Seismic Analysis of Siri Dam Using Pseudo-Static Approach

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Abstract: ***In this study, the seismic risk analysis of Siri embankment dam, situated on Meghna river has been performed using pseudo-static method. The dam was selected for four reasons: Firstly, the dam is situated in Zone II, which is becoming very vulnerable to Earthquake. Secondly, there is a lack of case history performance, which made it more unpredictable. Thirdly, the embankment dam is situated on Meghna, which is one of the most important river of Bangladesh. And lastly but not least, no earthquake occurred in these faults for many years, which means huge strength has gathered around the fault that could cause serious earthquakes in Bangladesh and its neighboring areas at any time. This paper represents a seismic risk assessment on a small scale, which is only for the dam area. The Factor of safety obtained for slope stability analysis and the liquefaction indicates the safety of the structures. But as Earthquake is one of the catastrophic and unpredictable disaster, safety measures like constructing houses and other infrastructures near the dam should be avoided. The dam was analyzed at U/S & D/S considering seismic coefficient in the range of 0.05 ~ 0.15. It is found that at k = 0.2, the dam is vulnerable in earthquake.***

Keywords: Embankment dam, Pseudo-static, factor of safety, seismic coefficient, Upstream, Downstream

1. Introduction

Dam should be safe to resist overturning moment, seepage, earthquake etc. Its stability depends on shape of the dam, its profile, filter and seepage profile & quality of earth dam etc. Because of the lack of case history performance, the prediction of Embankment behavior under Earthquake loading generally has significant uncertainty[1]. So seismic risk analysis is needed for the safety of the dam. It is needed for preventing the settlement and cracking of embankment, particularly near crest of dam. Seismic analysis is needed for reducing the instability of upstream and downstream slopes of dam. It is essential for the reduction of freeboard due to settlement or instability which may result in overtopping of dam. Another purpose of seismic design & analysis is to prevent damages to outlet works through embankments, leading to leakage & potential internal erosion of Embankment dam. Embankment dams resting on unconsolidated landfill can turn into a great threat to human civilization during earthquake. Sociologic factors like the population nearby the dam, the importance of the area, time of the earthquake occurrence, community preparedness for the possibility of such an event is also very important[2].

The study of probability analysis of Naulong dam [3] was carried out on Mula river at Sunth, about 30 Km from Gandava town in Tehsil and District Jhal Magsi of Balochistan Province. From the analysis, it was concluded that the pseudo-static case is critical for this dam. Another study on the liquefaction analysis of Tendaho Earth-fill dam which is a part of Tendaho Dam and Irrigation Project was done[4]. The dynamic analysis results revealed that the loosely deposited alluvium foundation would completely liquefy under earthquake loading, endangering the stability of the dam. Hence, following the recommendations made in this study, the 6 to 10 m thick alluvium foundation under the dam seat has been completely removed prior to placement of the dam. Construction of the dam has been completed recently.

2. Dam Details

2.1 Location and Structure

- The dam is around 36.5 meter in length.
- This is adjacent with a closure dam of length 3.85 kilometer.
- The maximum height of the crest is 12.02 m from datum.
- The length of the reservoir is 75meter.
- The volume of the reservoir is 24637 m^3, with a length of 75 m and hydraulic head of 9 m.

