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Seepage Analysis of Senggarang Coastal Embankment with Chemically-Stabilised Backfill

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Abstract: One of the common problems faced at embankment is water seepage. In this study, seepage happened at the inland area which causing floods and disrupted agriculture in the surroundings area. The objectives of this research are to investigate the senggarang coastal embankment (SCE) seepage problem with a focus on the engineering properties of the backfill and to recommend the best chemical stabilization strategy for SCE seepage mitigation by using PLAXIS 8 software This study involved numerical simulation with the usage of the PLAXIS 8 software. Embankment was simulated using bedrock while the foundation of the embankment was treated and untreated silty clay. Data parameters were collected from previous study. Different water level was applied to see the changes of pore pressure distribution which lead to instability of the embankment. As water level increase, the total displacement increase. Therefore, in this study, the use of two chemical agents which are cement-CSP and lime-ZnO will be compared to determine which one is the best chemical agent that can solve the seepage problem at the embankment. As a result, after the outputs from the PLAXIS software for both chemical agents which are total displacement, effective stress, excess pore pressure, and seepage analysis were being compared, this study have identified that the cement-CSP was the best chemical agent that can stabilize the silty clay and reduce seepage problems at the embankment.

Keywords: Embankment, Seepage, Silty Clay, Cement-CSP, lime-ZnO

1. Introduction

An earthen embankment could be a raised confining structure made up of compacted soil. These also are used for detention and retention of water to facilitate deep percolation. Embankment cross-sections are typically trapezoidal in shape as shown in Figure 1. Seepage is one of the most failure occurred in earth embankment. Seepage can occur due to hydraulic failure, seepage failure, piping through dam body and structural failure due to earthquake.

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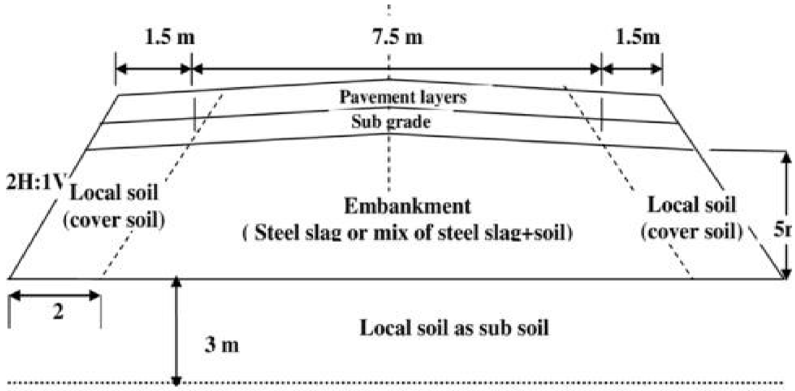

Figure 1: cross-section of embankment [1]

Soil stabilization is the process of adding a special soil, cementing material, or other chemical materials to a natural soil in order to improve one or more of its properties [2]. When this stabilizing agent is used, it can increase the soil particle cohesion and could be served as cementing and water proofing agent [3].

Stabilization is a soil mechanics technique that uses various methods and procedures to improve the properties of test soils. However, this research will more focusing on chemical stabilization method such as cement, cockle shell powder (CSP), lime, and Zinc Oxide (ZnO).

There is a major seepage problem on the Senggarang coastal embankment (SCE) as shown in Figure 2. There is also sign of embankment currently happening in the inland area as shown in Figure 3. Backfill with poor engineering properties may have low strength and high compressibility. It can result in both low bearing capacity and high permeability. Chemical stabilization of backfill soil will be used in this study to improve engineering properties.

Figure 2: Coastal embankment in Senggarang, Batu Pahat

Figure 3: Seepage problem in inland area

This study was conducted to investigate the SCE seepage problem with a focus on the engineering properties of the backfill and to recommend the best chemical stabilization strategy for SCE seepage mitigation by using PLAXIS 8 software. This study will use an existing preventive system can be installed into a coastal embankment that. The software is known as PLAXIS. It has the ability to address geotechnical problems with precision and assess embankment safety [1].

2. Materials and Methods

Figure 4 depicts the study's methodology flow chart. The embankment was simulated using PLAXIS 8 software. The Google coordinates for the site are 1°43'01.7"N 103°02'59.1"E. The embankment was built at Senggarang, Batu Pahat.

