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SEISMIC STABILITY OF SLOPES IN LAYERED COHESIVE SOILS

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ABSTRACT

Earthquake is one of the major causes of slope failure throughout the world. It is pretty rare to find soil slope which has similar property throughout its whole formation. Significance attention ought to be given to layered slope dependability, in light of the fact that the real soil slope is regularly complex with an organization of multilayer soils because of natural arrangement or sometimes artificial filling. These slopes, when exposed to forces of an earthquake, leads to catastrophic events. Bangladesh is situated in the world's one of the most active earthquake zones and has often been exposed to the various magnitude of earthquakes over the years which sometimes led to catastrophes. Recent events have made it ever so important that a proper analysis must be done in order to avoid countless losses of lives, livestock, structures and other resources. However, cohesion (c) a shear strength parameter of soil can contribute to achieving a greater factor of safety.

The goal of this study is to analyze the relationship between cohesion of soil and the factor of security of a clay layered slope model under various combinations of horizontal and vertical seismic coefficients. This was done by assuming a standard slope model with two layers. Two cases were considered. In the first case, the cohesion value of the bottom layer was fixed and the value of cohesion of the other layer was varied. The second case was vice-versa. Then various combinations of earthquake force were applied on the slope model. All the other properties such as unit weight angle of friction etc. were kept constant for all cases. The effect of greater cohesion values on the top or bottom layer is also assessed. Suitability of greater cohesion value on either top or bottom layer was also assessed on the basis of the factor of safety for different combinations and conditions. From the study, two major decision was made for the particular layered slope model. It was observed that the factor of safety decreases with the increase in seismic coefficients and increases with the increase in cohesion value for all ratios of horizontal and vertical seismic coefficients. The second decision was that when the greater value of cohesion is placed at the top layer of the slope the factor of safety is substantially larger than the factor of safety which is achieved when the larger value of cohesion is placed at the bottom. This decision was made by observing the maximum and minimum factor of safety of the slope considering all ratios, all horizontal seismic coefficient values and all cohesion values.

It was observed that when greater cohesion placed and fixed at top layer maximum factor of safety that is achievable rose up to as high as 1.43 and a minimum factor of safety was 0.79 considering all of the bottom the layer the maximum factor of safety only got to rise as high 1.37 as and minimum factor of safety in was only 0.61. The LEM module of GEO5 software (2019 version) was used for this study.

Keywords: *Earthquake, Slope, Layer, LEM, GEO5.*

1. INTRODUCTION

Bangladesh is in a delta formed by three major rivers which are Brahmaputra, Ganges, and Meghna. The system drains a basin of some 1.76 million sq km and carries not only snowmelt water from the Himalayas but also runoff water from some of the highest rainfall areas of the world. During the last thousand years, the silt conveyed by the tremendous releases of these streams has assembled an expansive delta, framing the greater part of the huge zone of Bangladesh and the submerged delta-plain. These enormous residues are the significant wellsprings of the arrangement of 80% soils of the nation. (Brammer H., 1996) Soil slope related calamities cause loss of lives, livestock, buildings, structures overall contributing to massive tragedy in a country's economy. In Bangladesh, disasters such as landslide in the hilly areas of the country are mostly triggered by slope failure. So in a sense, the slope failure directly contributes to the massive loss of infrastructure, food insecurity, scarcity of safe drinking water, environmental challenges, poverty and livelihoods, environmental catastrophe etc. River embankment and bank failures also lead to the destruction of massive investments. Bangladesh is located in one of the most active seismic zones has always been a victim of slope related failure especially in CHT tracts. On 11 June 2007, heavy monsoon rain triggered a series of landslides and floods in Rangamati, Chittagong and Bandarban - three hilly districts of Bangladesh and killed at least 107 people. (Sarker & Rashid, 2013) On June 12, 2018, another 11 people died due to Landslide failure in Chattogram. Recent incidents of slope related failures such as landslides due to an earthquake in Sunamganj and Sylhet (2009), Chittagong (2017), Rangamati (2003) claimed numerous lives and added distresses to even more people. (Daily Star, n.d.). In this study, the factor of safety was evaluated for a fixed slope model having two layers. In the first stage, a fixed value of cohesion was kept in the bottom layer of slope and increasing the value of cohesion in the top layer of the slope. For each case, an earthquake is applied in the form of a seismic coefficient and the factor of safety is measured. Then the cohesion value of the top layer of the slope model is kept fixed and the same process is repeated. The pattern of factor safety was observed for a fixed bottom layer cohesion and fixed top layer cohesion under increasing seismic coefficient for various ratios of the horizontal seismic coefficient to the vertical seismic coefficient. The study was conducted by using the "Slope Stability" module of the GEO5 (2019) software.

