Research Article

Slope Stability of Soft Clay Embankment for Flood Protection

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Abstract

The purpose of this research was to study the characteristics and stability of the embankments used for flood protection. The embankments used in the research had a height of 2.00 and 3.00 meters, respectively. The width at the top of each embankment was 1.00 meter. The slopes of the embankments were equal to 1V:1H on both sides. The soil type used for filling soil in the embankment was soft clay. There were no soil compaction techniques used during the construction of the embankment. The steps taken in this research consisted of a soil shear strength test and permeability test for seepage analysis of the water flow through the simulation embankment in the laboratory, and a slope stability analysis of the soft clay embankment. The safety factor of the embankment would be reduced due to flooding over a period of time. Thus, the stability of the embankment was reduced due to increased moisture content in the soil and the seepage force in the embankment. The two-meter high soft clay embankment, with a slope ratio of 1V:1H and a maximum of 2.00 meters of water level on the side facing the flood water can protect from flooding for 60 days. Conversely, the three meter high soft clay embankment, with a slope ratio of 1V:1H and a maximum of 2.50 meters of water level on the side facing the flood water cannot protect from flooding for any length of time as deterioration starts from day 1.

Keywords: Flood protection; soft clay embankment; seepage; stability; moisture content

1. Introduction

In 2011, there was the biggest ever flood in Thailand. Many significant areas were damaged from this flood [1]. Flood protection with sand-bag embankments and clay embankments was used during the flood. Due to the large volume of water over a long period of time, the flood protection system designed could not withstand the flooding. There were many factors that caused the failures in the flood protection embankment. These were the water flowing through the cracks of soil in the embankment and the soil in the foundation; water pressure on the soil and the increased weight of the embankment; and cracks in the soil on the top of the embankment which allowed water to flow through and cause erosion at the toe of the slope [2, 3]. These incidents often occur in clay embankments and cause loss of soil shear strength during the rainy season. Therefore, this research paper will describe the study with the focus on the geotechnical engineering characteristic of the flood protection ability of soft clay embankment, such as the soil shear strength, moisture content in soil and water flow through the embankment, plus the stability of the embankment.

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2. Research Procedure

The research procedure consisted of the following steps:

2.1 Soft clay was used as the material for the embankment. The embankments used in the research had a height of 2.00 and 3.00 meters, respectively. The width at the top of each embankment was 1.00 meter.

2.2 Soft clay was collected from borrow pits at Pamok district in Angthong Province for testing in the laboratory to determine the soil shear strength with water flowing through the embankment.

2.3 A simulation embankment was also used in the laboratory for shear strength testing and seepage analysis. The technique for making the simulation embankment was to construct a one meter embankment separated into soil areas, all with an overburden pressure applied to each area. The unit weight of soft clay used in the embankment was 1.5 t/m^3. For example, as shown in table 1 and Figure 1, a three-meter high embankment was divided into four areas: A, B, C and D. Area "A" was located at the top of the embankment, Area "B" was located at a depth of 1.00 meter from the top of the embankment, Area "C" was located at a depth of 2.00 meters from the top of the embankment, and Area "D" was located at a depth of 3.00 meters from the top of the embankment.

Table 1. Zoning of soft clay embankment.

Zone	Depth (m)	Unit Weight of Soft Clay (t/m^3)	Overburden Pressure (t/m^2)
A	0.00	1.50	0.00
B	1.00	1.50	1.50
C	2.00	1.50	3.00
D	3.00	1.50	4.50

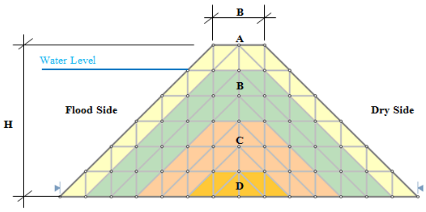


Figure 1. Zoning of soft clay embankment.

2.4 A soil permeability test was used in the laboratory to determine water flow through the soft clay embankment [4].

2.5 An unconfined compression test [4] was used to determine the shear strength of the soft clay. There were two predetermined varieties used for the tests.