Title selection

Literature review

Information preparation

1) **Collect data parameters from past studies such as soil unit weight, permeability, young's modulus, Poisson's ratio, cohesion, and friction angle.**
2) **Embankment model**

Simulation creation

By using PLAXIS software, senggarang coastal embankment was constructed.

Analytical simulation

Step 1: geometry line

Step 2: insert data parameters for untreated silty clay, treated silty clay (cement-CSP), and treated silty clay (lime-ZnO)

Step 3: mesh generation

Results

Analysis and discussion

Conclusion and recommendation

end

Figure 4: Methodology flowchart

2.1 Types of Soil Used

Type of soil used to simulate the embankment was silty clay. Then, treated silty clay (cement-CSP) and treated silty clay (lime-ZnO) were used to replace the untreated silty clay. This is because to see the effect of the chemical agents to the embankment's soil. The silty clay need to be treated to improve the strength to become more stabilized and minimize seepage problem. As at the real site at senggarang, the foundation of the embankment was marine clay but for the simulation in PLAXIS, the foundation of the embankment was simulated as bedrock in PLAXIS software. This is because, bedrock has high strength and stability compared to marine clay. This will be proof by comparing the marine clay and the bedrock as the foundation while the embankment's soil will maintain as silty clay.

2.2 Material Sets

Soil properties are collected in PLAXIS material data sets, which are then stored in a material database. Three geometric models of embankments were simulated with three distinct water levels which are 1 m, 2 m, and 3 m. Table 1 shows the material characteristics that were utilized in the model for the various water levels. The literature and previous work were used to generate all data and parameters.

Table 1: Material properties of the embankment and subsoil [4] & [5]

Parameter	Name	Unit	Bedrock	Untreated silty clay	Treated silty clay (cement-CSP)	Treated silty clay (lime-ZnO)
Model	-	-	Linear elastic	Mohr-coulomb	Mohr-coulomb	Mohr-coulomb
Drainage type		-	Undrained	Drained	Drained	Drained
Dry unit weight	γunsat	kN/m^3	26	16	17.2	16.5
Bulk unit weight	γsat	kN/m^3	26	17	19.5	18
Friction angle	φ	°	50	34	38.7	40
Cohesion	c_{ref}	kN/m^2	100	14	520	74
Poisson ratio	υ	-	0.3	0.34	0.15	0.25
Young Modulus	E_{ref}	kN/m^2	85400	1300	187353	22000
Horizontal permeability	k_x	m/day	0.6	0.778	0.034	0.078
Vertical permeability	k_y	m/day	0.6	0.778	0.034	0.078

2.3 Calculation

The several phases of embankment construction are usually defined using these calculations. The computation for the modelling analysis is divided into five stages. Since this was not done at the entry of the starting conditions, the initial stress field must be determined first. The loading is defined in the third phase. The load applied in this study was 1.79 kN/m^2. The calculation steps in PLAXIS can be seen as in Figure 5.

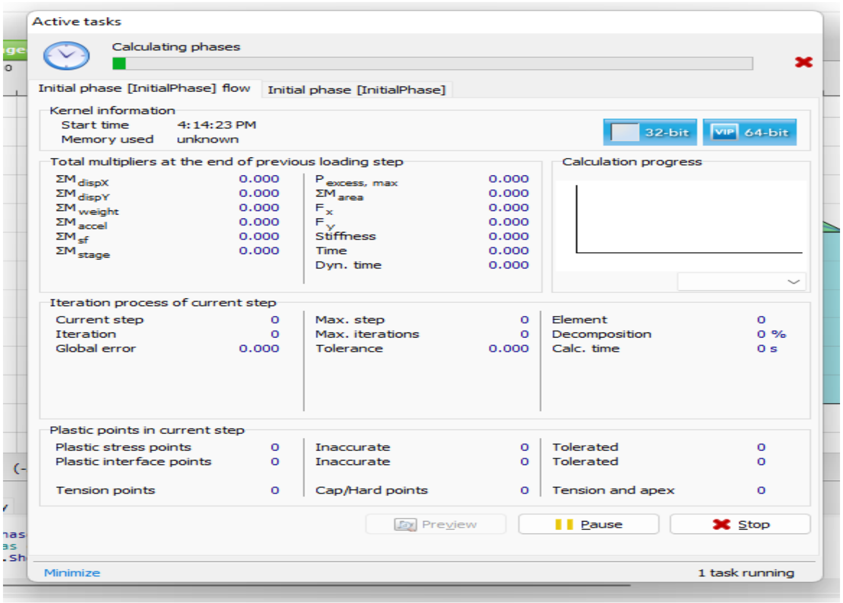

Figure 5: Calculation steps in PLAXIS

3. Results and Discussions

The results that have been observed in PLAXIS software were total displacement, effective stress, excess pore pressure, and discharge of seepage. Before that, the total displacement and seepage will be compared between the marine clay and the bedrock as the foundation of the embankment while the embankment's soil will maintain as silty clay for both simulations.

