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Seismic Slope Stability Analysis of Mahananda River Embankment in Bangladesh

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Abstract: Stability of structures such as embankments, dams and natural riverside slopes are hampered due to the seismic loading. To evaluate the seismic effect on stability of slopes is a major concern in the field of geotechnical engineering. Two-dimensional limit equilibrium method (LEM) is common approach for analyzing slope stability. Usually LEM is used to find out potential failure mechanisms and factors of safety for slopes. The aim of this study is to evaluate the effect of seismic loading on the stability of Mahananda River Embankment of Bangladesh by using LEM. The Bishop, Spencer, Fellenious, Janbu and Morgenster-price simplified methods are used for LEM. To conduct the study three locations of Mahananda River Embankment are selected. Soil properties are obtained from laboratory testing. The numerical analysis is carried out using geotechnical software GEO5 which is generally used for analyzing LEM based slope stability problems. From the analysis, it is noted that the factors of safety decrease with the increase of horizontal seismic coefficient for slopes. The horizontal seismic coefficient alone affects the stability of slope severely than the combined effect of horizontal and vertical seismic coefficient. The results conclude that present condition of Mahananda river embankment is stabilized under seismic loading.

Keywords: *Stability of Slope, Limit Equilibrium Method, Seismic Coefficient.*

Introduction:

Bangladesh is a land of river. Many rivers have flown through in this country. Three of Asia's largest rivers, the Ganges (locally known as the Padma), the Brahmaputra (locally known as the Jamuna) and the Meghna, flow through Bangladesh and form the fertile Bengal delta which is the largest delta in the world. In rainy season, flood is a common phenomenon in Bangladesh. Many types of crop are damaged during that time. River bank locality is also affected by flood. The houses and roads go underwater. To overcome this sever problem embankments are constructed parallel those rivers to protect living lands, towns, cities, important structures etc. The Mahananda River is a trans-boundary river originates in the Himalayas, Paglajhora Falls on Mahaldiram Hill near Chimli, east of Kurseong in Darjeeling district at an elevation of 2,100 metres (6,900 ft). It flows through the Indian states of West Bengal, Bihar, and Bangladesh. Its right bank tributary, the Mechi River forms part of Nepal's eastern boundary with West Bengal while the Kankai flows out of Nepal. The total length of the river is 360 kilometers, out of which 324 kilometers are in India and 36 kilometers are in Bangladesh. The heavy monsoonal rainfalls on the upstream catchment sometimes increase the river water level above the danger level. In most of the year the land near the bank of river floods in the normal flooding condition. For this reason in 2000 the Mohananda embankment was constructed at the bank of Mohananda river which is situated at the district of Chapai in division of Rajshahi of Bangladesh. The Mahananda embankment is 18 kilometers long. 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. A slope becomes unstable when the shear stresses on a potential failure plane exceed the shearing resistance of the soil. The additional stress due to earthquake further increases the stresses on these planes and decreases the factor of safety further [1]. Present of water also play vital role to evaluate the factor of safety of soil slope. Combined effect of earthquake and present of water can create worst condition for the slope of riverfront structure. Tayler and Burns (2005) reported that earthquake which is a burning issue is a great threat to the long term stability of slopes, particularly in earthquake active zones [2]. Xip HP (2008) showed that Wenchuan's (Sichuan province of china) embankment slope destructively ruined during the effect of earthquake [3]. Most commonly adopted methods for slope stability analysis in static condition are the limit equilibrium methods. This method is implemented in the field of geotechnical engineering due to their simplicity and effectiveness. Many methods based on this approach are available. For example, Bishop (1955), Janbu (1957), Morgentern and Price (1965), Spencer (1967), Sarma (1979). Yu et al. (1998) compared the results of LEM with other rigorous methods for the stability analysis of simple earth slopes [4]. They concluded that LEM could achieve reasonable results. Roohollah and Nazri ali (2013) presented a review on the applications and limitations of existing three-dimensional slope stability analyses based on limit equilibrium method [5]. Delwyn et al. (1999) combined finite element analysis to obtain the stresses in soil and a limit equilibrium method to obtain the factor of safety [6]. The present study evaluates the seismic effect on the stability of Mohananda embankment. Two-dimensional limit equilibrium method (LEM) is used to analyze the stability of slope of the embankment. GEO5 software is used for numerical analysis.