The first test was done for un-soaked soft clay, while the second test used soaked soft clay to test its strength as protection against flooding.

2.6 Test results from the laboratory were analyzed.

2.7 Seepage analysis was done. The type of water flowing through the soft clay used as flood protection model was a transient flow. The durations of the flooding being analyzed were one day, 10 days, 20 days, 30 days, and 60 days, accordingly. The experiment was for checking at the contour lines to see if there was any change in the moisture content of the soft clay embankment as shown in Figure 5.

2.8 Conditions used to make a soft clay slope stability analysis consisted of the following:

- The slopes of the embankment on the flood side and the dry side were the same. The slope was a ratio of one vertical to one horizontal (1V:1H). The embankment model plus an addition of contour lines was used to analyze the amount of seepage that could be observed. These lines show the amount of moisture content absorbed by the soft clay as shown in Figure 5. This model enabled the checking of the relation between the un-drained shear strength of soft clay and the soil moisture content (Figure 4) in each contour line at zone A, B, C and D and showed the difference in the embankment strength as shown in Figure 6.
- For the two-meter high embankment, the level of water on the flood side of the embankment consisted of 1.50 meters and 2.00 meters. For the three-meter high embankment, the level of water on the food side of the embankment was 2.50 meters.
- Seepage force was used in the slope stability analysis. The seepage force (F) can be derived from equation 1 [7].

$$F = i\gamma_w V \quad (1)$$

Where

i = Hydraulic Gradient

γ_w = Unit weight of water

V = Volume of soil sample

- Total stress type was used for Slope Stability Analysis of a soft clay embankment [5]: the un-drained shear strength, with the angle of internal friction equal to zero.
- The Fellenius method was used in slope stability analysis [6, 8-13]. This method is based on limited equilibrium and method of slices. The cross section of slope failure surface and dividing the soil mass into a slice as shown in Figure 2. Figure 3 shows the forces used in the analysis.

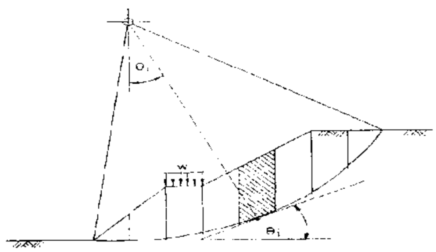


Figure 2. Cross section of the sliding and the soil slices (Mairaing, 2003).

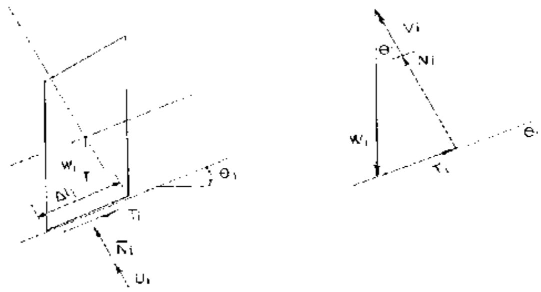


Figure 3. The forces in soil slice and direction of forces in soil (Mairaing, 2003).

- Allowable Factor of Safety ($F.S_{allowable}$) for the analysis was 1.25, for an embankment having a duration of use of not more than 60 days.

3. Research Results

According to the results of the research, the shear strength of the clay reduced due to the increase in the moisture content, as presented in Figure 4. Figure 5 shows the moisture content of soil in a three-meter high soft clay embankment with 2.50 meter-high water at the flood side. The strength in soft clay is proportional to the moisture content as presented in Figure 5. Figure 6 shows the shear strength of soft clay in the embankment proportional to the moisture content read from the graph in Figure 4. The value from Figure 6 and the seepage force from Figure 7 were used for slope stability analysis of a soft clay embankment.