Table 2: soil parameters of marine clay, bedrock, and untreated silty clay [6]

Parameters	Unit	Marine clay	Bedrock	Untreated silty clay
Drain type	-	Undrained	Undrained	Drained
Dry unit weight, γ_{unsat}	kN/m^3	15.6	26	16
Bulk unit weight, γ_{sat}	kN/m^3	15.6	26	17
Friction angle, φ	°	1	50	34
Cohesion, c_{ref}	kN/m^2	13.5	100	14
Poisson's ratio, υ	-	0.4	0.3	0.34
Young's modulus, E_{ref}	kN/m^2	3100	85400	1300
Horizontal permeability, k_x	m/day	0.165	0.6	0.778
Vertical permeability, k_y	m/day	0.069	0.6	0.778

3.1 Comparison Between Marine Clay and Bedrock as Foundation of the Embankment

Table 3: Comparison between Marine Clay and Bedrock from PLAXIS output

Water level	Type of soil of the embankment's foundation	Total displacement (mm)	Discharge of seepage (m^3/day)
1 m	Marine clay	11.73	95.85 x 10^{-3}
	Bedrock	5.15	38.08 x 10^{-3}
2 m	Marine clay	17.31	195.40 x 10^{-3}
	Bedrock	9.69	170.90 x 10^{-3}
3 m	Marine clay	26.54	520.35 x 10^{-3}

	Bedrock	15.78	485.80 x 10^{-3}

As shown in Table 3, it can be concluded that Bedrock has higher stability and strength compared to marine clay. This is because, the total displacement of the embankment when using marine clay as the foundation was higher than bedrock. For example, at 1 m water level, the total displacement of marine clay was 11.73 mm while 5.15 mm for the bedrock. The discharge of seepage of marine clay also higher than the bedrock. For example, at 3 m water level, the seepage of marine clay was 520.35 x 10^{-3} m^3/day while the bedrock was lower which was 485.80 x 10^{-3} m^3/day. This is because bedrock had a greater cohesion (100 kN/m^2) than marine clay (13.5 kN/m^2). From this comparison, this study has decided to use the bedrock as the foundation of the embankment because it has a higher stability and strength compared to marine clay. So, this study can only focus to stabilize the embankment.

3.2 Total Displacement

Figure 6 shows the water level vs total displacement for untreated silty clay, treated silty clay (cement-CSP), and treated silty clay (lime-ZnO). Untreated silty clay has a larger total displacement value than treated silty clay (cement-CSP) and treated silty clay (lime-ZnO), as seen in the graph. When the total displacement values for treated silty clay (cement-CSP) and treated silty clay (lime-ZnO) were being compared, it can be seen that the total displacement value for treated silty clay (cement-CSP) is lower than the total displacement value for treated silty clay (lime-ZnO). The total displacement value for treated silty clay (cement-CSP) was 0.47 mm at a 2 m water level, whereas the treated silty clay (lime-ZnO) was 1.03 mm. This is because treated silty clay (cement-CSP) had a greater cohesion value (520 kN/m^2) than treated silty clay (lime-ZnO) (74 kN/m^2). This suggests that the cement-CSP might increase soil strength more effectively than the lime-ZnO.