2. METHODOLOGY

The basic of LEM is to assume a failure surface of a slope and then analyse that. This factor of safety is calculated by dividing the shear strength of the soil by the stresses working on that particular section.

2.1 Literature Review

Fellenius introduced this method with an ordinary slip circle(Fellenius, 1936). After that Bishop developed the method by considering the inter-slice normal force in the equation which then became non-linear(Bishop & Morgenstern, 1960). Janbu further developed the formula(Janbu, 1954) for all shapes of failure. Morgenstern-Price, Spencer, and others then took the method to another level by considering other factors and criteria of equilibrium condition.(Morgenstern & Price, 1965; Spencer, 1967). Fellenius introduced this method with an ordinary slip circle(Fellenius, 1936). After that Bishop developed the method by considering the inter-slice normal force in the equation which then became non-linear(Bishop & Morgenstern, 1960). Janbu further developed the formula(Janbu, 1954) for all shapes of failure. Morgenstern-Price, Spencer and others developed it considering other factors and criteria of equilibrium condition.(Morgenstern & Price, 1965; Spencer, 1967).

2.2 Horizontal and Vertical Seismic Coefficients

Horizontal and vertical earthquake force is defined by the following equations:

$$F_h = \frac{a_h * w}{g} = K_h * W \quad (1)$$

$$F_v = \frac{a_v * w}{g} = K_v * W \quad (2)$$

Here, a_h and a_v are, respectively, horizontal and vertical pseudo-static accelerations, g is the gravitational acceleration constant, and W is the slice weight. The acceleration ratio is given as a/g which is a dimensionless coefficient. The inertia effect is specified as K_h and K_v, the coefficients of acceleration in horizontal and vertical directions, respectively. The recommendations for choosing an earthquake coefficient value is given below. (Melo & Sharma, 2004)

Table 1. Recommended Horizontal Seismic Coefficients (Summarized by Cristiano Melo & Sunil Sharma)

Horizontal Seismic Coefficient, K_h	**Description**	
0.05 - 01.5	In the United States	
0.12 – 0.25	In Japan	
0.1	Severe earthquakes	Terzaghi
0.2	Violent destructive earthquakes	
0.5	Catastrophic earthquakes	
0.1	Major Earthquake, FOS > 1.0	Corps of Engineers
0.15	Great Earthquake, FOS > 1.0	

2.3 Geometry of Numerical Model

In all dimensions, the SI unit was adopted. The lateral width of the model slope was fixed by taking minimum X-axis distance as 0 and maximum X-axis distance as 30 meters. Also, the depth of the model below the deepest interface point was set to 5.0 meters. After fixing up the ranges, the slope was plotted textually by the following co-ordinates shown in the following table 2.

Table 2: Co-ordinates of Model Slope

	Step 1					**Step 2**	
x(meter)	0	6	18	30	**x(meter)**	6	0
z(meter	0	0	12	12	**z(meter)**	30	0

The following figure 1 shows the geometrical model of the slope used.

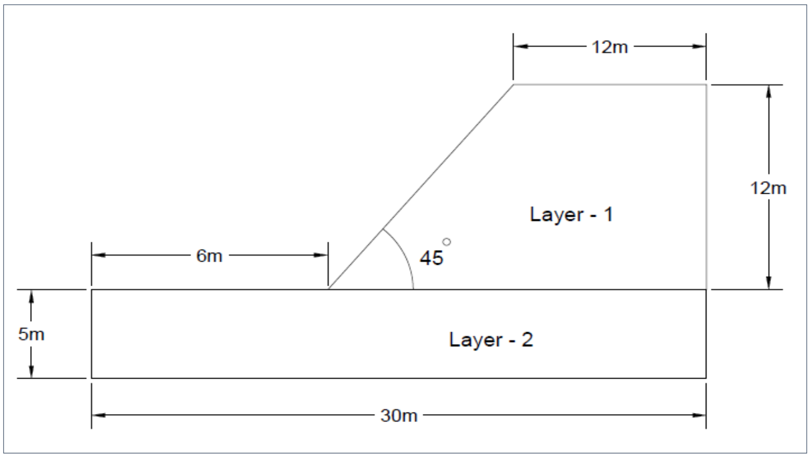

Figure 1: Geometry of Layered Slope Model

In the case of soil, by considering two layers of different soil cohesion, the work is done. The classification type of soil was set to Standard. CL, CI – Clay with medium or low plasticity was adopted for the study where the consistency of the soil was stiff consistency and degree of saturation, S_r< 0.8 (Easy to penetrate by a nail). Stress state was considered effective without the effect of soil foliation.

The mode of uplift pressure was considered standard. The properties of Soil used for this study are given in table 3.