Field and Laboratory Tests:
To conduct the research three samples i.e., sample 1, sample 2 and sample 3 are collected from three different locations which are known as Dhainagor, Nakkatitola and Moheshpur located at the Chapai Nawabganj district, Rajshahi of Bangladesh. Figure 1 shows the three locations of Mahananda River embankment from where the samples are collected.

Figure 1: *Three locations of Mahananda River embankment from where the samples are collected.*

After collecting samples, different laboratory tests are performed such as field density, specific gravity, moisture content, direct shear test, grain size analysis in our laboratory. From those test results void ratio, dry unit weight, saturated unit weight are calculated.

Field density measurement:
Field density test is performed to determine the in-place density of undisturbed soil obtained by pushing or drilling a thin-walled cylinder using core cutter method. ASTM D2937-00-Standard Test is followed to measure the field density. It is found, the field densities are 15.46 kN/m^3, 15.08 kN/m^3 and 15.87 kN/m^3 for sample 1, sample 2 and sample 3 respectively.

Specific gravity:
The specific gravity of soil is measured by using a pycnometer. First, weight of the empty clean and dry pycnometer is determined and 10g of a dry soil sample in the pycnometer is placed. Weight of the pycnometer containing dry soil is determined. Then added distilled water to fill about half to three-four of the pycnometer. A partial vacuum to the contents for 10 minutes is applied to remove the entrapped air. The pycnometer with distilled water is filled to the mark. The weight of the pycnometer and contents was determined. Then it is filled with distilled water only (to the mark). Finally the weight of the pycnometer and distilled water is determined. Specific gravity of sample 1, sample 2 and sample 3 are 2.70, 2.67 and 2.66 respectively.

Direct shear test:
A direct shear test is a laboratory or field test which is used by geotechnical engineers to measure the shear strength properties of soil. ASTM D 3080 is followed to perform this test. First the test is executed on three or four specimens from a relatively undisturbed soil sample. Then a specimen is placed in a shear box which has two stacked rings to hold the sample; the contact between the two rings is at approximately the mid-height of the sample. A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails, or through a specified strain. The local applied and the strain induced is recorded at frequent intervals to determine a stress-strain curve for each confining stress. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (C) and the angle of internal friction. Finally the results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the y-axis and the confining stress on the x-axis. The y-intercept of the curve which fits the test results is the cohesion, and the slope of the line or curve is friction angle. It is found that cohesion (C) of samples are 6.96, 7.94 and 7.53 and angle of internal frictions are 34.82, 29.89 and 30.76 for sample 1, sample 2 and sample 3 respectively.

Grain size analysis:
This test is carried out to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. The grain size distribution curves of three types of sample are shown as below:

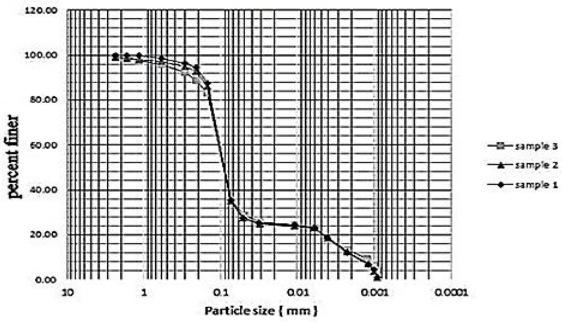

Figure 2: *Grain size distribution curves of three samples.*

From the above graph it is found that the type of samples is sandy clay loam. Table 1 represents the basic properties of soil.

