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Original research article

Increase Stability of Soft Clay Embankment for Flood Prevention Using Compaction and Lining Techniques

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ABSTRACT

The purpose of this research is to study and compare the stabilities of soft clay embankments for flooding protection using soil compaction and soil lining techniques in construction. There are five types of soft clay embankments with three-meter height used in this research. The width at the top of the embankment is one meter and the vertical to horizontal ratio of slope of embankment on the water side equals 1:1. The soil compaction technique was used to construct the embankment types 1, 2 and 3 and the value of coefficient of permeability of clay in embankment to be $1x10^{-5}$ cm./sec was given. The vertical to horizontal ratio of slope of embankments on the dry side equal 1:1, 1:1.5 and 1:2, respectively. The soil lining was used to construct the embankment types 4 and 5 and the vertical to horizontal ratio of slope of embankments on the dry side equals 1:1, without compaction techniques. Lining material with 0.10 meter thickness was placed on the water side surface of the embankment. The coefficient of permeability of lining material used in embankment types 4 and 5 equals $1x10^{-5}$ cm/sec. and $1x10^{-6}$ cm./sec., respectively. The research process consisted of using parameters obtained from shear strength test and water flow test through soft clay embankment simulated in laboratory to analyze water flow and slope stability analysis of the embankment. In addition, the area and budget for construction of embankment, not including the soil compaction and soil lining cost, were used to select the suitable type of soft clay embankment. The results showed that the soft clay embankment type 5, using soil lining on the water side surface of the embankment, was the most suitable embankment. Also, the level of stability of the soft clay embankment type 5 had the highest value with the need to use area and budget for construction less than embankment types 1, 2 and 3.

Keywords: Flood protection; Soft clay embankment; Seepage; Stability; Moisture content; lining; Compaction.

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1. Introduction

In general, the vertical to horizontal ratio of clay embankment slope used for temporary flooding protection equals 1:1.5. The clay in embankment shall be compacted every 0.15 or 0.20 meter depth under inspection of an engineer when the foundation of the embankment is soft clay and has severe erosion [1]. In 2011, there was extensive flooding caused by a massive volume of water. In some areas, there was a strong current of water and flooding lasted longer than 60 days. The clay embankments in these areas could not withstand flooding and collapsed. There are many factors which cause clay embankments to collapse. First, the strength of clay in the embankment will decrease after a long flooding period [2]. Second, water flow through cracks at the foundation of the embankment cause erosion and collapse at the slope of the embankment [3]. Third, the increased water pressure in soil combined with the increased weight of the embankment cause the landslide at the dry side of the embankment, and water flow through cracks at the top of the embankment, due to the heat of the sun, causes the erosion at the toe of the slope of clay embankments [4,5]. In 2015, there was a research study on the geotechnical characteristics of soft clay embankments without soil compaction [6]. The characteristics consisted of shear strength and moisture content in soil, the water flow through the embankment, and the stability of the embankment. The result showed that the soft clay embankment with three meter height could not withstand the flood [6]. Therefore, this research has conducted continuous study on increasing the flooding protection stability of soft clay embankments, with three meter height, by using compaction and lining techniques.

2. Research Process

Details of the research process include

2.1 In 2015, the result of research showed the value of strength and coefficient of permeability (k) of soft clay obtained from unconfined compression test and water flow test through a soft clay embankment simulated in a laboratory [6]. The values of k of soil in separated areas of the embankment were as follows: area A, k=2.6 x 10^{-3} cm/sec; area B. k= 1.1x 10^{-3} cm/sec; area C, k = 1.2x10^{-4} cm/sec.; and area D, k =3.1x10^{-5} cm/sec. The process of operation consists of the following:

2.1.1 Soft clay was used as a filling soil in the embankment, with three meter height and one meter width at the top of the embankment.

2.1.2 In order to determine the strength of soft clay, there were two models of the soft clay embankment simulated in laboratory. The first model was the case without flooding, while the second model was the case with flooding. The concept of simulation was to make four sets of soil samples representing each layer of soft clay in an embankment that consisted of four layers of soft clay with the height of each layer being one meter. The unit weight of soft clay equals 1.5 t/m^3. As shown in figure 1, the three meter height was separated into four areas based on depth of soil. Area A was the area at surface of the embankment. Area B, area C and area D were areas at the depth of 1, 2, and 3 meters from the surface of the embankment, respectively.

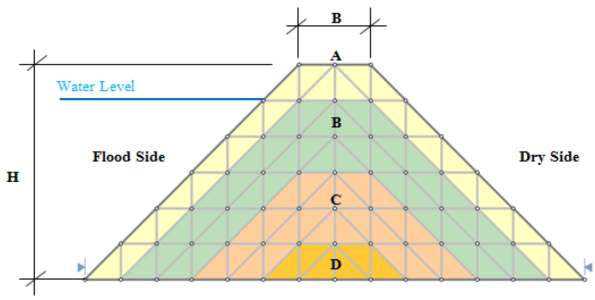


Fig.1. Separated areas of the soft clay embankment [6].