Table 3: Properties of Soil used for this study

Properties	Values
Unit weight, γ (kN/m^3)	21.00
The angle of internal friction, ϕ_{ef} (˚)	19.00
Saturated unit weight, γ_{sat} (kN/m^3)	21.00

The analysis was done by five methods. Bishop, Fellenius, Spencer, Janbu and Morgenstern by considering fixed cohesion value in one (top/bottom) layer and gradually increasing cohesion value in another layer. Earthquake force was applied as horizontal and vertical seismic coefficients and four ratios of K_v/K_h were considered (0.25, 0.5, 0.75 and 1.0). For horizontal seismic coefficient 4 values were considered (0.1, 0.2, 0.3 and 0.4).

At first bottom layer's cohesion is taken as fixed and the top layer's cohesion is changed randomly. After this, top layers cohesion is taken as fixed and the bottom layer's cohesion is changed randomly. Table 4 shows the cohesion values for the layered slope model.

Table 4: Cohesion values for the layered model

When cohesion for the bottom is fixed		When cohesion for the top is fixed	
Bottom Layer's Cohesion, kPa	**Top Layer Cohesion, kPa**	**Top Layer's Cohesion, kPa**	**Bottom Layer's Cohesion, kPa**
40	20	40	20
40	25	40	25
40	30	40	30
40	35	40	35

3. RESULTS & DISCUSSION

3.1 Relationship between Factor of Safety and Seismic Coefficients for all Cohesion Values

The analysis results for homogeneous layered clay slope model are shown in the following four tables i.e. table 6, table 7, table 8, and table 9. In the first part, the results are shown when the cohesion value of the bottom layer is fixed at 40 kPa. In the other part of the table, the results are shown when the cohesion value of the top layer is fixed at 40kPa. In both cases the cohesion value of other layer is varied. In the other layer at first, the cohesion value is put as 20 kPa. Then the cohesion value was gradually increased by 5 kPa. The value of K_h for all ratios of K_v/K_h is varied as 0.1 to 0.4. In all the tables C_1 represents bottom layer cohesion and C_2 represents top layer cohesion. The following tables show the variation of a factor of safety for layered clay slope model when the fixed value of cohesion is 40 kPa and the value of cohesion of other layers is varied from 20 KPa to 35 KPa.

Table 5: Factor of safety for all values of K_v/K_h for variable C = 20kPa

For C_1=40 kPa and C_2=20 kPa						**For C_1=20 kPa and C_2=40 kPa**					
K_v/K_h	K_h	0.1	0.2	0.3	0.4	K_v/K_h	K_h	0.1	0.2	0.3	0.4
0.25	Bishop	0.96	0.84	0.73	0.64	0.25	Bishop	1.30	1.13	0.98	0.85
	Fellenius	0.93	0.81	0.70	0.61		Fellenius	1.25	1.07	0.93	0.80
	Spencer	0.96	0.84	0.78	0.71		Spencer	1.32	1.14	1.03	0.91
	Janbu	0.96	0.84	0.79	0.71		Janbu	1.31	1.14	1.03	0.90
	Morgenstern	0.97	0.85	0.79	0.72		Morgenstern	1.33	1.15	1.00	0.90
0.5	Bishop	0.97	0.85	0.74	0.64	0.5	Bishop	1.31	1.14	0.98	0.85
	Fellenius	0.93	0.82	0.71	0.61		Fellenius	1.26	1.09	0.93	0.80
	Spencer	0.97	0.85	0.80	0.71		Spencer	1.33	1.16	1.08	0.92
	Janbu	0.97	0.85	0.85	0.77		Janbu	1.32	1.15	1.01	0.93
	Morgenstern	0.98	0.87	0.84	0.77		Morgenstern	1.34	1.16	1.01	0.93
0.75	Bishop	0.98	0.86	0.74	0.63	0.75	Bishop	1.32	1.15	0.99	0.84
	Fellenius	0.94	0.83	0.72	0.61		Fellenius	1.27	1.10	0.94	0.80
	Spencer	0.98	0.86	0.81	0.72		Spencer	1.34	1.17	1.01	0.91
	Janbu	0.98	0.87	0.84	0.79		Janbu	1.32	1.16	1.02	0.91
	Morgenstern	0.99	0.88	0.86	0.78		Morgenstern	1.35	1.18	1.02	0.95
1	Bishop	0.99	0.87	0.75	0.62	1	Bishop	1.34	1.17	0.99	0.84
	Fellenius	0.95	0.84	0.72	0.60		Fellenius	1.28	1.11	0.94	0.79
	Spencer	0.99	0.87	0.82	0.73		Spencer	1.36	1.18	1.04	0.92
	Janbu	0.99	0.88	0.87	0.79		Janbu	1.35	1.18	1.05	0.95
	Morgenstern	1.00	0.90	0.87	0.79		Morgenstern	1.37	1.19	1.05	0.95