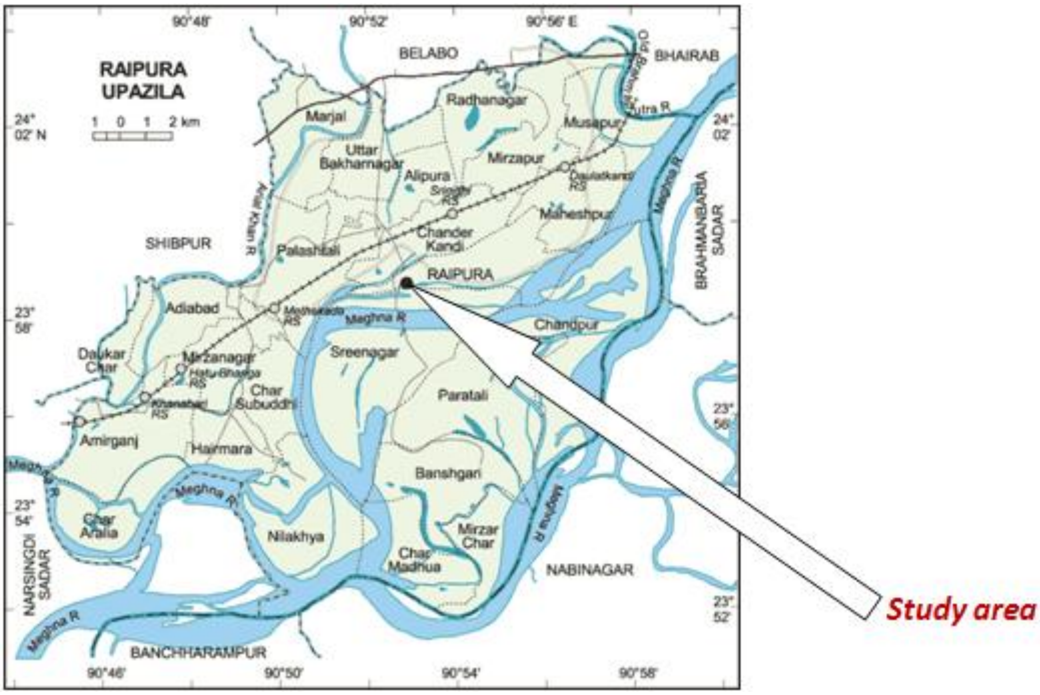

Figure 2.1: Study area at Siri Dam in Raipur Upazela, Mymansingh District, Bangladesh.

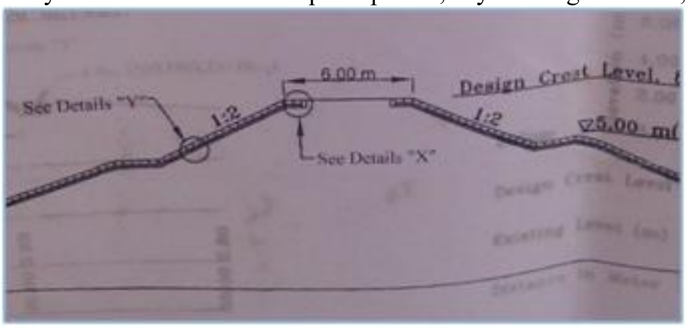

Figure 2.2: Cross section of The selected embankment dam (water development board)

2.2 Section of Dam

The dam is built for the protection against flood for Siri and the surrounding area. The embankment dam will be considered as a small dam.

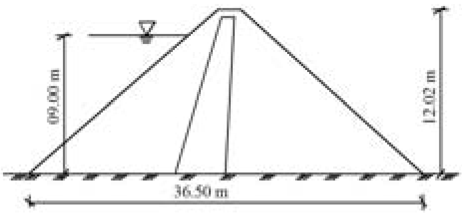

Figure 2.3: Cross section of the Embankment Dam

2.3 Soil Properties

Table 2.3.1: Soil Texture

Soil Type	*Amount (in %)*
Clay	30.8
Silt	21.5
Sand	48.3
Others	1.4

(Source: Bangladesh Geological Board Of Survey)

Table 2.3.2: Soil properties for design

Material	Shear Wave Velocity (m/s)	Mass Density (kg/m^3)	Poisson's Ratio	Angle of Internal Friction	Cohesion Kpa
Core	180	1910	0.28	26.5°	32.2
Shell	190	2050	0.36	38°	0

(Source: Bangladesh Geological Board Of Survey)

3. Pseudo-static Method

Circular arc method [IS 7894-1975] is used to determine the slip circle. Three sample trial circles are shown in **Figure 3.1** and **Figure 3.2**, for which analysis is done. Factor of safety is evaluated by the following equation for the three samples[5].

$FS = C\,Lab + [\{(W - F_v)\cos\beta\} - F_h \sin\beta]\tan\varphi / [(W - Fv)\sin\beta + F_h \cos\beta]$

Where,

L=Length of the arc a-b, C=cohesion,

β=Angle between the vertical and the line passing through the C.G. of the slice

φ =Angle of internal friction,

F_h =Horizontal seismic coefficient

Fv =Vertical seismic co-efficient

A team which consists of geologists, seismologists and geotechnical engineers, are concerned about foundation of dam, in-situ geotechnical properties of dam. Since earthquake loading is rapid, stability for an earth dam is generally considered under un-drained condition[1].

Seismic slope stability is influenced by cyclic stresses induced by earthquake shaking and the cyclic stress-strain behavior of the materials within the body of the dam and that of foundation soils.

