankment, Bangladesh

Since the objective of this study is to investigate the effect of the variation of water level on the stability of existing Rajshahi city protection embankment, therefore, the stability of the slope without the presence of water is studied first and then, water is considered. The factor of safety of slopes both considering the water and without considering the water are computed for the same shape of model by FEM. For the present of water, three types of phreatic line conditions are considered. There are:

(1) Constant phreatic line of water with 5 degree downward inclination
(2) Constant straight phreatic line of water
(3) Constant phreatic line of water with 5 degree upward inclination

Those are considered with the water level in all cases of analysis.

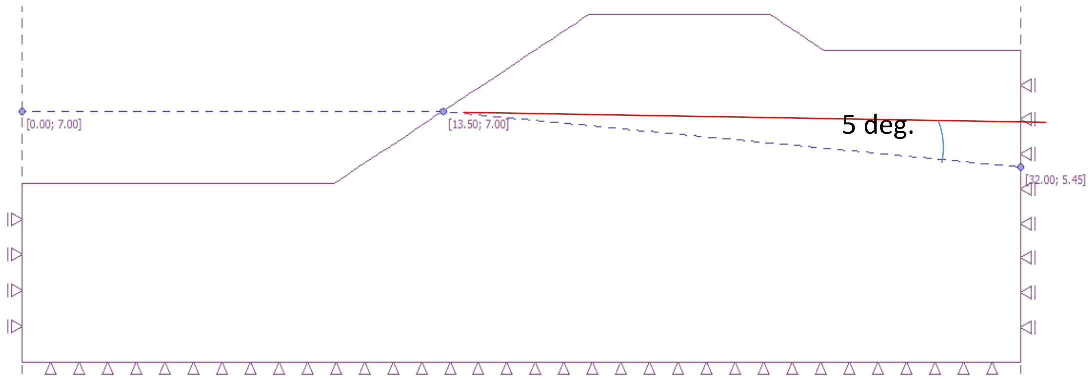

Figure 4: Geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh, considering phreatic line of water with 5 degree downward inclination

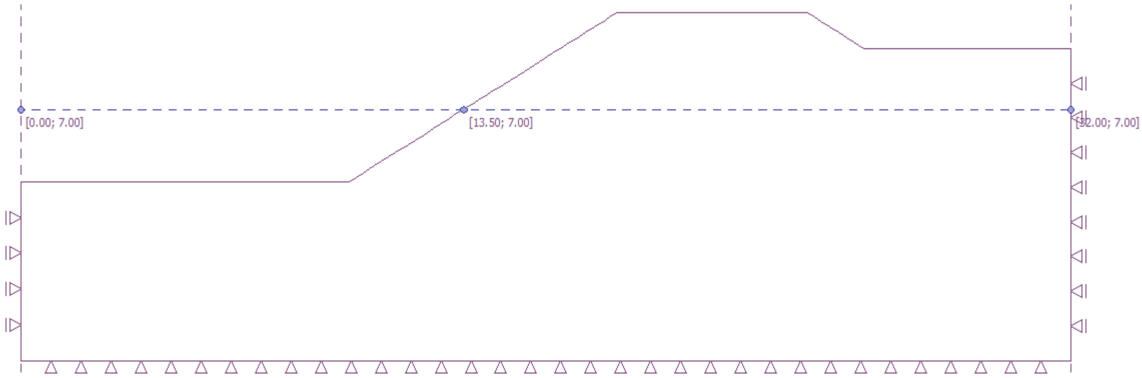

Figure 5: Geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh, considering straight phreatic line of water

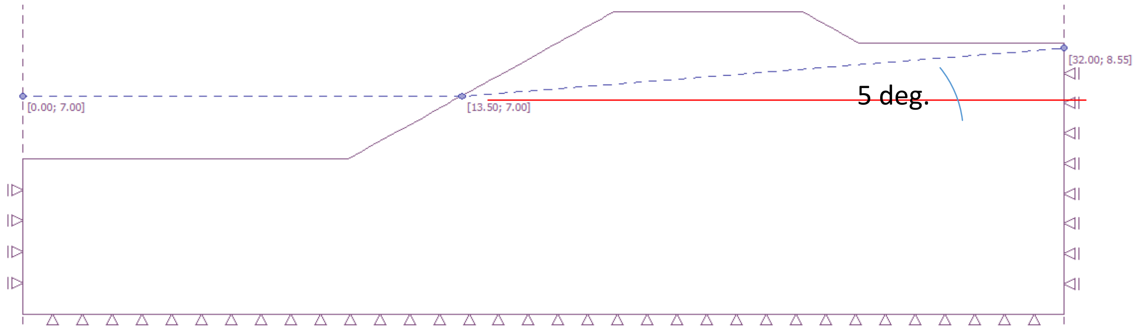

Figure 6: Geometric model of slope at Shohidminer location of Rajshahi city protection embankment, Bangladesh, considering phreatic line of water with 5 degree upward inclinatio

4. Soil properties:

Soil properties, used of these models for the stability analysis are determinate by laboratory test. The shear strengtproperties of soil (i.e. cohesion, c and angle of internal friction, ∅) is determined by direct shear test and dry unit weight is determined by in-situ density determination test. The results evaluating from laboratory test are given in Table 1.

