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SLOPE STABILIZATION OF WASTEWATER TREATMENT PONDS: CASE STUDY OF KHON BURI SUGAR MILL FACTORY, THAILAND

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ABSTRACT

This study improves the soil stability of wastewater treatment ponds of Khon Buri Sugar Mills, located at Amphoe Khon Buri, Nakhon Ratchasima Province, Thailand. The wastewater treatment system consists of two areas. The first area contains 15 wastewater treatment ponds with a total area of 212 rai (83.8 acres). The second area has three wastewater treatment ponds with a total area of 103 rai (40.7 acres). The characteristic of local soil is dispersive soil with the degree of dispersive about 50.50 by double hydrometer test. The slope stabilization of ponds calculated using KUslope® program found that 11 ponds have the safety factor is less than 1.5. There are three methods that suitable for stabilization with surface protection including Buttress by Counter Berm, Sheet pile wall, and Cement Column. Using the hierarchy method, the study finds that the best suitable method of slope stabilization is Buttress by Counter Berm with surface protection. The weight of Counter Berm is to use soil-cement with a ratio of soil and cement is 7:1 by weight. The density of soil-cement is 1.95 g/cm^3. After the improvement of slope stability, the safety factors of all slopes are more than 1.5.

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1. INTRODUCTION

The soil at different locations will have different soil engineering properties. Computations of slope stability have been suggested by Janbu (1973), Lee (1996). The modern slope stability analysis is to use a finite element analysis method such as Griffiths and Lane (1999). Soil slope stability and stabilization methods have been summarized e.g. by Abramson et al. (2001), Duncan et al. (2014). Chearnkiatpradab (2005; 2015) discussed the expert system for slope stabilization.

To increase strength of soil slope stability and stabilization, there are many methods that can be used such as by adding RC piles (Poulos, 1995), using soil-cement for soft soil stabilization (Chen & Wang, 2006), using liquid ionic stabilizer suitable for subgrade and base soils (Katz et al, 2001).

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Chearnkiatpradab and Mairaing (2002) evaluated soil slope stabilization for the Bangpakong river bank and Namkor watered area.

2. SLOPE FAILURE OF WASTEWATER PONDS OF KHON BURI SUGAR MILL

Khon Buri Sugar Mill is located at Amphoe Khon Buri, Nakhon Ratchasima Province, the Northeastern region of Thailand. The sugar mill has a problem with the wastewater treatment system. Some slopes of wastewater pond are failures so it made the wastewater treatment system cannot treat properly. The wastewater pond has 2 parts total 18 ponds as shown in Figure 1

(a) Wastewater pond Area 1 (b) Wastewater pond Area 2

Figure 1: The wastewater pond of Khon Buri Sugar Mill Factory.

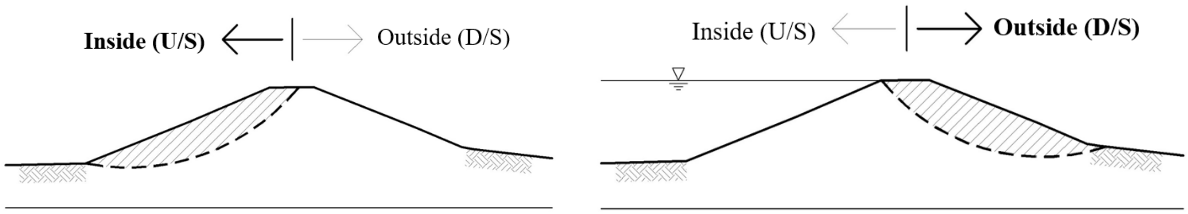
3. SCOPE OF ANALYSIS

The scope of slope analysis is specified as the followings

a. The number of soil boring is a total of 18 holes spread throughout the two areas of wastewater ponds. The location of each boring hole as shown in Figure2. Data on soil property for slope analysis is used from the beneath soil boring location.

Figure 2: The geo-location of boring holes (courtesy of Google Earth).

b. The surcharge load for analysis is one ton per square meter
c. The water level for analysis is separate in two cases as below
   1) The water level in the wastewater pond is empty. Slope failure analysis is analyzed inside the pond as upstream slope, U/S.
   2) The water in the wastewater pond is full. Slope failure analysis is analyzed outside the pond as downstream slope, D/S.
d. The allowable of safety factor (SF) for slope failure is 1.5.