Table 1: Basic properties of soil

No.	Soil Properties		Sample 1	Sample 2	Sample 3
1	Grain size distribution (mm)	D_{10}	0.002	0.0019	0.0015
		D_{30}	0.06	0.076	0.063
		D_{60}	0.12	0.13	0.12
2	Specific gravity, G_s		2.70	2.67	2.66
3	Shear strength parameters	Cohesion, C (KN/m^2)	6.96	7.94	7.53
		Angle of internal friction, ϕ (degree)	34.82	29.89	30.76
4	Field density, γ (KN/m^3)		15.46	15.08	15.87
5	Moisture content, w (%)		13	11	13
6	Void ratio, e		0.93	9.2	0.86
7	Dry Unit Weight, γ_d (KN/m^3)		13.68	13.59	14.04
8	Saturated Unit Weight, γ_{sat} (KN/m^3)		18.43	18.29	18.57
9	Soil type		Sandy clay Loam	Sandy clay loam	Sandy clay loam

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Numerical Analysis:

The slopes of three locations are measured. Using those measurements, the geometric model of three locations are plotted. GEO5 software is used to obtain numerical analysis of those models [7]. Figure 3, 4 and 5 show the geometric model of three locations.

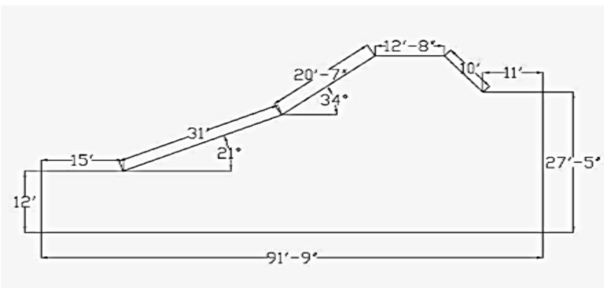

***Figure 3:** Geometric model of slope at Dhainagor location*

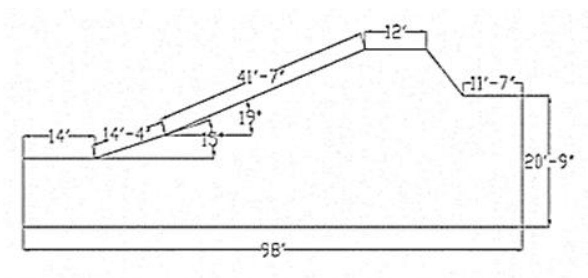

***Figure 4:** Geometric model of slope at Nakkatitola location*

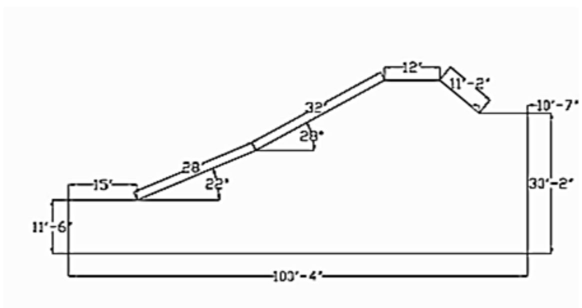

***Figure 5:** Geometric model of slope at Moheshpur location*

Figure 6 indicates the numerical model of slope at Dhainagor location which is analyzed by GEO5 software.

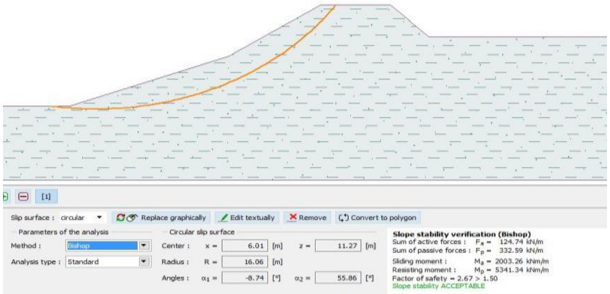

Figure 6: Numerical model of slope at Dhainagor location

Input parameters:

It has been needed some parameters in order to analyze GEO5 software such types of parameter are known as input parameters such as cohesion ©, Angle of internal friction (φ), Field density (γ), Specific gravity (Gs) , Saturated Unit Weight (γ_{sat}) and soil type.