Table 6: Factor of safety for all values of K_v/K_h for variable C = 25kPa

For C_1=40 kPa and C_2=25 kPa						**For C_1=25 kPa and C_2=40 kPa**					
K_v/K_h	K_h	0.1	0.2	0.3	0.4	K_v/K_h	K_h	0.1	0.2	0.3	0.4
0.25	Bishop	1.08	0.94	0.83	0.72	0.25	Bishop	1.36	1.18	1.03	0.90
	Fellenius	1.05	0.91	0.8	0.70		Fellenius	1.31	1.13	0.97	0.84
	Spencer	1.08	0.94	0.87	0.79		Spencer	1.37	1.19	1.05	0.95
	Janbu	1.08	0.95	0.89	0.84		Janbu	1.37	1.19	1.05	0.96
	Morgenstern	1.09	0.95	0.92	0.84		Morgenstern	1.39	1.2	1.07	0.94
0.5	Bishop	1.09	0.96	0.83	0.72	0.5	Bishop	1.37	1.2	1.04	0.90
	Fellenius	1.06	0.93	0.81	0.70		Fellenius	1.32	1.14	0.98	0.84
	Spencer	1.09	0.96	0.89	0.80		Spencer	1.38	1.21	1.07	0.98
	Janbu	1.09	0.98	0.89	0.86		Janbu	1.37	1.21	1.07	0.98
	Morgenstern	1.10	0.98	0.89	0.86		Morgenstern	1.40	1.22	1.07	0.98
0.75	Bishop	1.10	0.97	0.84	0.72	0.75	Bishop	1.39	1.21	1.04	0.90
	Fellenius	1.07	0.94	0.82	0.69		Fellenius	1.33	1.15	0.99	0.85
	Spencer	1.10	0.97	0.91	0.82		Spencer	1.40	1.23	1.12	0.98
	Janbu	1.10	0.99	0.97	0.87		Janbu	1.40	1.23	1.12	0.99
	Morgenstern	1.11	0.99	0.93	0.86		Morgenstern	1.42	1.23	1.08	0.99
1	Bishop	1.11	0.99	0.85	0.71	1	Bishop	1.40	1.23	1.05	0.90
	Fellenius	1.08	0.96	0.82	0.69		Fellenius	1.34	1.17	1.00	0.85
	Spencer	1.12	0.99	0.93	0.83		Spencer	1.41	1.24	1.21	1.01
	Janbu	1.11	1.01	0.99	0.90		Janbu	1.41	1.24	1.08	1.02
	Morgenstern	1.13	1.01	0.99	0.90		Morgenstern	1.43	1.25	1.08	1.02

Table 7: Factor of safety for all values of K_v/K_h for variable C = 30 kPa

For C_1=40 kPa and C_2=30 kPa						**For C_1=30 kPa and C_2=40 kPa**					
K_v/K_h	K_h	0.1	0.2	0.3	0.4	K_v/K_h	K_h	0.1	0.2	0.3	0.4
0.25	Bishop	1.20	1.05	0.91	0.80	0.25	Bishop	1.39	1.21	1.06	0.92
	Fellenius	1.16	1.02	0.89	0.77		Fellenius	1.35	1.18	1.02	0.88
	Spencer	1.20	1.05	0.96	0.88		Spencer	1.40	1.22	1.08	0.99
	Janbu	1.20	1.05	0.96	0.93		Janbu	1.40	1.22	1.09	1.01
	Morgenstern	1.21	1.06	0.97	0.93		Morgenstern	1.39	1.20	1.07	0.94
0.50	Bishop	1.21	1.06	0.93	0.80	0.5	Bishop	1.40	1.23	1.07	0.93
	Fellenius	1.18	1.03	0.90	0.78		Fellenius	1.36	1.19	1.03	0.89
	Spencer	1.21	1.06	0.99	0.89		Spencer	1.41	1.24	1.10	1.01
	Janbu	1.21	1.08	1.04	0.95		Janbu	1.41	1.24	1.10	1.03
	Morgenstern	1.22	1.08	0.99	0.95		Morgenstern	1.42	1.26	1.12	1.00
0.75	Bishop	1.22	1.08	0.94	0.80	0.75	Bishop	1.41	1.25	1.08	0.93
	Fellenius	1.19	1.05	0.91	0.78		Fellenius	1.38	1.21	1.04	0.89
	Spencer	1.22	1.08	1.02	0.91		Spencer	1.42	1.26	1.12	1.06
	Janbu	1.22	1.10	1.07	0.95		Janbu	1.42	1.27	1.12	1.01
	Morgenstern	1.23	1.10	1.07	0.97		Morgenstern	1.44	1.28	1.13	1.01
1	Bishop	1.24	1.10	0.95	0.80	1	Bishop	1.43	1.27	1.09	0.93
	Fellenius	1.20	1.07	0.92	0.78		Fellenius	1.40	1.23	1.05	0.90
	Spencer	1.24	1.10	1.04	0.95		Spencer	1.44	1.29	1.16	1.05
	Janbu	1.24	1.13	1.07	1.00		Janbu	1.44	1.29	1.25	1.06
	Morgenstern	1.25	1.12	1.06	1.00		Morgenstern	1.46	1.30	1.15	1.06