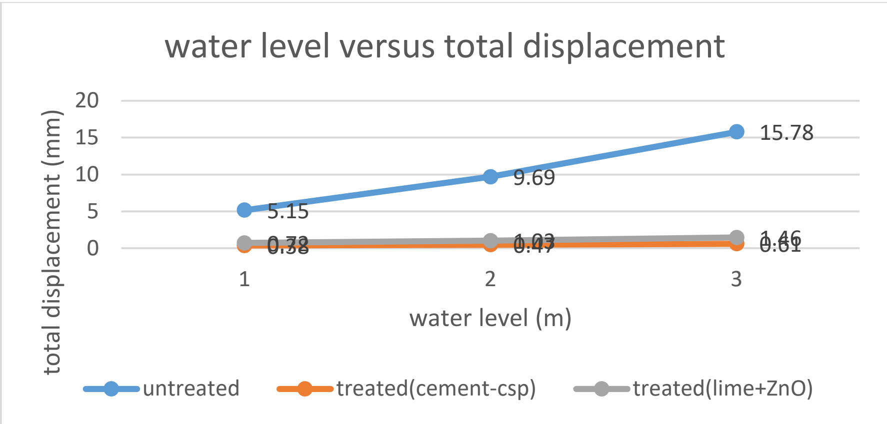

Figure 6: Graph of water level versus total displacement

3.2 Effective Stress

The findings of effective stresses from numerical simulation of an embankment with untreated and treated (cement-CSP) silty clay are shown in Table 4.

Table 4: Effective stresses of embankment with untreated and treated silty clay

Water Level (m)	Soil types	Effective stresses (kN/m^2)
1	Untreated silty clay	-122.7
	Treated silty clay (cement-CSP)	-123.8
	Treated silty clay (lime-ZnO)	-123.5
2	Untreated silty clay	-118.9
	Treated silty clay (cement-CSP)	-120.8

	Treated silty clay (lime-ZnO)	-120.4
3	Untreated silty clay	-116.5
	Treated silty clay (cement-CSP)	-119.0
	Treated silty clay (lime-ZnO)	-117.9

From Table 4, it is apparent that the increase of effective stress for treated silty clay was smaller than the untreated silty clay. For example, the effective stress increase for treated silty clay (cement-CSP) was 4.8 kN/m^2, smaller than the untreated silty clay, 6.2 kN/m^2. It means the settlement of the treated silty clay (cement-CSP) was smaller than the untreated silty clay. As shown in Table 4, the increase of effective stress for treated silty clay (cement-CSP) (4.8 kN/m^2) was smaller than the treated silty clay (lime-ZnO) (5.6 kN/m^2). It means cement-CSP could improve the strength of silty clay better than (lime-ZnO). It could also reduce the compression rate of the soil. This is because when the increase of the effective stress becomes smaller, the soil compression rate also decreases. Hence, the settlement of the soil could be lower. Figure 7 shows the graph of water level vs. effective stresses for untreated and treated silty clay. The graph was created by using the results data from Table 4.

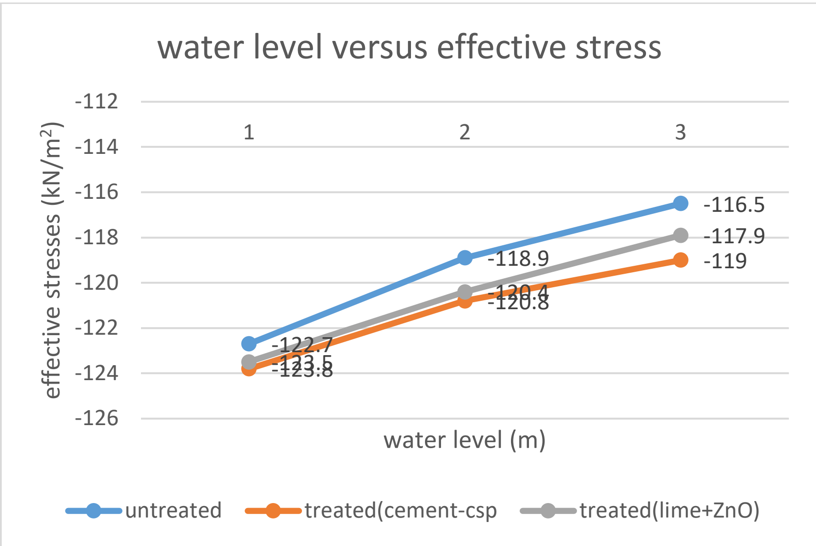

Figure 7: Graph of water level versus effective stresses

3.3 Excess Pore Pressure

Excess pore pressure results from numerical simulation of embankment with untreated silty clay, treated (cement-CSP) silty clay, and treated silty clay (treated with lime-ZnO) are shown in Table 5. From Table 5, it can be concluded that the excess pore pressure rises with it when the water level rises. For example, the excess pore pressure of untreated silty clay at 1 m water level was 0.039 kN/m^2, while at 3 m water level, it was 0.120 kN/m^2. Because the material is saturated due to water seepage into the embankment's body, an increase in water level can increase excess pore pressure. From the Table 5, it also shows that excess pore pressure for untreated silty clay were bigger than the treated silty clay.