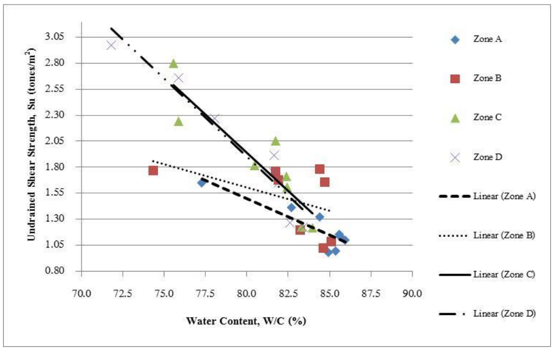


Figure 4. The relation between the un-drained shear strength of soft clay and the soil moisture content in the clay embankment.

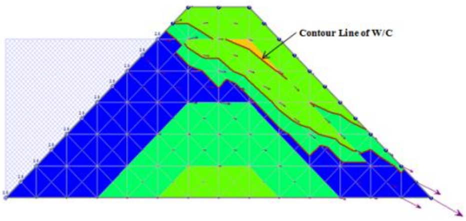


Figure 5. Contour lines indicate changes in the moisture content of soft clay embankment model.

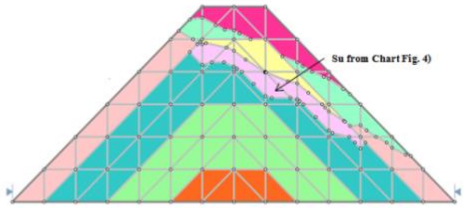


Figure 6. The shear strength of soft clay, extrapolated from the graph in Figure 4, in a 3 meter high soft clay embankment.

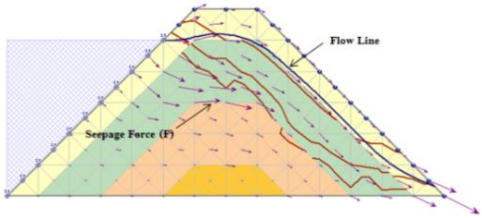


Figure 7. Cross section of the soft clay embankment and the seepage force in embankment type 2 when the water level on the flood side of the embankment is equal to 2.50 meters.

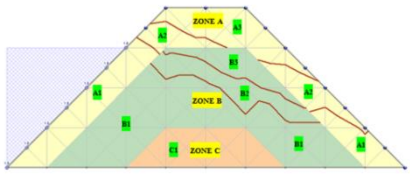
The detailed result of slope stability analysis can be given by two types as the following.

3.1 Type 1: A two-meter high embankment, with a top width of one meter. The ratio of the embankment slope was 1V:1H. There was no soil compaction in the construction of the soft clay embankment. Table 2 and Figure 8 shows the shear strength of the soft clay used for the stability analysis. The level of water on the flood side equals 1.50 meters and 2.00 meters. Figure 9 shows the seepage force used for the slope stability analysis.

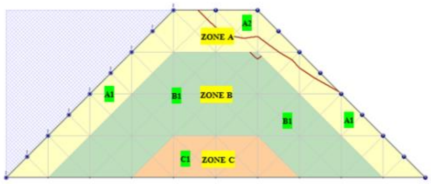
Table 2. Soil moisture content and un-drained shear strength of soft clay in each area for type 1.

No.	Water Content, W/C (%)	Un-drained Shear Strength, Su (t/m^2) A	B	C
1	85.61	1.10	1.10	-
2	82.87	1.28	1.46	1.46
3	80.13	1.48	1.59	1.88

Note: Area A is at the top of the embankment. Area B is at a depth of 1.00 meter from the top of embankment. Area C is at a depth of 2.00 meters from the top of the embankment.

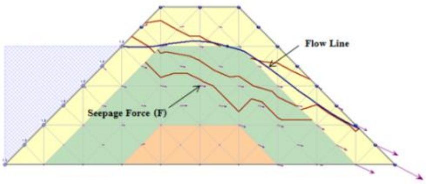


(a)

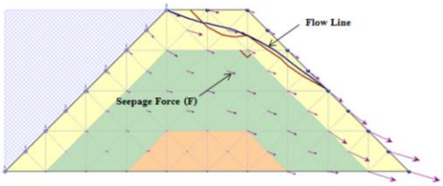


(b)

Figure 8. Zoning of soil shear strength in a soft clay embankment type 1 (a) 1.50 meter high water on the flood side, and (b) 2.00 meter high water on the flood side.