2.2 The characteristic of water flow used in the seepage analysis was Transient Flow which varied according to the flooding period from one to sixty days.

2.3 The requirements for slope stability analysis of five types of flooding protection soft clay embankment include

2.3.1 Total Stress was used in the analysis.
2.3.2 Fellenius' method was used in slope stability analysis of the embankment.
2.3.3 There were two cases of the water height on the water side of the embankment: two and a half meters and three meters.
2.3.4 The vertical to horizontal ratio of slope of the five types of embankment on the water side was 1:1.
2.3.5 Construction with the soil compaction technique was used for embankment types 1, 2 and 3, with coefficient of permeability of $1x10^{-5}$ cm/sec. and vertical to horizontal ratio of slope of the embankment on the dry side at 1:1, 1:1.5 and 1:2, respectively.
2.3.6 Construction without soil compaction technique was used for embankment types 4 and 5, with vertical to horizontal ratio of slope of the embankment on the dry side of 1:1 and coefficient of permeability for Area A; k = 2.6 x 10^{-3} cm/sec, Area B; k = 1.1x 10^{-3} cm/sec, Area C; k = $1.2x10^{-4}$ cm/sec and Area D; k = $3.1x10^{-5}$ cm/sec.
2.3.7 Lining material with coefficient of permeability of $1x10^{-5}$ cm/sec and 0.10 meter thickness was used to line the surface on the water side of embankment type 4.
2.3.8 Lining material with coefficient of permeability of $1x10^{-6}$ cm/sec and 0.10 meter thickness was used to line the surface on the water side of embankment type 5.
2.3.9 Seepage force was used for analysis of the water flow through the embankment.
2.3.10 Value of the allowable factor of safety ($F.S_{allowable}$) was 1.25.
2.3.11 Analysis results of each type of embankment were compared in order to recommend the soft clay embankment most efficient and suitable for flood protection.

3. Research Results

Results from research in 2015 [6] showed that the shear strength will be decreased when moisture content in the soft clay embankment increases as presented in figure 2. Figure 3 shows the moisture content as a contour line when seepage occurs through the embankment with three meter height and two and half meter water height on the water side. Shear strength of soft clay in the embankment, which can be read from the graph in figure 2, is presented as a zoning area of shear strength shown in figure 4 and table 1. The value of seepage force, caused by water flow through the embankment, is shown in figure 5.

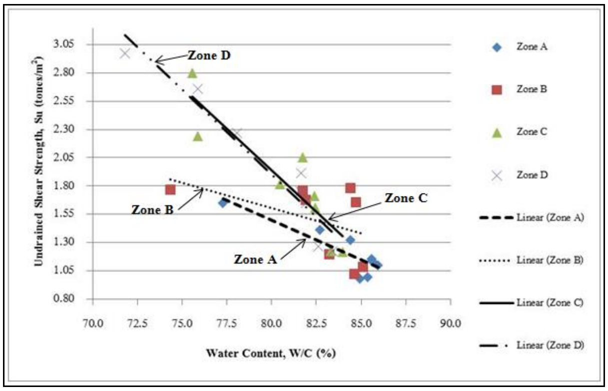


Fig.2. Relation between shear strength and moisture content in the soft clay embankment [6]

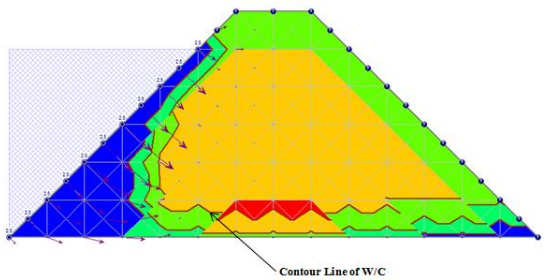


Fig.3. Contour line of moisture content in the simulated soft clay embankment.

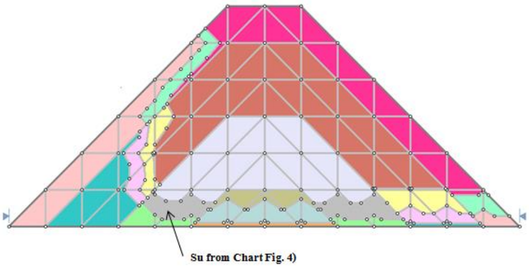


Fig. 4. Zoning areas of shear strength of soft clay in the three meter height soft clay embankment.

Table 1. Moisture content and shear strength of soft clay in each zone of the embankment.