According to pseudo-dynamic method, a dynamic factor of safety of less than a unity for a short time during earthquake shaking does not indicate complete failure. It means there is a potential relative motion between the soil above the slip surface and the rest of the sliding block.

3.1. Analysis for U/S Slope

From the past studies and IS 7894-1975, it can be inferred that U/S slope of the embankment dam become very vulnerable in the sudden drawdown and reservoir partial pool condition. While calculating various forces acting on the dam, whole section is divided into two parts: 1. Zones above phreatic line: All the zones above phreatic line have been considered as moist in the computation of driving as well as stabilizing forces

2. Zones in drawdown range:

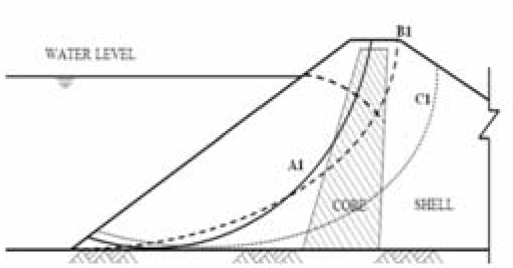

Figure 3.1: Trial slip circles on Upstream Side

For the calculation of driving forces, core materials is considered as saturated and shell material is considered as moist while for the resisting forces both core and shell are considered as submerged.

3.2. Analysis for D/S slopes:

The method is repeated for downstream slope. In the analysis for the D/S slope, steady seepage condition is considered. The condition is developed when water table is maintained at a constant level for sufficiency for longer time and due to that phreatic line is developed in the dam body.

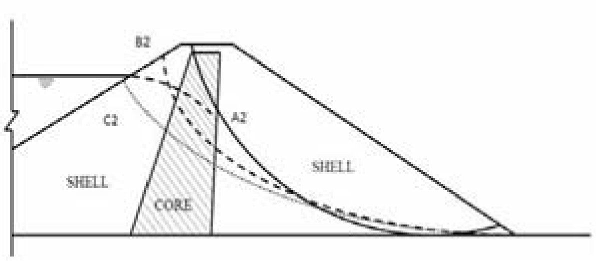

Figure 3.2: Trial slip circles on Downstream Side

The procedure for the drawing of circular arc and calculation is same as that of mentioned for U/S slope, only change is made in direction of earthquake excitation, which is now considered in the downward direction. Three different circles are shown in the figure.

Table 4.1: Required Factor of Safety

Case	*Slope*	*Required*
Steady state seepage-normal pool	DS	1.5
Steady state seepage-surcharge pool	DS	1.4
Steady state seepage-partial pool	US	1.5
RDD-Normal pool	US	1.3
Pseudo-static Earthquake	US	>1
Pseudo-static Earthquake	DS	>1
Pseudo-dynamic Earthquake	US & DS	>1
Liquefaction		>1

4. Factor of Safety in Pseudo-static Method

The minimum required factor of safety for different cases are given in the table 4.1[3]:

4.1 Factor of Safety for Upstream Slope

In this method, empirical values(k_h, k_v) are typically adopted for the seismic co-efficient. This lies in the range of 0.05-0.15.From the analysis of dam for Upstream slope(pseudo-static method) following chart has been obtained:

Table 4.2: Factor of safety for U/S

K_h	K_v	*Up-stream Side*		
		Slice A1	*Slice B1*	*Slice C1*
0		1.56	2.12	2.39
0.1	0	1.24	1.61	1.77
0.1	0.05	1.20	1.59	1.75
0.15	0	1.11	1.43	1.56
0.15	0.075	1.08	1.39	1.51
0.2	0	1.00	1.28	1.39
0.2	0.1	0.96	1.22	1.32