(a)



(b)

Figure 9. Seepage force in a soft clay embankment type 1 (a) 1.50 meter high water on the flood side, and (b) 2.00 meter high water on the flood side.

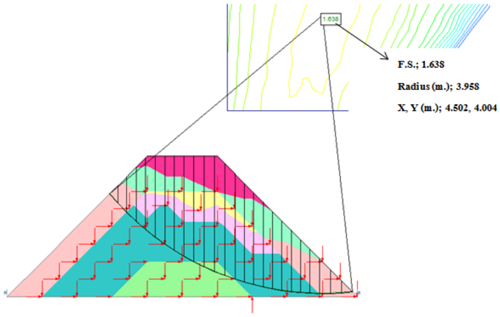


Figure 10. The results of Slope Stability Analysis in Type 1, the water level was 1.50 meters and the flooding period was 60 days.

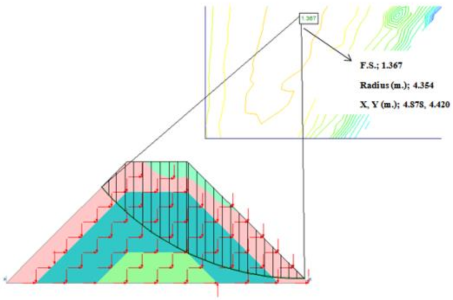


Figure 11. The results of Slope Stability Analysis in Type 1, the water level was 2.00 meters and the flooding period was 60 days.

Figures 10 and 11 illustrate the results of the slope stability analysis of flood protection of a soft clay embankment when inundated by flood water for 60 days, with water at 1.50 meters and 2.00 meters high on the flood side. Factor of Safety (F.S.) was higher than the allowable Factor of Safety, $F.S._{allowable}$. Thus, the soft clay embankment type 1, with water a maximum of 2.00 meters high on the flood side, can prevent flooding for 60 days. The results of the slope stability analysis for embankment type 1, is presented in table 3. Figure 12 shows the relation between Factor of Safety and flooding time. Factor of Safety of the embankment reduces when the period of flooding increases.

Table 3. Summary of slope stability analysis for flood protection with soft clay embankment, type 1.

Water Level (m.)	Factor of Safety (F.S.)				
	1 Days	**10 Days**	**20 Days**	**30 Days**	**60 Days**
1.50	1.684	1.676	1.670	1.654	1.638
2.00	1.417	1.407	1.399	1.385	1.367

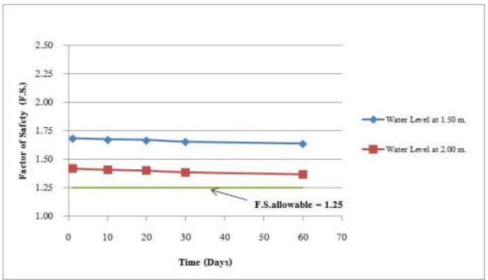


Figure 12. The relationship between Factor of Safety (F.S.) and flooding period of type1.

3.2 Type 2: A three-meter high embankment, with a one meter width at the top. The ratio of the embankment slope was 1V:1H. There was no soil compaction in the construction of a soft clay embankment. Table 4 and Figure 13 show the shear strength of soft clay, used for the slope stability analysis. The height of water on the flood side is 2.50 meters. Figure 7 shows the seepage force used for the slope stability analysis of a soft clay embankment.

Table 4. Soil moisture content and un-drained shear strength of soft clay in each area for type 2.