Water Content, W/C	Soil Shear Strength, Su (ton/m^2)			
(%)	Zone A	Zone B	Zone C	Zone D
85.61	1.10	1.10	-	-
82.87	1.28	1.46	1.46	
80.13	1.48	1.59	1.88	1.88
77.30	1.68	1.72	2.32	2.32
74.56	-	-	-	2.72

Note: Area A is the area at top of embankment. Areas B, C and D are the areas at the depth one, two, and three meters from the top of embankment, respectively.

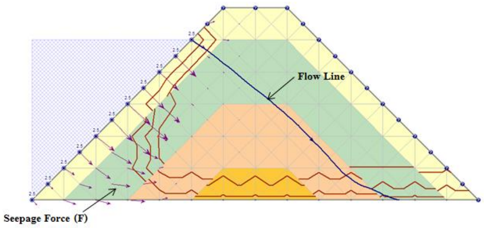


Fig. 5. Seepage force in soft clay embankment type 1, with two and half meter water height on the water side.

The results of slope stability analysis of each type of embankment are presented as follows:

3.1 The zoning areas of shear strength of soft clay and the seepage force in embankment type 1, with two and a half meter water height on the water side, are shown in figures 6 and 7, respectively. The shear strength and seepage force, as mentioned above, were used in slope stability analysis of embankment type 1.

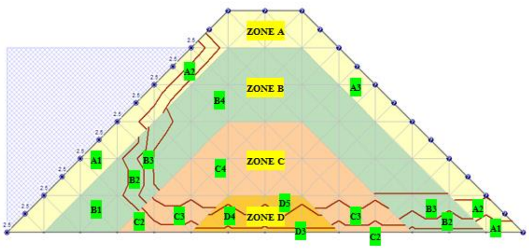


Fig. 6. Zoning areas of shear strength of soft clay in embankment type 1, with two and a half meter water height on the water side.

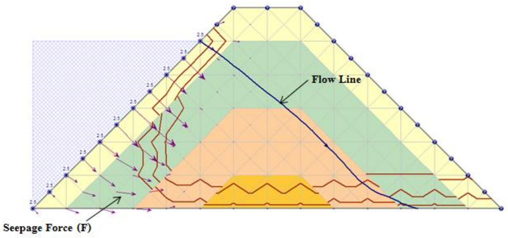


Fig. 7. Seepage force in embankment type 1 with two and a half meter water height on the water side.

Figure 8 shows the slope stability analysis result of embankment type 1, with two and a half meter water height on the water side and a sixty day flooding period. The minimum factor of safety from the analysis is less than the allowable factor of safety (F.S.$_{\text{allowable}}$). Thus, embankment type 1 could not withstand flooding for 60 days when water height on the water side was 2.50 meters. The relation between factor of safety (F.S.) and flooding period was plotted and is presented in figure 9. As shown in figure 9, the factor of safety decreases when the flooding period increases and the maximum period for flooding protection of embankment type 1 was 10 days.

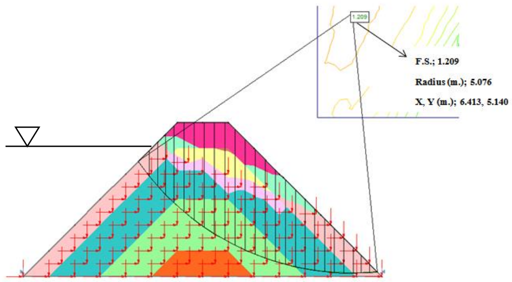


Fig. 8. Slope stability analysis result of the soft clay embankment type 1, with two and a half meter water height on the water side and flooding period of 60 days.

3.2 The zoning areas of shear strength and the seepage force in embankment type 2, with two and a half meter water height on the water side, are shown in figure 10(a) and figure 11(a), respectively. The zoning areas of shear strength and the seepage force in embankment type 2, with three meter water height on the water side, are shown in figure 10(b) and figure 11(b), respectively. The shear strength and seepage force, as mentioned above, were used in slope stability analysis of embankment type 2.

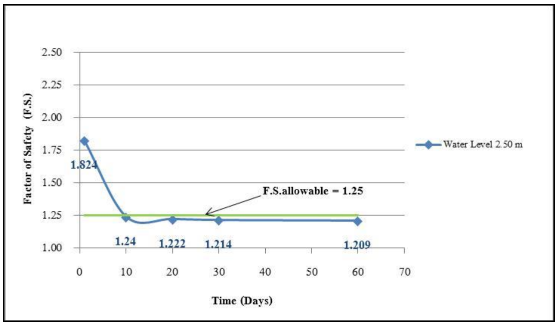
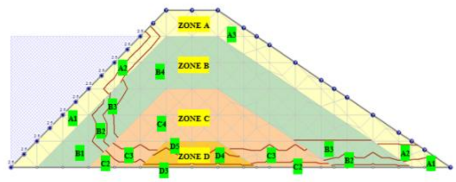
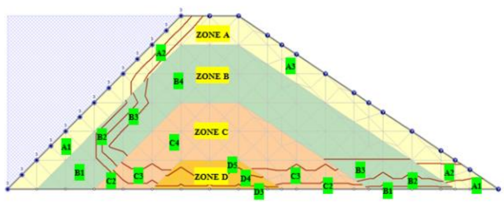


Fig.9. Relation between factor of safety (F.S.) and flooding period of the embankment type 1.