Table 8: Factor of safety for all values of K_v/K_h for variable C = 35 kPa

For C_1=40 kPa and C_2=35 kPa						**For C_1=35 kPa and C_2=40 kPa**					
K_v/K_h	K_h	0.1	0.2	0.3	0.4	K_v/K_h	K_h	0.1	0.2	0.3	0.4
0.25	Bishop	1.31	1.15	1.00	0.87	0.25	Bishop	1.41	1.23	1.08	0.94
	Fellenius	1.28	1.12	0.97	0.85		Fellenius	1.37	1.20	1.04	0.91
	Spencer	1.32	1.15	1.05	0.96		Spencer	1.42	1.24	1.11	1.00
	Janbu	1.31	1.15	1.06	0.98		Janbu	1.42	1.23	1.12	1.02
	Morgenstern	1.33	1.16	1.06	1.00		Morgenstern	1.43	1.25	1.13	1.05
0.5	Bishop	1.32	1.17	1.01	0.88	0.5	Bishop	1.43	1.25	1.09	0.95
	Fellenius	1.29	1.14	0.99	0.86		Fellenius	1.39	1.22	1.06	0.92
	Spencer	1.33	1.17	1.08	0.99		Spencer	1.43	1.26	1.14	1.02
	Janbu	1.33	1.19	1.09	1.01		Janbu	1.43	1.26	1.14	1.05
	Morgenstern	1.34	1.18	1.10	1.02		Morgenstern	1.44	1.27	1.16	1.04
0.75	Bishop	1.34	1.19	1.03	0.89	0.75	Bishop	1.44	1.28	1.10	0.95
	Fellenius	1.31	1.16	1.01	0.86		Fellenius	1.40	1.24	1.08	0.93
	Spencer	1.34	1.19	1.12	1.00		Spencer	1.45	1.28	1.16	1.07
	Janbu	1.34	1.21	1.15	1.02		Janbu	1.44	1.29	1.16	1.06
	Morgenstern	1.34	1.21	1.16	1.05		Morgenstern	1.46	1.31	1.19	1.06
1	Bishop	1.36	1.21	1.04	0.89	1	Bishop	1.46	1.3	1.12	0.96
	Fellenius	1.33	1.18	1.02	0.87		Fellenius	1.42	1.27	1.09	0.94
	Spencer	1.36	1.22	1.14	1.03		Spencer	1.47	1.31	1.18	1.12
	Janbu	1.36	1.24	1.17	1.13		Janbu	1.47	1.31	1.20	1.12
	Morgenstern	1.37	1.23	1.18	1.06		Morgenstern	1.48	1.33	1.21	1.12

From tables, it is visible that,

• The factor of safety decreases with the increase in the horizontal seismic coefficient for both cases for all ratios.

• The factor of safety increases when the cohesion value of the other layer is gradually increased for both cases for all ratios.

3.2 Relationship between Cohesion and Factor of Safety for All Ratios of Seismic Coefficients

The relation between cohesion and factor of safety is shown in figure 2 to figure 9. Worst cases were considered for each ratio i.e. considered the value of horizontal seismic coefficient as 0.4 for all the cohesion values of the variable layer. Following figure 2, figure 3, figure 4, and figure 5 show the relationship between the factor of safety and cohesion for all ratios of K_v/K_h when cohesion 40 kPa is fixed at the bottom layer.