(a) Water level is empty
Upstream Slope (U/S) analysis

(b) Water level is full
Downstream Slope (D/S) analysis

Figure 3: The two cases of wastewater pond's slope analysis.

4. THE ENGINEERING PROPERTY AND DISPERSION OF SOIL

4.1 THE ENGINEERING PROPERTY OF SOIL

From the summarized soil testing, most of soil is silty sand (SM). some boring holes are found clayey sand (SC) and clay. After analyzing the soil data with the depth of each borehole it can show as Figures 4 and 5

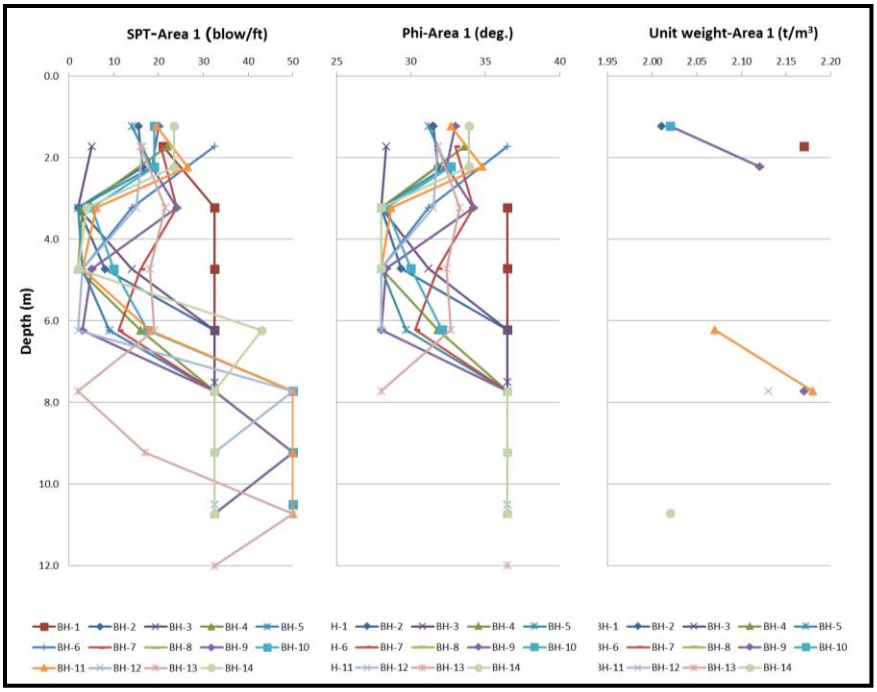


Figure 4: Soil Property of soil with depth at area 1.

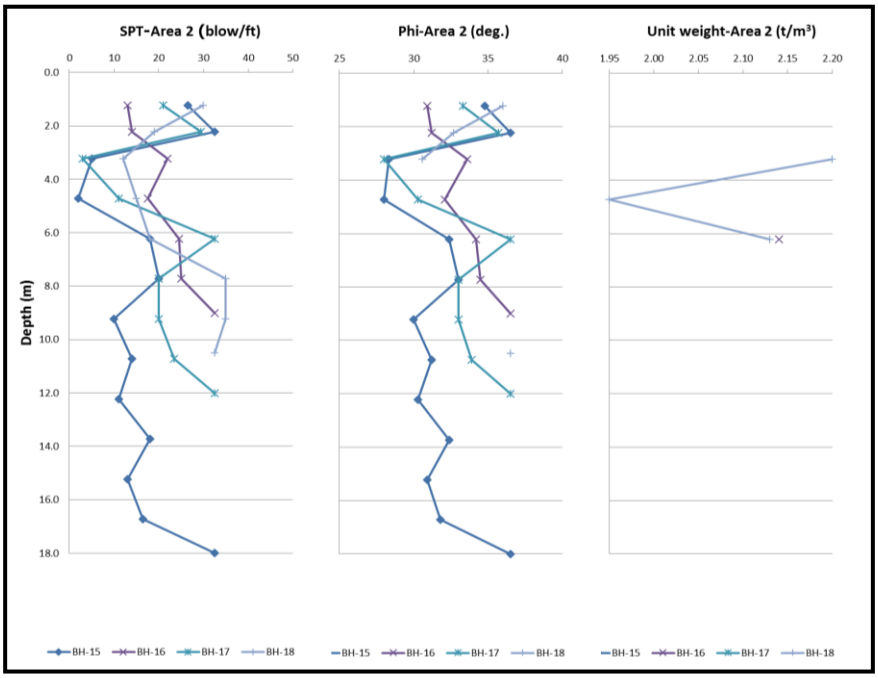


Figure 5: Soil Property of soil with depth at area 2.