Results and Discussions:

The stability of slope is analyzed under 4 cases i.e. existing condition (without any consideration of seismic load and moisture content), various moisture content condition, seismic load condition and under seismic load with moisture content (30%) condition. The factor of safety is calculated of three locations by using different methods such as Bishop, Fellenious, Spencer, Janbu etc. For existing condition by using GEO5 software. Table 2 shows the factor of safety of three locations of Mahananda river embankment at different methods for existing condition. From the table, it is shown that factor of safety for existing condition is more than 1.5. So, the slopes of three locations are stable. Because it is considered that when the factor of safety is larger than 1.5, then the slope is taken as a stable and otherwise it is called unstable.

Table 2: factor of safety of three locations of Mahananda river embankment at different methods for existing condition.

Location	Bishop	Fellenious/ Petterson	Spencer
Dhainagor	2.62	2.47	2.59
Nakkatitola	3.27	3.18	3.27
Mohespur	2.27	2.18	2.26

Now the factor of safety is evaluated under the variation of moisture content at Dhainagar location. Then it is found that factor of safety decreases with the increase of moisture content. So, Table 3 presents the factor of safety at Dhainagar location for vaeiation of moisture content.

Table 3: Evaluating the factor of safe at Dhainagar location for variation of moisture content

Moisture Content, W(%)	Bishop	Fellenious/ Petterson	Spencer
0	2.72	2.59	2.71
5	2.67	2.54	2.66
10	2.62	2.49	2.61
15	2.58	2.45	2.57
20	2.54	2.41	2.53
25	2.50	2.38	2.50
30	2.47	2.34	2.46

According to the same procedure factor of safety is calculated of Nakkatitola and Moheshpur under various moisture content. And Figure 7, 8 and 9 show the variation of factor safety against moisture content of three locations according to Bishop method.

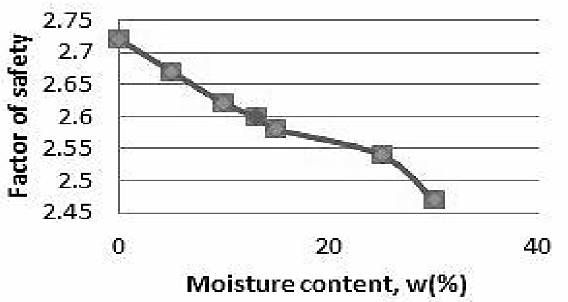

Figure 7: variation of factor of safety against moisture content of Dhainagor location (Bishop method).

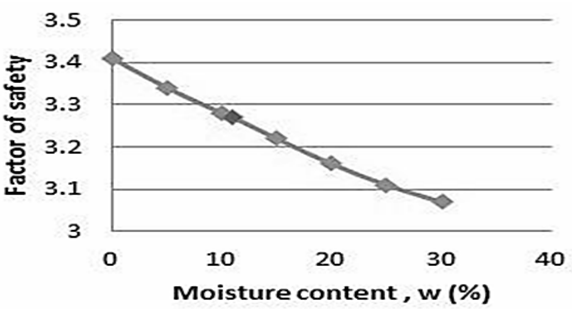

Figure 8: variation of factor of safety against moisture content of Nakkatitola location (Bishop method).

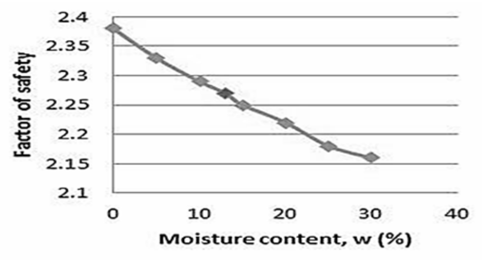

Figure 9: *variation of factor of safety against moisture content of Moheshpur location (Bishop method).*

Now Table 4 indicates relation among horizontal seismic coefficient K_h, MCS scale and Ricter scale which is followed by GEO5.