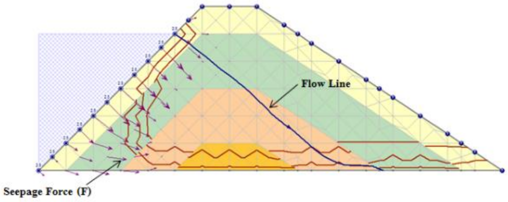


(a)



(b)

Fig. 10. Zoning areas of shear strength of soft clay in embankment type 2, with (a) two and half meter water height on the water side, and (b) three meter water height on the water side.



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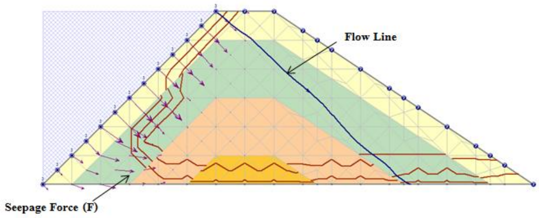


(b)

Fig. 11. Seepage force in embankment type 2, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.

Figure 12 shows the slope stability analysis result of embankment type 2, with two and a half meter water height on the water side and flooding period of 60 days. The minimum factor of safety from the analysis is more than the allowable factor of safety. ($F.S._{allowable}$). Thus, embankment type 2, with two and a half meter water height on the water side, could withstand flooding for 60 days. On the other hand, embankment type 2, with three meter water height on the water side, could not withstand flooding, as shown in figure 13. The relation between factor of safety (F.S.) and flooding period was plotted and is presented in figure 14. As shown in figure 14, the factor of safety decreases when the flooding period increases.

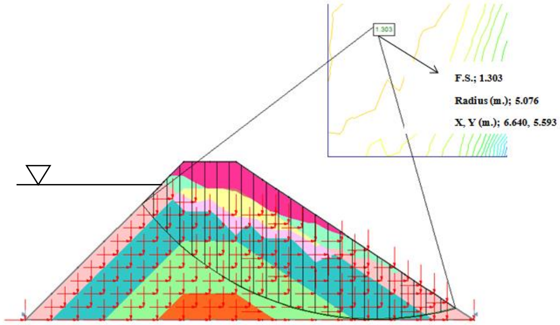


Fig. 12. Slope stability analysis result of embankment type 2, with two and a half meter water height on the water side and flooding period of 60 days.

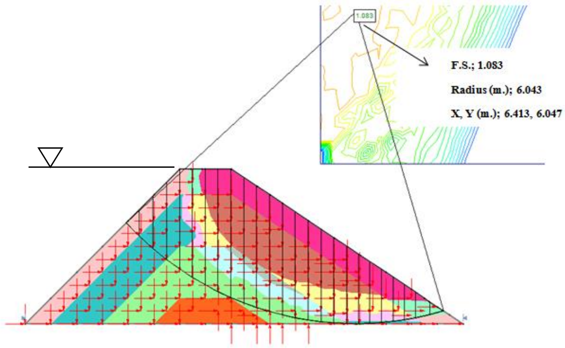


Fig.13. Slope stability analysis result of embankment type 2, with three meter water height on the water side and flooding period of 10 days.

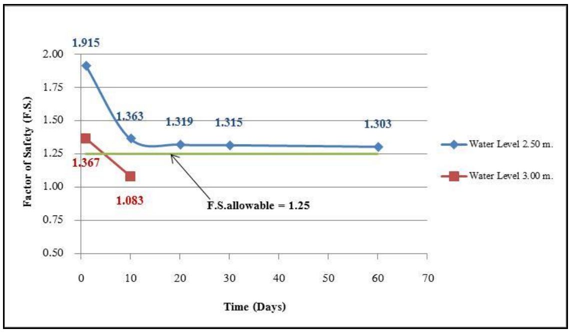
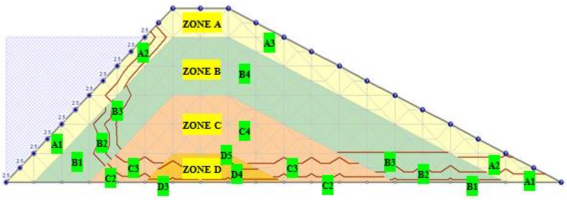


Fig.14. Relation between factor of safety (F.S.) and flooding period of embankment type 2.