4.2 DETERMINATION THE DISPERSION OF SOIL

Dispersive soils are those in which the clay content has a high percentage of sodium so the clay fraction readily breaks down to form a suspension in water. In Thailand, the dispersive soils are widely distributed in northeastern and eastern area region. The colors of dispersive soil in Thailand are reddish-brown, brown and gray. The black soil that has high content in organic matter is not found in dispersive soils. The soil slope and color of soil shown in Figure 6.

Figure 6: Dispersive soil slope of the Khon Buri Sugar Mill Factory.

The dispersion of soil was determined by the double hydrometer test according to ASTM D4221– 99 (2005) as

$$\text{Degree of Dispersion} = \frac{\%\text{finer more than 0.005 mm without chemical dispersion}}{\%\text{finer more than 0.005 mm with chemical dispersion}} \times 100 \qquad (1).$$

The ASTM D4221-99 Standard stated that the value under 30% classified as nondispersive (ND), 30-50% classified as intermediate dispersive (ID), >50% classified as highly dispersive (HD)

From testing the degree of dispersive of soil by double hydrometer testing, the degree of dispersive is about 50.50 so the local soil of wastewater treatment pond is highly dispersive soil (HD) as shown in Figure 7.

DOUBLE HYDROMETER TEST (ASTM D 422 , ASTM D 4221)														
Standard Hydrometer (with chemical dispersant)	Diameter (mm.)	0.0290	0.0163	0.0120	0.0086	0.0062	0.0044	0.0037	0.0032	0.0029	0.0017	0.0015		
	%Passing	65.85	64.35	60.29	58.56	55.69	51.87	40.19	33.42	31.46	27.74	23.59		
Double Hydrometer (without chemical dispersant)	Diameter (mm.)	0.0470	0.0335	0.0240	0.0172	0.0127	0.0091	0.0065	0.0046	0.0038	0.0033	0.0030		
	%Passing	60.23	49.64	43.58	42.60	40.76	34.51	29.05	26.25	21.35	19.21	14.42		
Degree of Dispersive : DDS %	50.50													

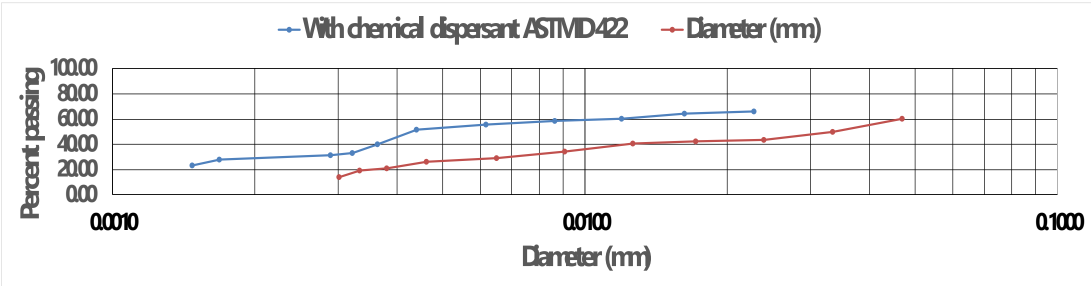


Figure 7: Double Hydrometer Test of soil

5. THE STABILITY ANALYSIS OF SLOPE

The stability analysis of wastewater pond was analyzed by KUslope®, slope stability analysis program developed by Geotechnical Engineering Research and Development (GERD) Civil Engineering Department, Faculty of Engineering, Kasetsart University Thailand (Rattatham, 2004). The total 38 sections were analyzed by the locations as shown in Figure 8. The summary result of the safety factor (SF) from the analysis is shown in Table 1.