Table 1**:** Properties of soil

Location	γ kN/m^3	C kN/m^2	φ (°)
Jahaj ghat	15.30	12	34
Shahid minar (talaimari)	15.05	11	33
Ponchoboty (I baad)	15.53	14	33

5.1.1 Stability analysis of embankment without earthquake

For this study, three locations of Rajshahi city protection embankment are considered to evaluate the factor of safety of existing Rajshahi city protection embankment. GEO 5 is used for these analysis. From table, we found that present condition of Rajshahi city protection embankment is satisfactory. All methods indicates factor of safety gheater then 1.5 without effect of earthquake.

Table 2**:** Stability of different location of Rajshahi city protection embankment

Location	**Bishop**	**Felleni ous**	**Spencer**	**Janbu**	**Morgen ster-price**
Jahaj ghat	2.32	2.20	2.31	2.31	2.31
Shahid minar (talaimari)	2.79	2.64	2.78	2.78	2.78
Ponchoboty (I baad)	1.82	1.79	1.83	1.87	1.83

5.2 Stability analysis of embankment with present of water:

The stability of existing Rajshahi city protection embankment is analyzed using GEO5 (2016) considering the effect variation of water level. Three phreatic line conditions are applied for analysis. The river water level variation have great effect on the on the stability of slope.Table 3, 4, 5, 6, 7, 8, 9, 10 and 11 which depicts the variation of factor of safety with water level variation. The slope stability against 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 has an advantage of maintaining the slope stability against sliding. At the same time, the greater water depth of tension crack on the tap of the slope is, the smaller the slope stability factor against sliding is. Water in tension cracks on the top of slope has disadvantage of maintaining the slope stability against sliding. So in practical engineering, we should try to avoid water seeping into the top of the cracks. At the same time, we must prepare for the seepage out of the slope.

Table 3: Evaluation of the factor of safety at Jahajghat location of Rajshahi city protection embankment, Bangladesh for variation of water level when phreatic line of water with 5 degree downward inclination

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	2.22	2.38	2.38	3.37	3.37
1	2.17	2.32	2.33	2.32	2.32
2	2.14	2.29	2.30	2.29	2.29
3	2.16	2.31	2.32	2.31	2.31
4	2.22	2.39	2.39	2.39	2.39
5	2.35	2.49	2.50	2.49	2.49
6	2.50	2.66	2.67	2.66	2.66
7	2.72	2.88	2.89	2.88	2.88
8	3.10	2.95	3.11	3.10	3.10
8.61	3.08	3.23	3.24	3.23	3.23

Table 4: Evaluation of the factor of safety at Jahajghat location of Rajshahi city protection embankment, Bangladesh for variation of water level with straight phreatic line of water

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	2.15	2.37	2.37	2.37	2.37
1	2.10	2.28	2.28	2.28	2.28
2	2.08	2.24	2.24	2.24	2.24
3	2.09	2.24	2.26	2.25	2.25
4	2.15	2.31	2.32	2.31	2.31
5	2.25	2.42	2.43	2.42	2.42
6	2.42	2.58	2.59	2.58	2.58
7	2.64	2.80	2.81	2.80	2.80
8	2.92	3.08	3.08	3.08	3.08
8.61	3.06	3.21	3.22	3.21	3.21

Table 5: Evaluation of the factor of safety at Jahajghat location of Rajshahi city protection embankment, Bangladesh for variation of water level when phreatic line of water with 5 degree upward inclination

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	2.06	2.29	2.29	2.29	2.29
1	2.02	2.21	2.21	2.21	2.21
2	2.00	2.16	2.17	2.16	2.16
3	2.00	2.17	2.17	2.17	2.17
4	2.06	2.22	2.23	2.22	2.22
5	2.17	2.34	2.34	2.34	2.34
6	2.30	2.46	2.48	2.46	2.46
7	2.50	2.65	2.66	2.65	2.65
8	2.88	3.03	3.04	3.03	3.03
8.61	3.06	3.21	3.22	3.21	3.21

Table 6: Evaluating the factor of safety at Shahidminar location of Rajshahi city protection embankment, Bangladesh for variation of water level when phreatic line of water with 5 degree downward inclination

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	2.58	2.78	2.78	2.78	2.79
1	2.53	2.70	2.71	2.70	2.70
2	2.63	2.81	2.82	2.81	2.81
3	2.92	3.11	3.12	3.11	3.11
4	3.46	3.64	3.66	3.64	3.64
4.72	3.99	4.15	4.17	4.15	4.15