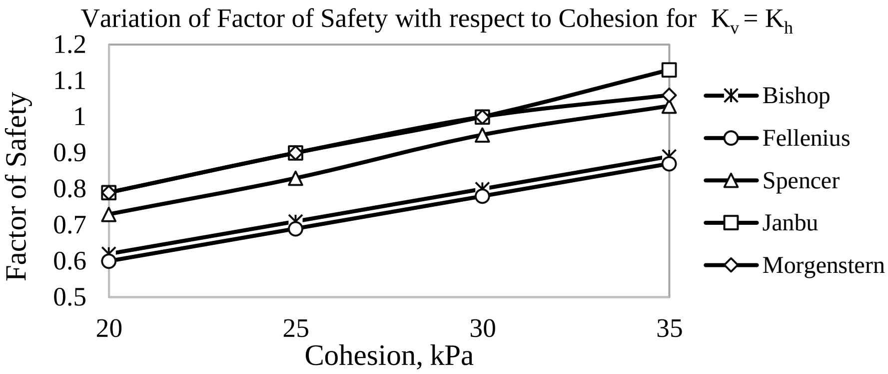

Figure 2: Variation of Factor of Safety with respect to Cohesion for $K_v = K_h$

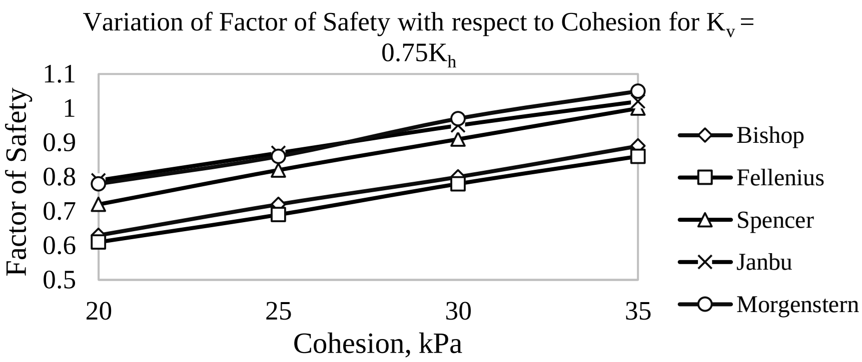

Figure 3: Variation of Factor of Safety with respect to Cohesion for $K_v = 0.75K_h$

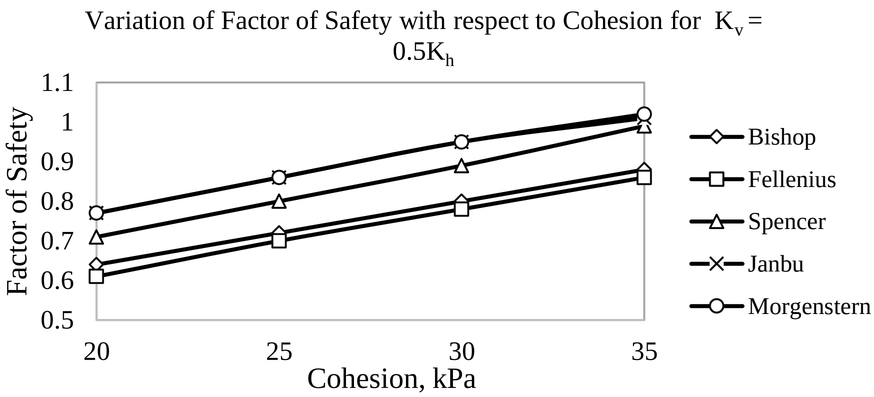

Figure 4: Variation of Factor of Safety with respect to Cohesion for $K_v=0.5K_h$

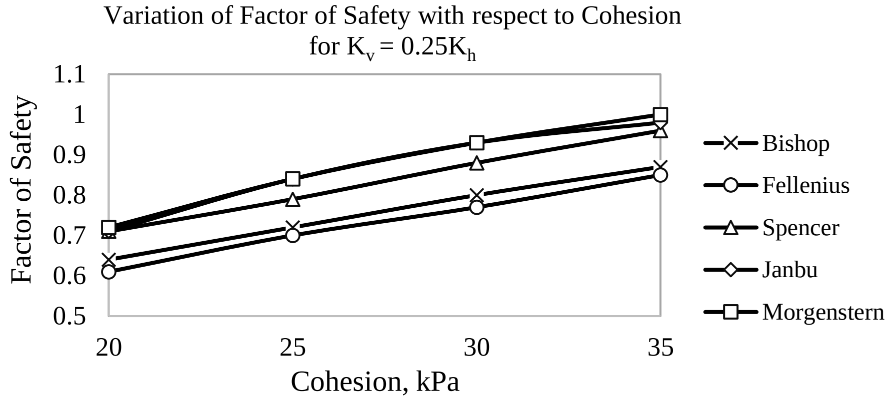

Figure 5: Variation of Factor of Safety with respect to Cohesion for $K_v = 0.25K_h$

Following figure 5, figure 6, figure 7, and figure 8 shows the relation between the factor of safety and cohesion for all ratios of K_v/K_h when cohesion 40 kPa is fixed at the top layer and bottom layer cohesion is varied from 20 kPa to 35 kPa.