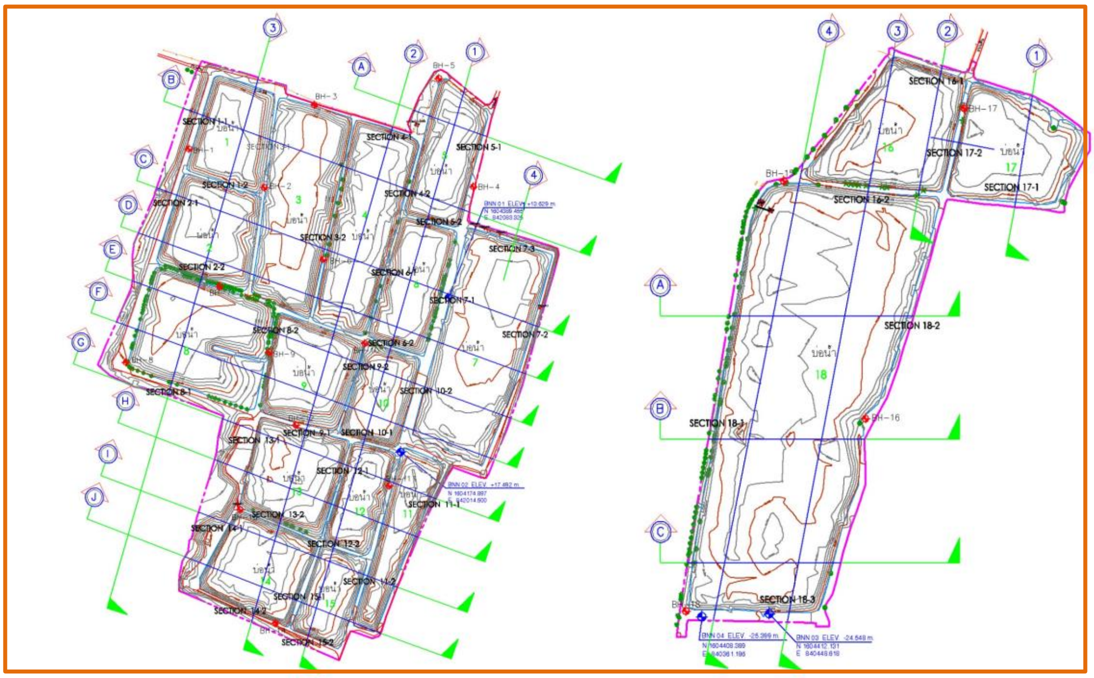


Figure 8: The location of the analysis section.

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Table 1: Result of safety factor (SF) from analysis of wastewater pond

Section	Bored Hole No	Factor of Safety (F.S.)		Section	Bored Hole No	Factor of Safety (F.S.)	
		Empty upstream slope ,U/S.	Full downstream slope ,D/S			Empty upstream slope ,U/S.	Full downstream slope ,D/S
1-1	BH-1	2.88	2.26	10-1	BH-12	1.41	1.81
1-2	BH-1	3.92	2.57	10-2	BH-11	1.84	2.31
2-1	BH-1	2.76	2.42	11-1	BH-11	1.45	1.51
2-2	BH-7	1.73	1.20	11-2	BH-11	1.69	1.59
3-1	BH-2	3.37	1.62	12-1	BH-12	1.97	1.20
3-2	BH-6	2.11	1.40	12-2	BH-13	1.76	1.73
4-1	BH-3	1.84	2.18	13-1	BH-13	1.66	2.88
4-2	BH-5	1.66	1.44	13-2	BH-13	1.53	1.31
5-1	BH-4	1.97	3.28	14-1	BH-13	1.69	1.86
5-2	BH-4	1.79	1.53	14-2	BH-14	2.10	2.15
6-1	BH-10	2.30	1.16	15-1	BH-14	2.16	1.46
6-2	BH-10	2.00	1.55	15-2	BH-14	1.64	1.87
7-1	BH-10	2.30	2.15	16-1	BH-17	1.57	1.85
7-2	BH-10	2.21	3.24	16-2	BH-15	2.44	1.74
7-3	BH-4	2.89	2.06	17-1	BH-17	3.77	4.57
8-1	BH-8	2.45	2.61	17-2	BH-17	2.11	2.24
8-2	BH-9	2.60	1.16	18-1	BH-18	1.76	2.09
9-1	BH-12	2.49	1.94	18-2	BH-16	3.61	4.42
9-2	BH-10	2.21	1.23	18-3	BH-18	2.28	2.62

When plotting the value of the safety factor of each section, see Figure 9, all of the safety factors are greater than 1.00, but some slopes need improvements because safety factor is less than 1.50. The example of slope analysis before stabilized by KUslope® is shown in Figure 10.