No.	Water Content, W/C (%)	Un-drained Shear Strength, Su (t/m^2)			
		A	**B**	**C**	**D**
1	85.61	1.10	1.10	-	-
2	82.87	1.28	1.46	1.46	
3	80.13	1.48	1.59	1.88	1.88
4	77.30	1.68	1.72	2.32	2.32

Note: Area A is at the top of the embankment. Area B, area C, and area D are at the depth of 1.00 meter, 2.00 meters, and 3.00 meters from the top of the embankment, respectively.

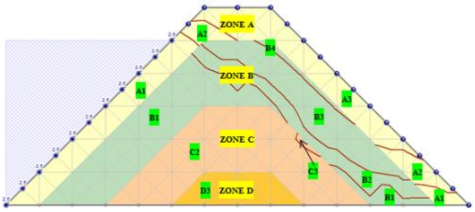


Figure 13. Zoning of the shear strength of soil in a soft clay embankment type 2, with water 2.50 meters high on the flood side.

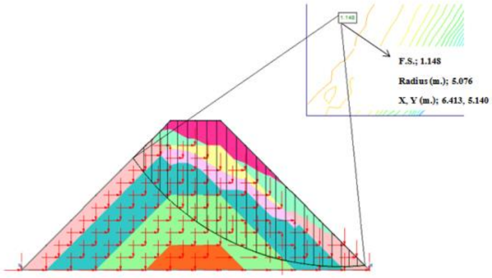


Figure 14. The results of Slope Stability Analysis in Type 2, the water level was 2.50 meters and the flooding period was 60 days.

Table 5. Summary of slope stability analysis for flood protection of soft clay embankment type2

Water Level (m.)	Factor of Safety (F.S.)				
	1 Days	10 Days	20 Days	30 Days	60 Days
2.50	1.165	1.151	1.150	1.149	1.148

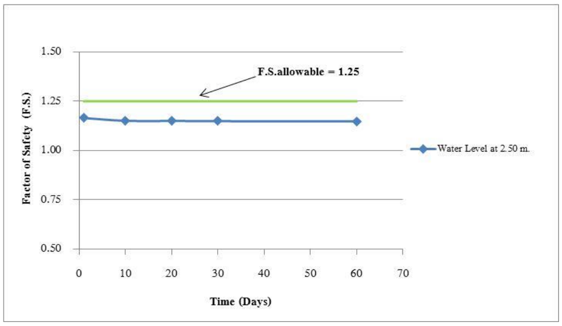


Figure 15. The relationship between Factor of Safety (F.S.) and time of the type 2.

Figure 14 illustrates the results of the slope stability analysis of flood protection of a soft clay embankment when inundated by flood water for 60 days, with water at 2.5 meters high on the flood side. Factor of Safety (F.S.) is lower than the allowable Factor of Safety, $F.S._{allowable}$. Thus, the soft clay embankment type 2, with water a maximum of 2.50 meters high on the flood side, cannot protect from flooding for a one day period. The results of the slope stability analysis for embankment type 2, are presented in table 5. Figure 15 shows the relationship between Factor of Safety and flooding time. Factor of Safety of the embankment reduces when the period of flooding increases.

4. Conclusion

In summary, the safety factor of flood protection utilizing the soft clay embankment reduces when the moisture content in the embankment increases. The increase of moisture content and of seepage force are the causes of the reduction of in soil shear strength and the reasons why the soft clay loses strength, which then causes the stability of flood protection using a soft clay embankment to also decrease. The two-meter high soft clay embankment, with a slope ratio of 1V:1H and a maximum of 2.00 meters of water level on the flood side can protect from flooding for 60 days. Conversely, the three-meter high soft clay embankment, with the slope ratio 1V:1H and the maximum of 2.50 meters of water level on the flood side cannot protect from flooding for any length of time as deterioration starts from day 1. There was no soil compaction in the construction of the soft clay embankments mentioned above.

4. Future Work

Currently, this research is focused only on the water flow through the embankment and the slope stability. Therefore, further research requires that other factors, such as piping, erosion and stability with top scouring, flow rates and wave magnitude, etc. be included in the analysis.

5. References

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