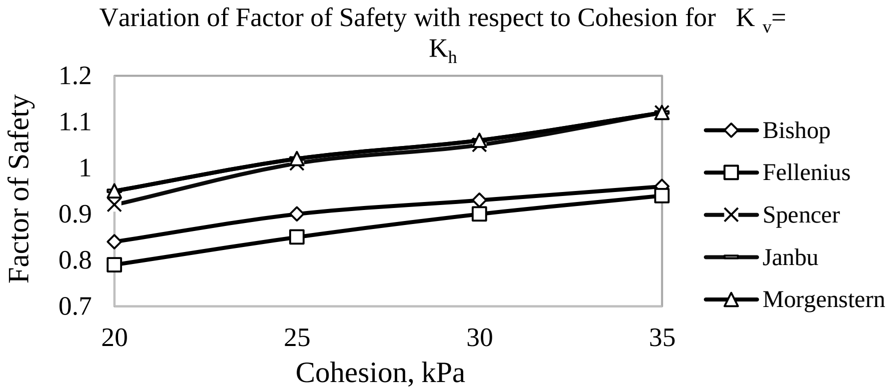

Figure 6: Variation of Factor of Safety with respect to Cohesion for $K_v = K_h$

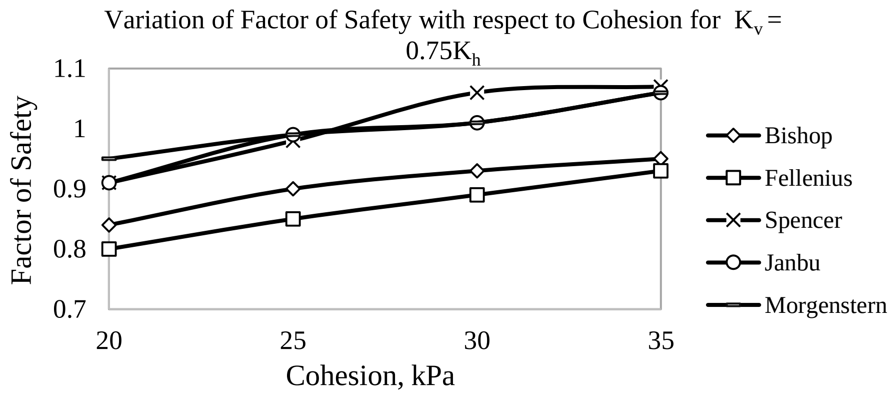

Figure 7: Variation of Factor of Safety with respect to Cohesion for $K_v = 0.75\ K_h$

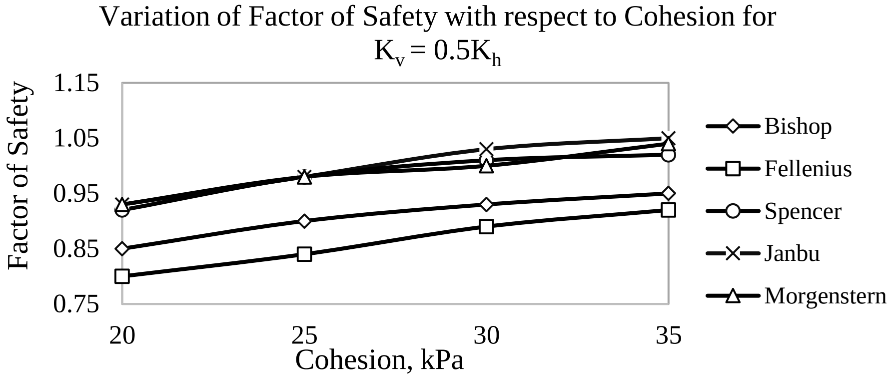

Figure 8: Variation of Factor of Safety with respect to Cohesion for $K_v = 0.5K_h$

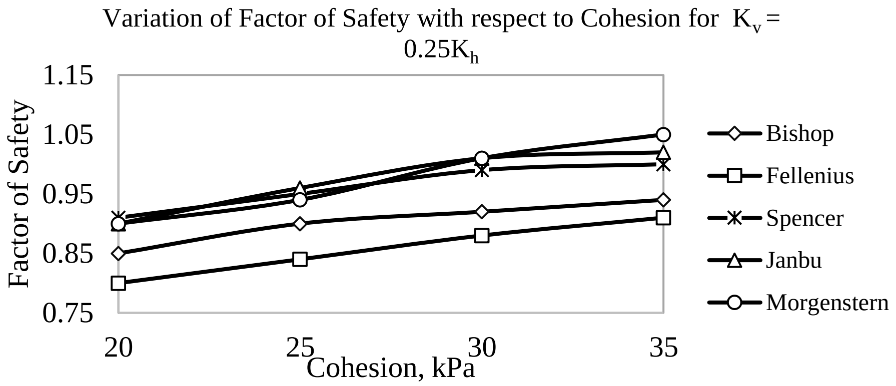

Figure 9: Variation of Factor of Safety with respect to Cohesion for $K_v = 0.25 K_h$

3.3 Comparison between Two Cases

Following table 10 shows the maximum and minimum factor of safety for the layered slope model. Note that, C x, y is used where x denotes top layer cohesion and y denotes bottom layer cohesion.