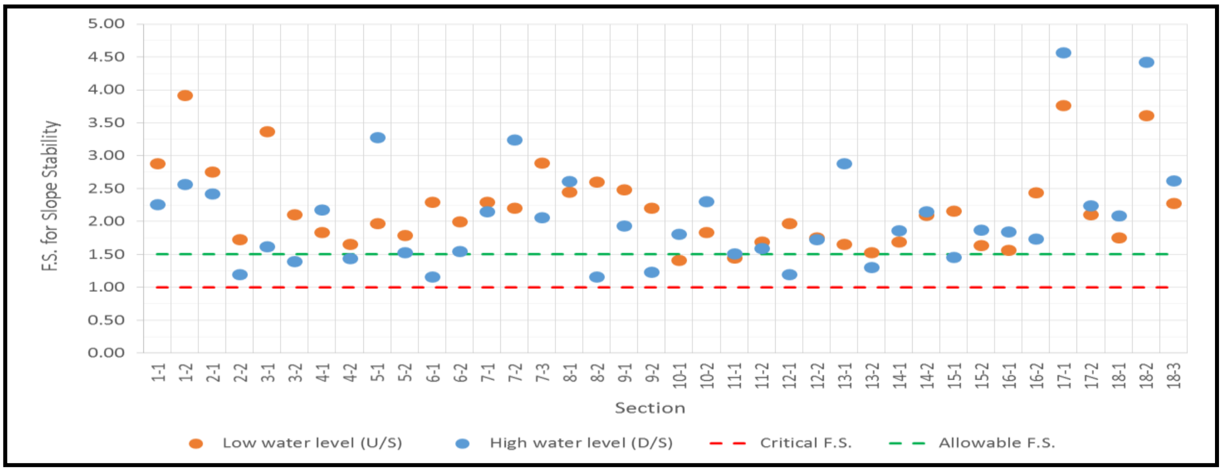
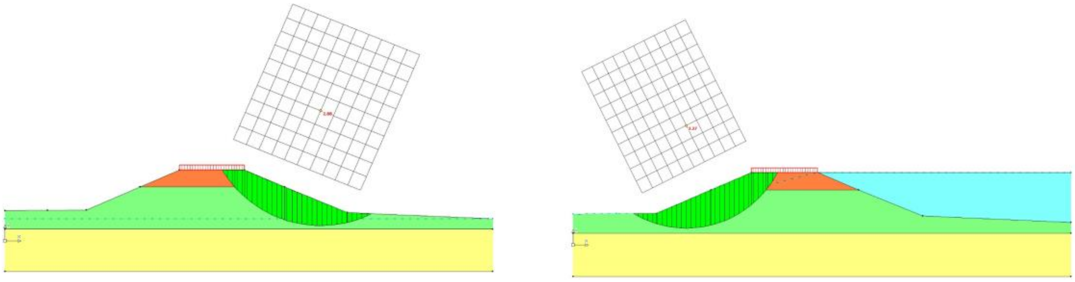


Figure 9: Summarized of safety factor from the slope stability analysis.

6. THE SLOPE STABILIZATION

Most of soil slope failure occurs from soil slopes that have insufficient shear strengths due to

1. There is too much water in the soil mass that causes the soil to have less shear strength.
2. The mass of soil slope is too large or has an external weight to be done on the soil slope thus the soil slope is not stable.



(a) Empty upstream slope, U/S. (b)Full downstream slope, D/S

Figure 10: Slope stability analysis of section 1-1 by KUslope® program

Therefore the principles of slope stabilization reduce the force acting on the soil slope such as digging the soil from slope and prepare the drainage system to reduce the pore water pressure or increase the resisting force and reduce the driving force at the same time.