Table 4: relation among horizontal seismic coefficient, MCS scale and Ricter scale

K_h	Earthquake intensity in MCS 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

Then the factor of safety is evaluated at Dhainagar location for seismic load, considering the ratio of vertical seismic coefficient and horizontal seismic coefficient is 0.5 (K_v/K_h = 0.5). From the Table 5, it is observed that factor of safety decreases with the increase of both horizontal and vertical seismic coefficient and also upto the value of k_h=0.25 and k_v=0.125 the slope is stable. So, table-5 indicates the factor of safety at Dhainagor location for seismic load, considering k_v/k_h =0.5.

Table 5: evaluating the factor of safety at Dhainagor location for seismic load, considering k_v/k_h =0.5

K_h	K_v	Bishop	Fellenious/ Petterson
0	0	2.60	2.47
0.005	0.0025	2.57	2.45
0.01	0.005	2.55	2.42
0.03	0.015	2.44	2.32
0.05	0.025	2.34	2.23
0.1	0.05	2.12	2.01
0.25	0.125	1.57	1.48
0.4	0.20	1.24	1.16
0.5	0.25	0.96	0.97

According to the same procedure factor of safety is calculated of Nakkatitola and Moheshpur under seismic load considering k_v/k_h =0.5. Now, Figure 10 is drawn to compare the stability condition among the three locations for seismic load, considering k_v/k_h =0.5. From this Figure 10, it is shown that Moheshpur location is the worst one among the three locations.

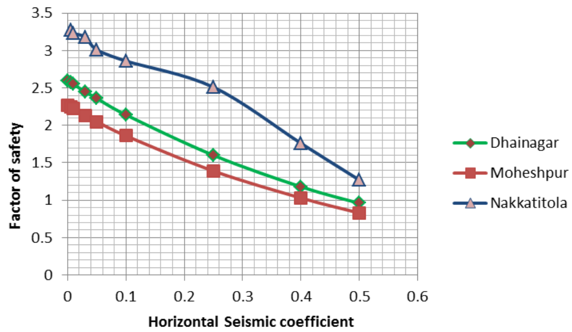

Figure 10: *comparing the stability condition among the three locations for seismic load, considering kv/kh =0.5.*

Now the factor of safety is evaluated at Dhainagar location for both moisture content (up to 30 %) and seismic load, considering the ratio of vertical seismic coefficient and horizontal seismic coefficient is 0.5 (K_v/K_h = 0.5). From the Table 6, it is observed that factor of safety decreases with the increase of both horizontal and vertical seismic coefficient and also upto the value of k_h=0.25 and k_v=0.125 the slope is stable. So, Table-6 indicates the factor of safety at Dhainagor location for both moisture content (30 %) and seismic load, considering k_v/k_h =0.5.

Table 6: Evaluating the factor of safety at Dhainagor location for both moisture content (up to30 %) and seismic load, considering k_v/k_h=0.5

K_h	K_v	Bishop	Fellenious
0	0	2.47	2.34
0.005	0.0025	2.45	2.32
0.01	0.005	2.42	2.30
0.03	0.015	2.33	2.21
0.05	0.025	2.24	2.12
0.1	0.05	2.02	1.92
0.25	0.125	1.50	1.41
0.4	0.20	1.10	1.02
0.5	0.25	1.05	0.94

According to the same procedure factor of safety is calculated of Nakkatitola and Moheshpur under for both moisture content (up to 30 %) and seismic load, considering k_v/k_h =0.5.And Figure 11, 12 and 13 are plotted for the variation of factor of safety against both seismic load and moisture content with seismic load (up to 30%) . Analyzing all the figures, according to the Bishop method it is found that the factors of safety against moisture content with seismic load (up to 30%) are lower than the factors of safety against seismic load (considering K_v/K_h = 0.5).