3.3 The zoning areas of shear strength and the seepage force in embankment type 3, with two and half meter water height on the water side, are shown in figure 15(a) and figure 16(a), respectively. The zoning areas of shear strength and the seepage force in embankment type 3, with three meter water height on the water side, are shown in figure 15(b) and figure 16(b), respectively. The shear strength and seepage force, as mentioned above, were used in slope stability analysis of embankment type 3.



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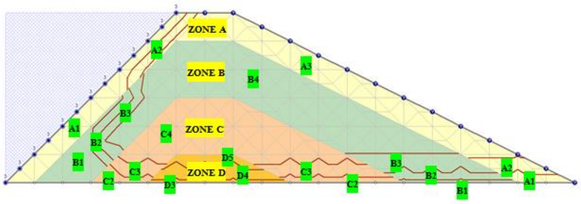
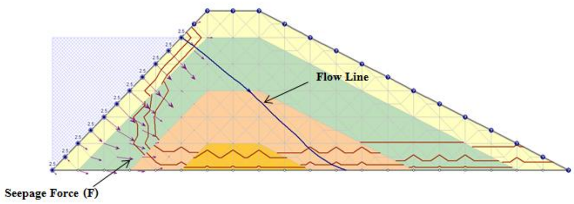


(b)

Fig. 15. Zoning areas of shear strength of soft clay in embankment type 3, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.



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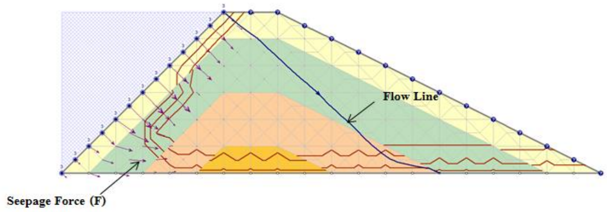


(b)

Fig.16. Seepage force in embankment type 3, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.

Figure 17 shows the slope stability analysis result of embankment type 3, with two and a half meter water height on the water side and flooding period of 60 days. Figure 18 shows the slope stability analysis result of the embankment type 3, with three meter water height on the water side and flooding period of 60 days. The minimum factor of safety from the two mentioned analyses above is more than the allowable factor of safety ($F.S._{\text{allowable}}$). Thus, embankment type 3, with two and half meter water height on the water side and three meter water height on the water side, could withstand flooding for 60 days. The relation between factor of safety (F.S.) and flooding period was plotted and is presented in figure 19. As shown in figure 19, the factor of safety decreases when flooding period increases.

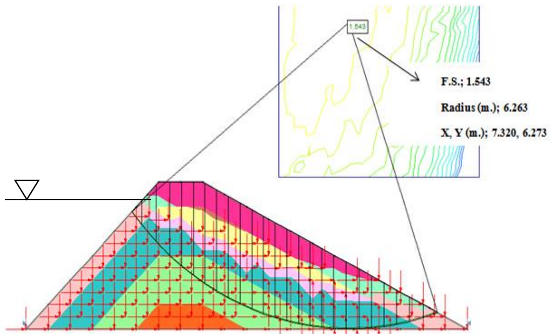


Fig. 17. Slope stability analysis result of embankment type 3, with two and a half meter water height on the water side and flooding period of 60 days.

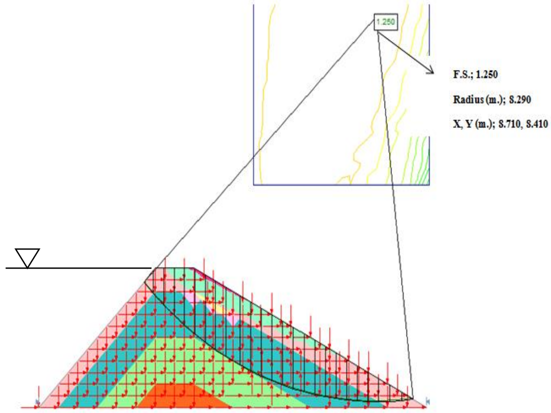


Fig. 18. Slope stability analysis result of embankment type 3, with three meter water height on the water side and flooding period of 60 days.