The resistance of the slope can be increased by the following reasons:

1. Unloading
   - Unloading is the technique for moving the unstable soil out of slope to reduce the driving for from slope such as benching slope, excavation
2. Buttressing
   - Buttressing is a simple method to increase slope stability by increasing the weight of the material at the toe, which creates a counterforce that resists slope failure such as counter berm, rock buttressing
3. Drainage
   - Drainage systems are one of the most effective remedial measures against slope instability due to their capacity to reduce pore-water pressure in the subsoil, increasing the shear strength of the soil.
4. Reinforcement
   - The slope reinforcement method is the technique for stabilizing slope by installing a system of reinforcing such as components metal bars or other rod-shaped to resist the slope failure by using the tensile resistance and torque resistance of the components such as soil nailing, geosynthetic reinforcement.
5. Retaining wall
   - Retaining wall is the technique for protecting the soil slope by using structure such as sheet pile, retaining wall.
6. Surface Slope protection by vegetation
   - Surface slope protection by vegetation is the technique to protect the erosion of soil slope surface by plant. Planting with shrubs adds vegetative cover and strong root systems, which in turn will enhance slope stability.
7. Soil Hardening
   - Soil hardening is the method to increase the soil strength by mixing lime or cement with soil such as a lime column or cement column.

The suitable method for stabilized the wastewater pond depends on many factors such as time for construction, cost of construction and maintenance, technology and local material use

From the schematic diagram for analyzing the suitable stabilization method as shown in

Figure11. It has derived three methods for stabilizing the soil slope with surface protection. Those methods are Buttress by Counter Berm, Sheet pile wall, and Cement Column. The most suitable method for stabilized slope can be derived from comparing the score by hierarchy method as shown in table 2. The comparative for selected the best suitable method for stabilization has four factors, time for construction, Construction cost, Maintenance cost and Technology and local material use consequently. The comparative scale is given as 1 for the minimum, 2 for medium and 3 for maximum. The best suitable method is the method that has the lowest of the comparative score.

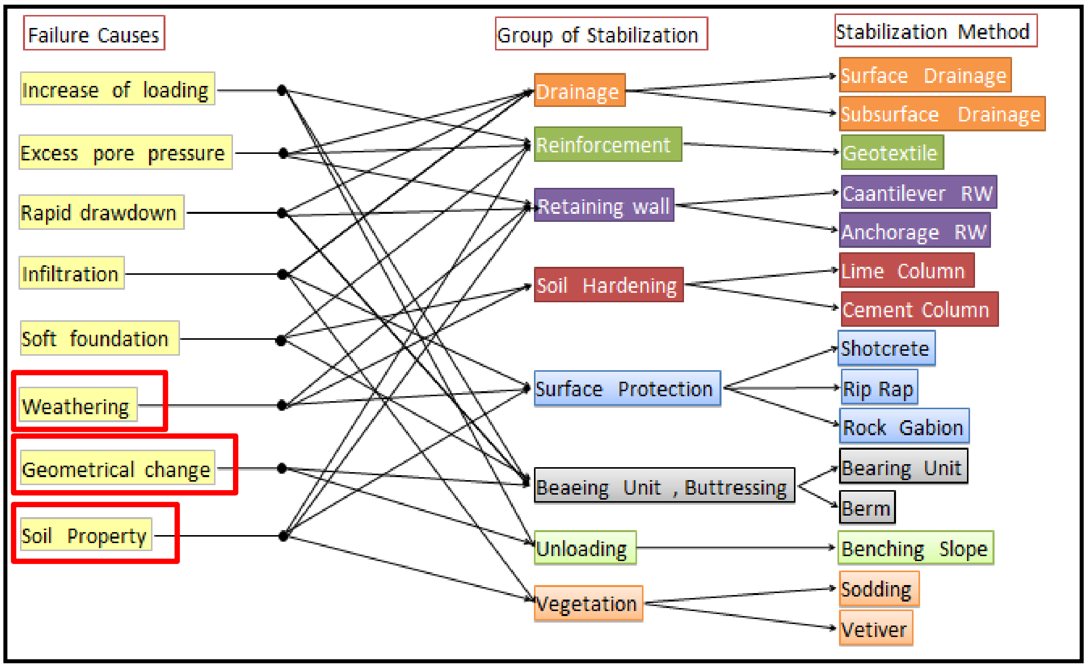


Figure 11: The schematic diagram for analyzed the suitable stabilization method (modified from Chearnkiatpradab (2005)).