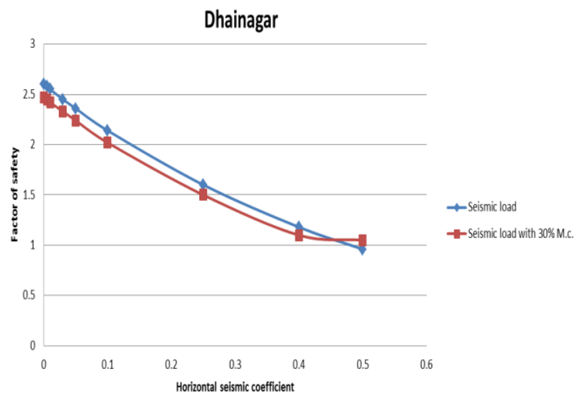

Figure 11: *variation of factor of safety against seismic load and 30 % moisture content with seismic load (Bishop method).*

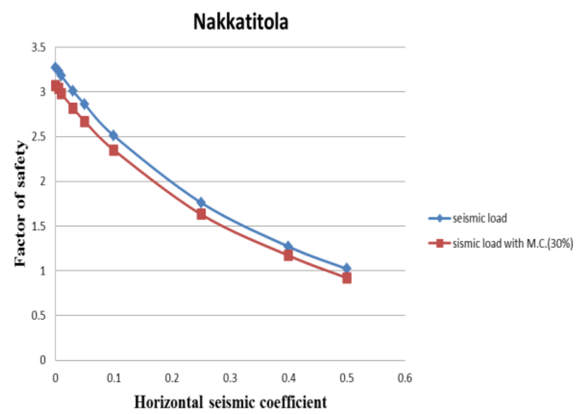

Figure 12: *variation of factor of safety against seismic load and 30 % moisture content with seismic load (Bishop method).*

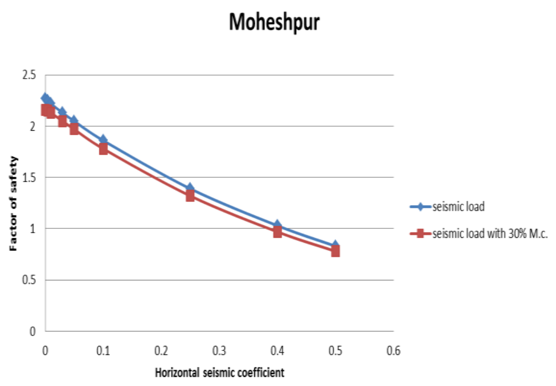

Figure 13: *variation of factor of safety against seismic load and 30 % moisture content with seismic load (Bishop method).*

Improving the stability:

If anchor is pushed on the embankment then the factor of safety is increased than previous condition. Many anchors may be used as a suitable distances or suitable force. So, this technique can be taken for improving the stability. Table 7 represents the Differentiation of factor of safety between with or without anchor considering up to 30 % moisture content and seismic load.

Table 7: Differentiation of factor of safety between with or without anchor considering up to 30 % moisture content and seismic load.

Dhainagar (without anchor)	1.05	0.97	1.07	1.06	1.06
Dhainagar (with anchor)	1.69	1.66	2.12	2.00	2.12

Conclusions:

In LEM, stability of slope varies 3.27 to 2.18 without seismic load that indicates the slopes are stable now.
Factor of safety decreases with increase of the horizontal seismic load coefficient (K_h)
In LEM, upto the value K_h= 0.25 and K_v= 0.125 (7 for Richter scale) slope is stable under seismic load condition.
In LEM, upto the value K_h= 0.25 and K_v= 0.125 (7 for Richter scale) slope is stable under (30%) moisture content with seismic load condition.

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