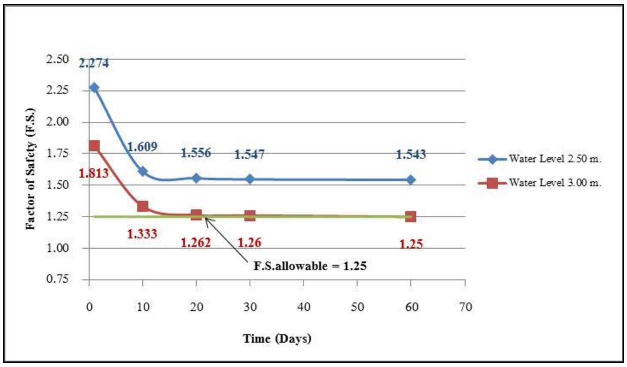
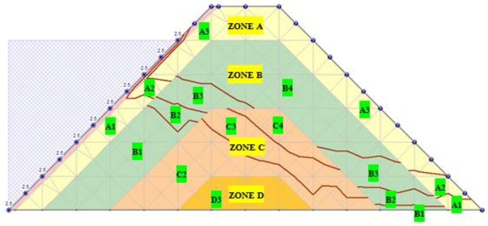
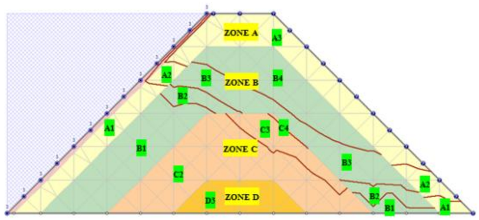


Fig. 19. Relation between factor of safety (F.S.) and flooding period of the embankment type 3.

3.4 The zoning areas of shear strength and the seepage force in embankment type 4, with two and a half meter water height on the water side, are shown in figure 20(a) and figure 21(a), respectively. The zoning areas of shear strength and the seepage force in embankment type 4, with three meter water height on the water side, are shown in figure 20(b) and figure 21(b), respectively. The shear strength and seepage force, as mentioned above, were used in slope stability analysis of embankment type 4.

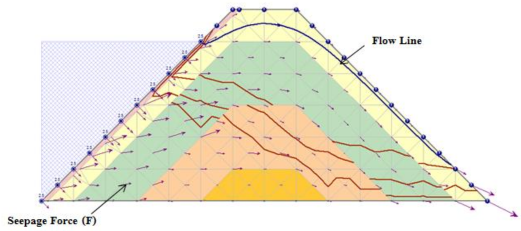


(a)



(b)

Fig. 20. Zoning areas of shear strength of soft clay in embankment type 4, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.



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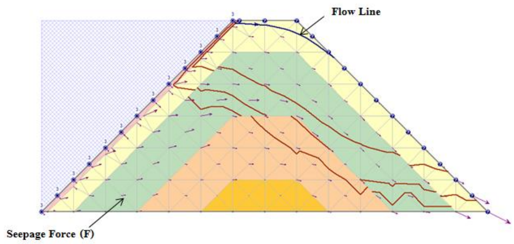


(b)

Fig. 21. Seepage force in embankment type 4, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.

Figure 22 shows the slope stability analysis result of type 4, with two and a half meter water height on the water side and flooding period of 60 days. The minimum factor of safety from the analysis is more than the allowable factor of safety, (F.S. $_{allowable}$). Thus, embankment type 4, with two and a half meter water height on the water side, could withstand flooding for 60 days. On the other hand, embankment type 4, with three meter water height on the water side, could not withstand flooding, as shown in figure 23. The relation between factor of safety (F.S.) and flooding period was plotted and is presented in figure 24. As shown in figure 24, the factor of safety decreases when flooding period increases.

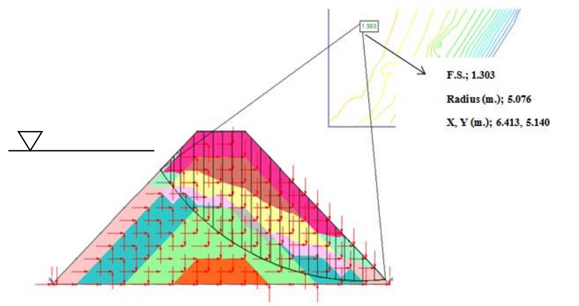


Fig. 22. Slope stability analysis result of soft clay embankment type 4, with two and a half meter water height on the water side and flooding period of 60 days.

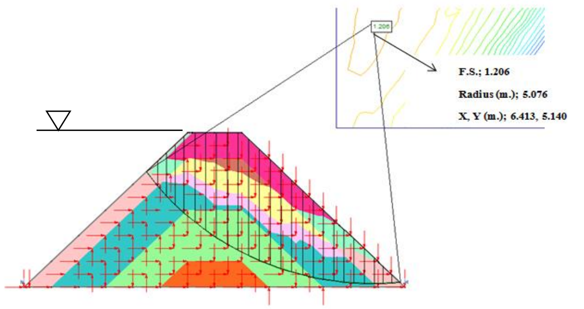


Fig. 23. Slope stability analysis result of soft clay embankment type 4, with three meter water height on the water side and flooding period of 10 days.