Table 7: Evaluating the factor of safety at Shahidminar location of Rajshahi city protection embankment, Bangladesh for variation of water level with straight phreatic line of water

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	2.50	2.74	2.75	2.74	2.74
1	2.46	2.64	2.64	2.64	2.63
2	2.55	2.73	2.74	2.73	2.73
3	3.05	3.02	3.05	3.02	3.02
4	3.37	3.56	5.57	3.56	3.56
4.72	3.92	4.11	4.11	4.11	4.11

Table 8: Evaluating the factor of safety at Shahidminar location of Rajshahi city protection embankment, Bangladesh for variation of water level when phreatic line of water with 5 degree upward inclination

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	2.40	2.65	2.66	2.65	2.65
1	2.38	2.56	2.56	2.56	2.55
2	2.46	2.64	2.64	2.64	2.63
3	2.73	2.92	2.92	2.92	2.92
4	3.26	3.44	3.45	3.44	3.44
4.72	3.92	4.11	4.11	4.11	4.11

Table 9: Evaluating the factor of safety at Ponchoboti location of Rajshahi city protection embankment, Bangladesh for variation of water level when phreatic line of water with 5 degree downward inclination

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	1.84	1.87	1.87	1.87	1.87
1	1.83	1.87	1.87	1.87	1.87
2	1.83	1.88	1.89	1.88	1.88
3	1.66	1.75	1.71	1.72	1.74
4	1.83	1.91	1.91	1.91	1.91
5	1.86	1.83	1.84	1.83	1.83
6	1.90	2.00	2.01	2.00	2.00
7	2.00	2.08	2.09	2.08	2.08
8	2.10	2.18	2.19	2.18	2.18
9	2.23	2.31	2.31	2.30	2.31
10	2.38	2.44	2.45	2.44	2.44
11	2.51	2.56	2.57	2.56	2.56
11.15	2.53	2.58	2.59	2.58	2.58

Table 10: Evaluating the factor of safety at Ponchoboti location of Rajshahi city protection embankment, Bangladesh for variation of water level with straight phreatic line of water

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	1.85	1.87	1.87	1.87	1.87
1	1.82	1.87	1.87	1.87	1.87
2	1.73	1.82	1.86	1.82	1.81
3	1.78	1.85	1.85	1.85	1.85
4	1.78	1.86	1.86	1.86	1.86
5	1.81	1.89	1.90	1.89	1.89
6	1.86	1.95	1.95	1.95	1.95
7	1.94	2.03	2.03	2.03	2.03
8	2.05	2.13	2.14	2.13	2.13
9	2.18	2.26	2.26	2.26	2.26
10	2.34	2.41	2.41	2.41	2.41
11	2.50	2.56	2.56	2.56	2.56
11.15	2.51	2.58	2.57	2.58	2.58

From the analysis, it is found that the most critical location of the water table is at about 35 % to 45% of the slope height. The minimum of the safety factor on the plot of factor of safety versus water level indicates a critical pool level. With the increase of water level horizontal thrust for water is increase and pore water pressure is decrease proportionally. Considering 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. Critical pool level indicate lowest factor of safety of the slope. From the analysis, Ponchoboti location indicates lower factor of safety for critical pool level is 1.52 which indicate slope is stable.

From analysis, it has been found that phreatic angle has great influence on the stability of slopes. Phreatic line of water with upward inclination has yielded lower factor of safety then phreatic line of water with downward inclination.

Table 11: Evaluating the factor of safety at Ponchoboti location of Rajshahi city protection embankment, Bangladesh for variation of water level when phreatic line of water with 5 degree upward inclination

Water level from ground (in meter)	LEM				
	Fellenius	Janbu	Bishop	Morgenstern-Price	Spencer
0	1.84	1.87	1.87	1.87	1.87
1	1.81	1.85	1.85	1.85	1.85
2	1.68	1.82	1.82	1.82	1.76
3	1.72	1.78	1.79	1.79	1.78
4	1.72	1.80	1.80	1.80	1.80
5	1.75	1.84	1.84	1.84	1.83
6	1.80	1.89	1.89	1.89	1.89
7	1.86	1.97	1.97	1.97	1.97
8	1.99	2.07	2.08	2.07	2.07
9	2.12	2.20	2.21	2.20	2.20
10	2.29	2.36	2.37	2.36	2.36
11	2.48	2.56	2.56	2.56	2.56
11.15	2.51	2.58	2.57	2.58	2.58

6. Conclusion:

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

1. In LEM, factor of safety of slope varies from 2.32 to 1.79 without present of water and that indicate that the slopes are stable at present without present of water.
2. In LEM, factor of safety of slope varies from 4.15 to 1.72 with variation of water level and that indicate that the slopes are stable at present with present of water.

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% to 45% of the highest water level in the slope range.
4. Phreatic line of water with upward inclination has yielded lower factor of safety then phreatic line of water with downward inclination.

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

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