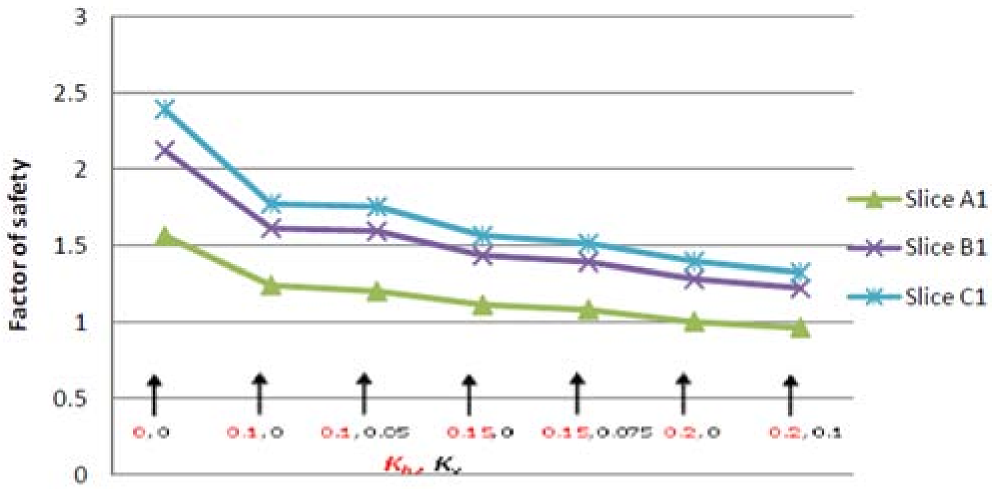

Figure 4.1: Factor of Safety of Different slices in U/S

4.2 Factor of Safety for Downstream Slope

Table 4.3: Summary of F.S. evaluated for Downstream Slope

K_h	K_v	Downstream Side		
		Slice A2	Slice B2	Slice C2
0		1.69	1.85	2.13
0.1	0	1.33	1.44	1.61
	0.05	1.31	1.42	1.59
0.15	0	1.19	1.28	1.43
	0.075	1.16	1.25	1.39
0.2	0	1.07	1.15	1.28
	0.1	1.03	1.10	1.22

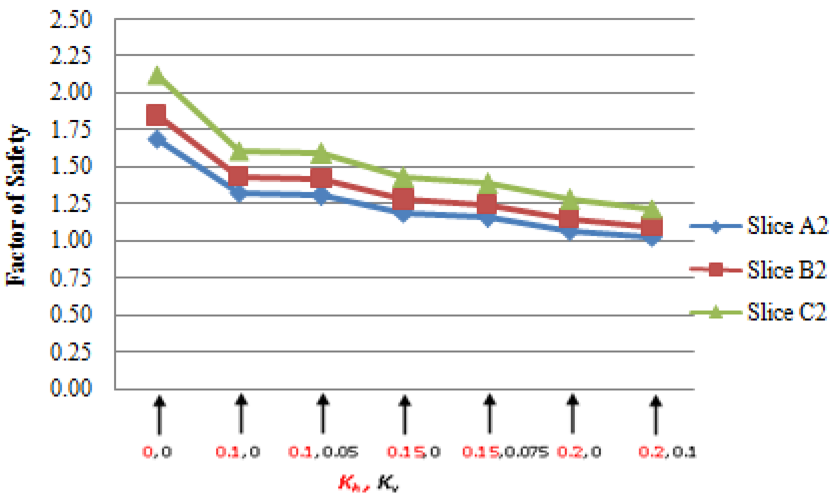

Figure 4.2: Factor of Safety of Different slices in D/S

From the table 4.2 ,it is observed that the minimum factor of safety for static case of upstream is 1.56.While for seismic case the minimum factor of safety is 0.96,which is obtained for K_h =0.2.It has been also observed that the value of factor of safety is decreasing with the enhancement of K_h. From the table 4.1, it has been observed that in seismic slope stability analysis, if factor of safety is more than or equal to 1, the slope is considered to be stable. But ,if the factor of safety is less than one, the slope is considered to be unstable. So, from the chart of Factor of safety for upstream slope, slice A1 is taken as unstable(for k_h=0.2,k_v=0.1). The minimum desirable Factor of safety for downstream slope of embankment dam subjected to earthquake condition is 1.