Table 10: Comparison between two cases of the layered slope model

Combination, $C_{x,y}$	Minimum FS when bottom layer cohesion is fixed at 40 kPa	Maximum FS when bottom layer cohesion is fixed at 40 kPa	Combination, $C_{x,y}$	Minimum FS when top layer cohesion is fixed at 40 kPa	Maximum FS when top layer cohesion is fixed at 40 kPa
$C_{20,40}$	0.61	1.00	$C_{40,20}$	0.79	1.37
$C_{25,40}$	0.69	1.13	$C_{40,25}$	0.84	1.43
$C_{30,40}$	0.77	1.25	$C_{40,30}$	0.88	1.46
$C_{35,40}$	0.85	1.37	$C_{40,35}$	1.00	1.48

It can be observed from table 10 that when 40 kPa is fixed at the top layer of the model, a greater factor of safety is achieved. This becomes even more evident from the following figure 10.

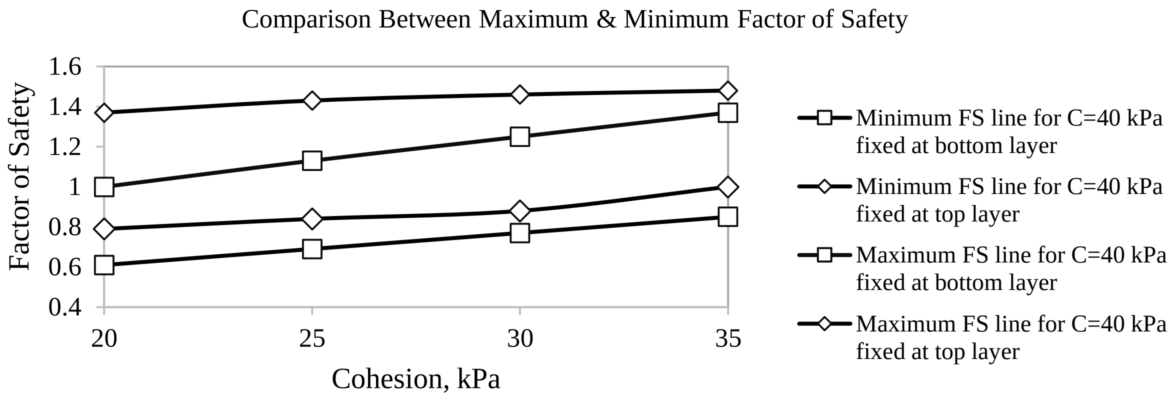

Figure 10: Comparison Between Two Cases for Minimum & Maximum FS

4. CONCLUSIONS

From the analysis in Results and Discussion, those following decisions can be made,

- For both cases, the factor of safety decreases with the increase in the horizontal seismic coefficient.
- For both cases, the factor of safety increases with the increase in cohesion value.
- The factor of safety is greater when the top layer cohesion value is fixed at 40 kPa and the bottom layer is varied than when the bottom layer cohesion value fixed at 40 kPa and top layer cohesion value is varied.

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REFERENCES

Bishop, A. W., & Morgenstern, N. (1960). Stability coefficients for earth slopes. *Geotechnique*. https://doi.org/10.1680/geot.1960.10.4.129

Brammer H. (1996). *The Geography of the Soils of Bangladesh*.

Bangladesh Landslide.(n.d.). Retrieved from https://www.thedailystar.net/tags/bangladesh-landslide

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, 4*.

Janbu, N. (1954). Application of composite slip surface for stability analysis. *Proceedings of European Conference on Stability of Earth Slopes, Stockholm*.

Melo, C., & Sharma, S. (2004). Seismic Coefficients for Pseudostatic Slope Analysis. *13th World Conference on Earthquake Engineering*.

Morgenstern, N. R., & Price, V. E. (1965). The analysis of the stability of general slip surfaces. *Geotechnique*. https://doi.org/10.1680/geot.1965.15.1.79

Sarker, A. A., & Rashid, A. K. M. M. (2013). *Landslide and Flashflood in Bangladesh*. https://doi.org/10.1007/978-4-431-54252-0_8

Spencer, E. (1967). A method of analysis of the stability of embankments assuming parallel inter-slice forces. *Geotechnique*. https://doi.org/10.1680/geot.1967.17.1.11