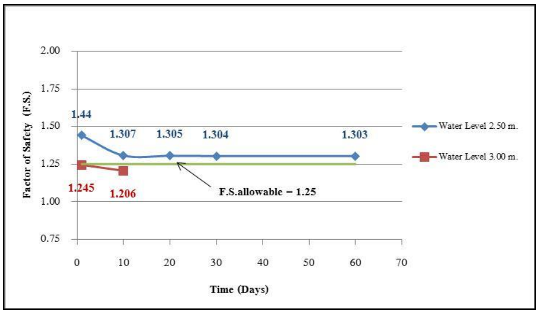
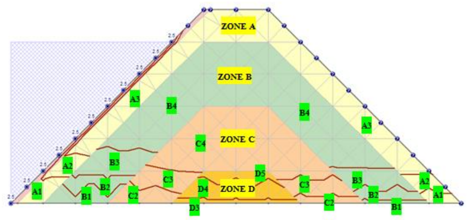
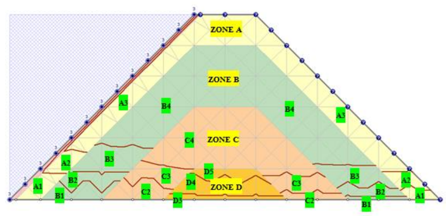


Fig. 24. Relation between factor of safety (F.S.) and flooding period of embankment type 4.

3.5 The zoning areas of shear strength and the seepage force in embankment type 5, with two and a half meter water height on the water side, are shown in figure 25(a) and figure 26(a), respectively. The zoning areas of shear strength and the seepage force in embankment type 5, with three meter water height on the water side, are shown in figure 25(b) and figure 26(b), respectively. The shear strength and seepage force, as mentioned above, were used in slope stability analysis of embankment type 5.

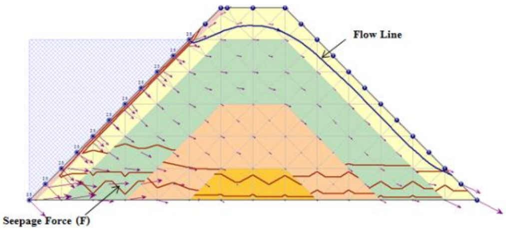


(a)



(b)

Fig. 25. Zoning areas of shear strength of soft clay in embankment type 5, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.



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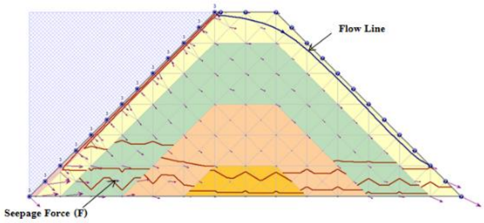

(b)

Fig. 26. Seepage force in embankment type 5, with (a) two and a half meter water height on the water side, and (b) three meter water height on the water side.

Figure 27 and figure 28 show the slope stability analysis results of embankment type 5 where water heights on the water side were 2.50 and 3.00 meters, respectively, and flooding period was 60 days. The results show the minimum factor of safety (F.S.) is higher than the allowable factor of safety (F.S. $_{allowable}$). Thus, embankment type 5, with water heights on the water side of 2.50 meters and 3.00 meters, could withstand flooding for 60 days. The relation between factor of safety and flooding period was plotted and is shown in figure 29. As shown in figure 29, the factor of safety decreases when the flooding period increases.

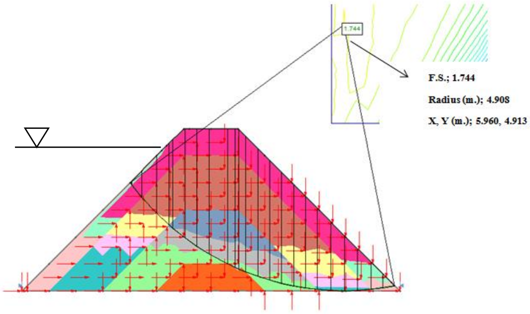

Fig. 27. Slope stability analysis result of embankment type 5, with two and a half meter water height on the water side and flooding period of 60 days.

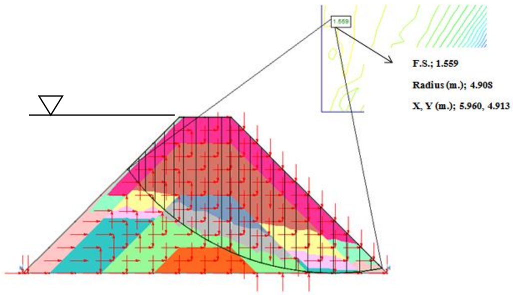

Fig. 28. Slope stability analysis result of embankment type 5, with three meter water height on the water side and flooding period of 60 days.