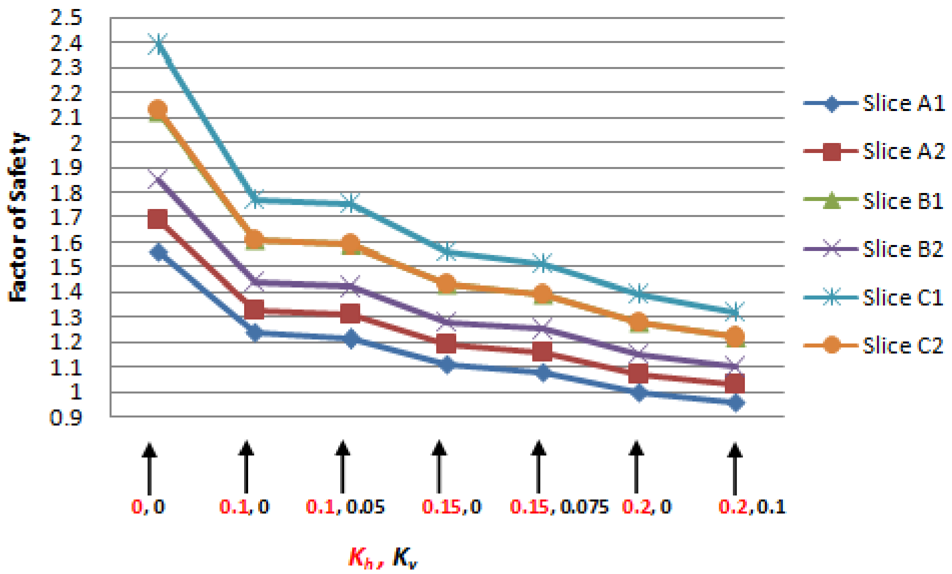

Figure 4.3: Comparison of Factor of Safety of Different slices in U/S and D/S

From the table 4.3, it is shown that the minimum factor of safety for static case is 1.69. While for seismic case, the minimum factor of safety has been obtained for K_h =0.2, 1.03.And it is also been observed that the values of factor safety is decreasing with the enhancement of value of K_h.

5.5 Liquefaction Analysis

F.S.=CRR/CSR=0.22881/0.18=1.27

Here, FS for liquefaction is greater than 1.So the soil will not be susceptible for liquefaction. Because a factor of safety less than 1.00 indicates failure is likely to be occurred[6]. Though sometimes for the inappropriate data and the inadequate knowledge of earthquake, soil with factor of safety greater than 1.00 can also be liquefied.

5. Conclusion

Siri embankment dam is one of the most important infrastructures for local area. Its primary object is to protect the surrounding area from flood during the monsoons. The dams total height is 12.02 meter, whereas the width of the crest is 6 meter and the length of the base is 36.5 meter. The Factor of safety has been derived for the Embankment dam through the Pseudo-static method and Pseudo-dynamic method. Factor of safety for liquefaction has been also derived here. An empirical value has been taken for horizontal seismic co-efficient and vertical seismic co-efficient during the calculation of factor of safety by Pseudo-static method. Due to the lacking of data regarding Earthquake, it is possible to derive factor of safety only for k_h =0.15. The minimum factor of safety for upstream slope by Pseudo-static method is 0.96 and for Downstream is 1.03. From the results, it has been seen that, the dam is almost safe during the Earthquake, as the value of Factor of safety only once crosses the line below 1. The structure is also not susceptible to liquefaction, as the factor of safety for liquefaction is also greater than 1, which indicates the safety of structure. This paper represents a seismic risk assessment application on a small scale, which is only for the dam area. The Factor of safety obtained for slope stability analysis and the liquefaction indicates the safety of the structures. But as Earthquake is one of the catastrophic and unpredictable disaster, safety measures like constructing houses and other infrastructures near the dam should be avoided.

References

[1] Tripathy L.K. (2011) "Seismic analysis of earth dams", Proceedings of Indian Geotechnical Conference(Paper No.F-205.)
[2] Geological Survey Board of Bangladesh
[3] Khan, & Malik, (2013), "Probability and Sensitivity Analysis of the Slope Stability of Naulong Dam" , *Pak. J. Engg. & Appl. Sci. Vol. 13,(p. 54-64).*
[4] Hadush Seged and Messele Haile, (2012), "Earthquake induced liquefaction analysis of Tendaho earth-fill dam".
[5] Cristiano Melo and Sunil Sharma (2004) , "Seismic coefficients for pseudostatic slope analysis" , 13th World Conference on Earthquake Engineering , Vancouver, B.C., Canada, Paper No. 369.
[6] Ajanta Sachan ,"Liquefaction",
[7] Jibson, R.W., (2011), Methods for assessing the stability of slopes during earthquakes—A retrospective: Engineering Geology, v. 122, p. 43-50.
[8] Maksat Omarov, B.S. (2010) , "Liquefaction potential and post-liquefaction settlement of saturated clean sands; and effect of Geo-fiber reinforcement".
[9] Water development board of Bangladesh
[10] Arora S.K.(1993)"Soil Mechanics and Foundation Engineering"