Table 2: The hierarchy table of the comparative score for the stabilization method

Activity	Stabilization Method		
	Counter berm	Sheet pile wall	Cement Column
Time for construction	1	3	2
Construction Cost	1	2	3
Maintenance Cost	3	2	1
Technology and local material use	1	3	2
Total Score	6	10	8

Remark: 1 minimum, 2 medium, 3 maximum

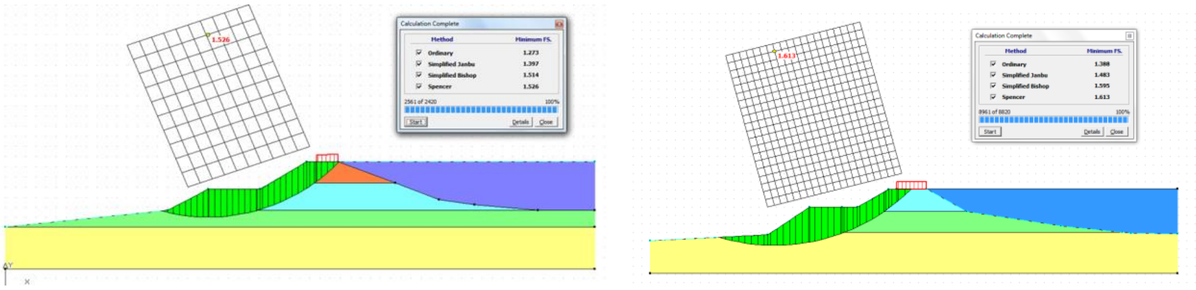
Table 2, the Counter berm has the lowest score so it the best suitable method that combines with surface protection to stabilization the soil slope of wastewater treatment pond. The counter berm uses the local soil mixed with Portland cement type 1 by the ratio of soil to Portland cement 7:1 by weight. From this ratio, the soil-cement has compressive strength 8 ksc (kilogram-force per square centimeter) and unit weight is 1.95 g/cm^3.

After stabilizing the wastewater treatment pond slope by counter berm the safety factor of the slope is increased to greater than 1.5 of all sections as shown in Table 3

Table 3: Result of safety factor (SF) after Stabilized by the counter berm.

Section	Bored Hole No	Factor of Safety (F.S.)		
		Empty upstream slope ,U/S.	Full downstream slope ,D/S	After Stabilized by Counter Berm
2-2	BH-7	1.73	1.20	1.59
3-2	BH-6	2.11	1.40	1.69
4-2	BH-5	1.66	1.44	1.64
6-1	BH-10	2.30	1.16	1.53
8-2	BH-9	2.60	1.16	1.61
9-2	BH-10	2.21	1.23	1.70
10-1	BH-12	1.41	1.81	1.74
12-1	BH-12	1.97	1.20	1.61
13-2	BH-13	1.53	1.31	2.18
15-1	BH-14	2.16	1.46	1.58

The example of slope analysis after stabilized by KUslope® is shown in Figure 12 and the typical drawing of the counter berm is shown in Figure 13.



(a) Section 6-1 (b) Section 12-1

Figure 12: Slope stability analysis after stabilized by Counter Berm of section 6-1 and 12-1

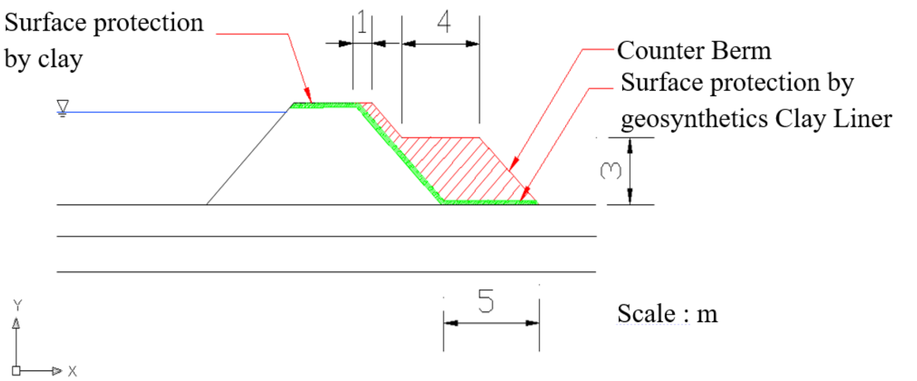


Figure 13: Typical drawing of the counter berm.

7. CONCLUSION

The best suitable method for stabilized the wastewater treatment pond is counter berm with surface protection. The berm is used the local soil mix with Portland cement type 1 by the ratio of soil: Portland cement is 7:1 by weight from this ratio the unit weight of soil-cement is 1.95 g/cm^3 and strength 8.07 ksc.

8. DATA AVAILABILITY STATEMENT

The used or generated data are available upon request to the corresponding author.

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