Table 5: Excess pore pressure for untreated and treated silty clay

Water Level (m)	Soil types	Excess pore presusre (kN/m^2)
1	Untreated silty clay	0.039
	Treated silty clay (cement-CSP)	0.006
	Treated silty clay (lime-ZnO)	0.023

2	Untreated silty clay	0.075
	Treated silty clay (cement-CSP)	0.01
	Treated silty clay (lime-ZnO)	0.058
3	Untreated silty clay	0.120
	Treated silty clay (cement-CSP)	0.020
	Treated silty clay (lime-ZnO)	0.107

Furthermore, Figure 8 depicts a graph of water level vs excess pore pressure for untreated and treated silty clay. The graph was created by combining the values from Table 5. The excess pore pressure value for treated silty clay (cement-CSP) was lower than that of treated silty clay (lime-ZnO). As indicated in Table 5, the excess pore pressure for treated silty clay (cement-CSP) at 2 m water level was 0.01 kN/m^2, while it was 0.058 kN/m^2 for treated silty clay (lime-ZnO). It may be inferred that treating the soil with cement-CSP improves soil stability more than treating it with lime-ZnO. This is because as the extra pore pressure decreased, the shear strength of the soil increased (Ali-Karni, A. A., 2001). As a result, the soil's strength could be improved.

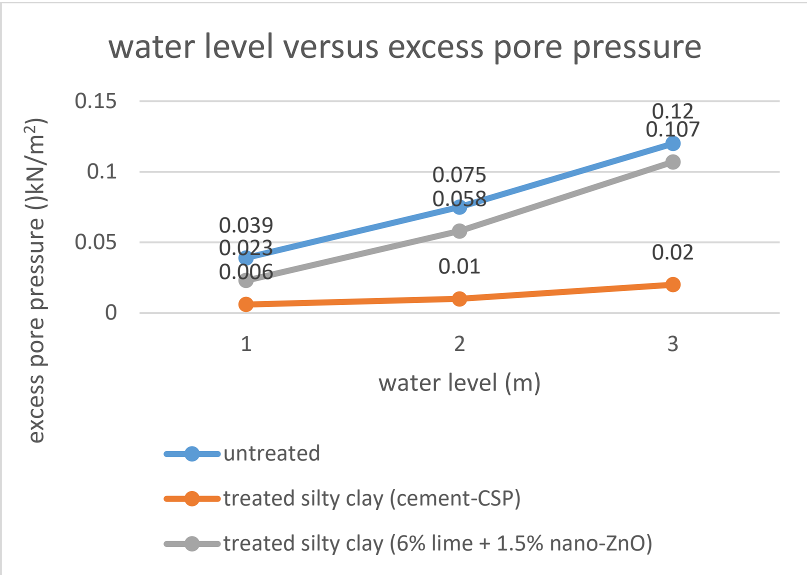

Figure 8: Graph of water level versus excess pore press

3.4 Seepage Analysis

Table 6 shows that the higher the water level, the greater the seepage flow. An increase in pore pressure causes a rise in seepage discharge. It also shows that the seepage discharge for untreated silty clay is larger than the treated silty clay. Meanwhile, treated silty clay (cement-CSP) has lesser discharge seepage than treated silty clay (lime-ZnO). As shown in Table 6, the value of discharge seepage for treated silty clay (cement-CSP) at 1 m water level was 1.78×10^{-3} m^3/day, while 3.95×10^{-3} m^3/day for treated silty clay (lime-ZnO). It demonstrates that cement-CSP can reduce seepage more effectively than lime-ZnO. The soil strength of treated silty clay (cement-CSP) would be greater than that of treated silty clay (lime-ZnO). In comparison to (lime-ZnO), cement-CSP was the best chemical agent for reducing seepage and increasing soil stability.

Table 6: Discharge of seepage analysis on embankment using PLAXIS

Water level (m)	Soil Types	Discharge of seepage using PLAXIS (m^3/day)
1	Untreated silty clay	38.08×10^{-3}

	Treated silty clay (cement-CSP)	1.78×10^{-3}
	Treated silty clay (lime-ZnO)	3.95×10^{-3}
2	Untreated silty clay	170.90×10^{-3}
	Treated silty clay (cement-CSP)	7.21×10^{-3}
	Treated silty clay (lime-ZnO)	16.77×10^{-3}
3	Untreated silty clay	485.80×10^{-3}
	Treated silty clay (cement-CSP)	21.34×10^{-3}
	Treated silty clay (lime-ZnO)	49.68×10^{-3}

In the meantime, Figure 9 depicts the relationship between displacement and seepage in treated silty clay (cement-CSP). The seepage discharge may result in displacement or settlement, which increases dramatically. The material changes in saturated conditions when displacement increases due to water seepage in the embankment body. The value of displacement will then alter as well. Figure 9 depicts the difference in horizontal and vertical displacement values. The load caused this exerted to the embankment in a vertical direction.