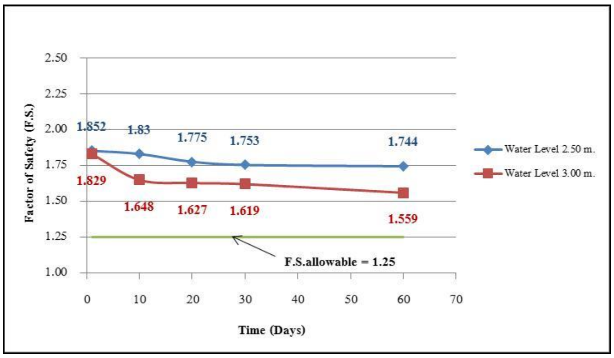

Fig. 29. Relation between factor of safety (F.S.) and flooding period of embankment type 5.

According to slope stability analysis results from items 3.1 to 3.5, it was found that the factor of safety of embankment types 2 and 4, with two and a half meter water height on the water side, and soft clay embankment types 3 and 5, with two and a half water height on the water side and three meter water height on the water side were higher than allowable factor of safety of 1.25. Thus, these soft clay embankments were stable and could protect against flooding for 60 days. Furthermore, additional factors, including construction area and construction budget (not including compaction cost and lining cost) were also considered as a factor for selection of the suitable soft clay embankment. As mentioned above, the comparison of the factor of safety, construction area and construction budget of each type of soft clay embankment are presented in table 2. As shown in table 2 and figure 30, embankment type 5, which was constructed by using soil lining laid on slope surface on the water side of the embankment, had the highest factor of safety when the flooding period was 60 days. Furthermore, embankment types 4 and 5 required less area for construction and also used less construction budget when compared with embankment types 2 and 3. Therefore, we can conclude that embankment type 5 is economical and efficient to use for flooding protection for 60 days.

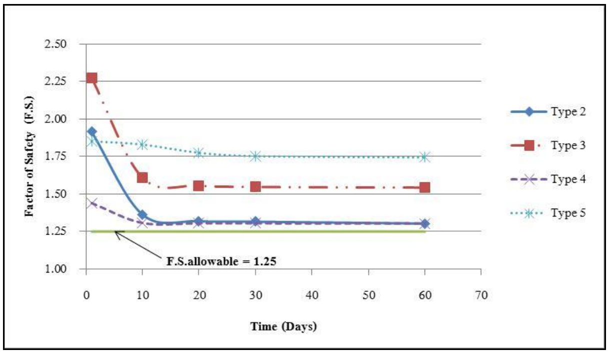

Fig. 30. The relation between allowable factor of safety (F.S.allowable) and flooding period for all types of clay embankment.

Table 2. Comparison of stability level and additional factors of embankment types 2, 3, 4 and 5, respectively.

Type	Water height (m)	Factor of Safety (F.S.) 1 Day	10 Days	20 Days	30 Days	60 Days	Construction Area (m^2)	Construction Budget (Bath/m)
2	2.50	1.915	1.363	1.319	1.315	1.303	8.50	4,145.67
3	2.50	2.274	1.609	1.556	1.547	1.543	10.00	4,799.76
	3.00	1.813	1.333	1.262	1.260	1.250		
4	2.50	1.440	1.307	1.305	1.304	1.303	7.00	3,386.46
5	2.50	1.852	1.839	1.775	1.753	1.744	7.00	3,386.46
	3.00	1.829	1.648	1.627	1.619	1.559		

4. Conclusion

From the results, seepage force is one of the factors which decreases stability of an embankment. Seepage force in the embankment varies directly with flooding period. Seepage force is increased when flooding period increases. Increase of seepage force in the embankment affects moisture content in the embankment. High moisture content in the embankment decreases the shear strength of clay in the stability of soft clay embankment to decrease. Lining material, with a coefficient of permeability of $1x10^{-6}$ cm/sec. and 0.10 meter thickness, was used to construct embankment type 5 where vertical to horizontal ratio of slope on the water side and dry side equal 1:1 and with 2.50 and 3.00 meter water height on the water side. From the results, soft clay embankment type 5 had highest Factor of Safety (F.S.). Thus, embankment type 5 could protect against flooding for 60 days. On the other hand, compaction technique was used to construct embankment type 3, with a coefficient of permeability of $1x10^{-5}$ cm./sec. The vertical to horizontal ratio of slope of embankment type 3 on the water side and dry side was 1:1 and 1:2, respectively, with 2.50 and 3.00 meter water height on the water side. The results show that the soft clay embankment type 3 also can protect against flooding for 60 days. However, when considering other facts such as construction area and construction budget (which does not include compaction cost and lining cost) it was found that soft clay embankment type 5 is the most economical and efficient.

5. Suggestion

The purpose of this research was to study the slope stability of soft clay embankments used for flood protection after using compaction technique and lining technique to improve the stability of the embankment. In order to make a slope stability analysis of five types of soft clay embankment, water flow through the embankment, which causes the level of embankment and shear strength of soft clay were considered in this research. Therefore, other factors such as piping, stability with toe scouring, water speed, severity of waves, etc. shall be considered in further research.

6. References

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