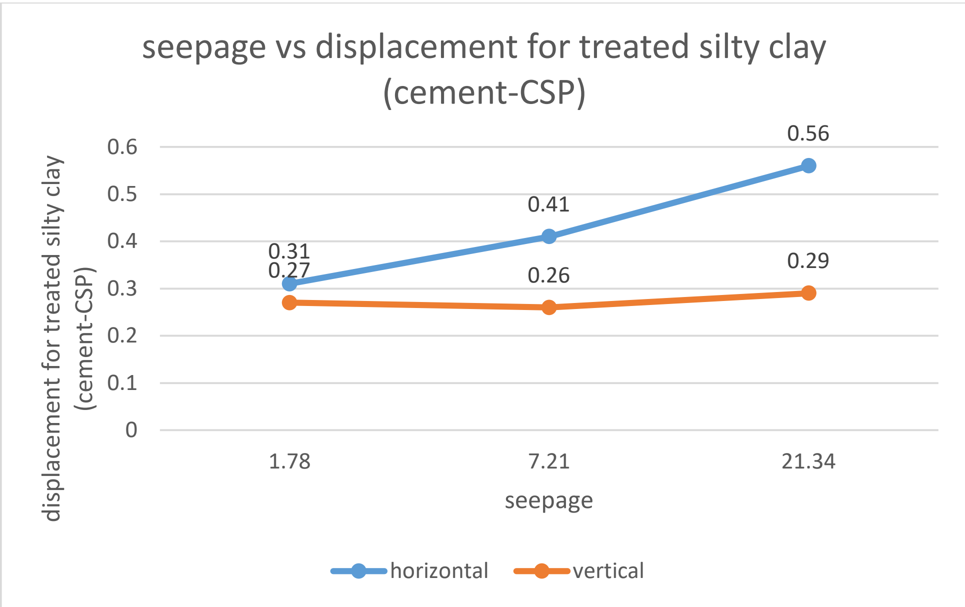

Figure 9: seepage vs displacement

4. Conclusion

All of the objectives were met due to this numerical simulation study. The numerical simulation of the Senggarang embankment with various soil types was successful. There were three types of embankments simulated which were untreated silty clay, treated silty clay (cement-CSP), and treated silty clay (lime-ZnO). All simulations were successful in displacement, effective stresses, excess pore pressure, and seepage discharge.

The first objective was to investigate the SCE seepage problem with a focus on the engineering properties of the backfill. All the parameters of the untreated and treated silty clay were obtained from past journals. The results show the discharge of seepage for embankment constructed with chemical stabilizing agents stabilized silty clay was lower than untreated silty clay embankment. The cement-CSP and the lime-ZnO could reduce the seepage discharge of the embankment.

The second objectives to recommend the best chemical stabilization strategy for SCE seepage mitigation by using PLAXIS 8 software. In this study, there were two types of chemical agents that can be used to stabilize the soil which are cement-CSP and lime -ZnO. All the results obtained by using PLAXIS software were being compared between these two chemical agents such as the total displacement, the effective stress value, excess pore pressure and discharge of seepage. 1.9 kN/m^2 was applied on top of the embankment. From the results, the total displacement of cement-CSP stabilized silty clay embankment was lower than lime-ZnO stabilised silty clay embankment. Low value of total displacement shows that the strength of the embankment increase. The cementation properties of treated silt clay (cement-CSP) enhanced the performance of the embankment and increase the shear strength of the embankment better than lime-ZnO. The value of seepage discharge for treated silty clay (cement-CSP) was also smaller than the treated silty clay (lime-ZnO). It can be said that the soil strength of the silty clay could be improved effectively when treated with cement-CSP than the lime-ZnO. So, it can be concluded that cement-CSP was the best chemical stabilization strategy than the lime-ZnO in order to reduce the seepage of the soil and to increase the strength soil strength hence increasing the stability of the embankment.

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