Progress in Engineering Application and Technology Vol. 4 No. 2 (2023) 762-771
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PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Development of Slope Protection Scheme for Senggarang Coastal Embankment Against Erosion

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DOI: https://doi.org/10.30880/peat.2023.04.02.079
Received 14 January 2023; Accepted 09 February 2023; Available online 09 February 2023

Abstract: Senggarang coastal embankment (SCE) is currently facing the risk of structure failure with the erosion activities keep on happening on the seaward side of the embankment slope. The seaward side of slope structure has been exposed to unprecedented rate of tidal assault causing it to require constant repair and reinforcement in severe cases. Therefore, PLAXIS 2D software is used for finite element analysis of Senggarang embankment model simulation, where the existing riprap slope protection is analysed further with three different water level to examine the effect towards the embankment. Then, the study is continued with the simulation of the embankment model without any slope protection as a control model, and add slope protection of cantilever retaining wall, and gabion retaining wall to analyse the total displacement, effective stresses, excess pore pressure, seepage analysis, and factor of safety. Each simulation is also implemented with geotextiles to check the effectiveness as underneath layers for slope protection. From the results, it is found that cantilever retaining wall with geotextiles gives proper protection more than the current riprap structure with safety factor of 1.987 at 3m water level. But, the process of collecting sample and sample testing must be revised again to get accurate parameter of the embankment. Regardless, PLAXIS 2D helps in developing cantilever retaining wall slope protection scheme while considering the sustainability towards the environment.

Keywords: Senggarang Coastal Embankment, Erosion, Plaxis 2D, Slope Protection

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1. Introduction

Climate change has brought effects to the increasing seawater level, while embankment structures like Senggarang coastal embankment helps contain the seawater from flooding the land [1]. During high tide, the seawater level could reach the same level as the top of the embankment and overtopping of seawater issues is frequent in SCE. In addition, there were slope erosion activities happening on the seaward side of the embankment that may have been caused by various reasons. The main reason for occurrence of the erosion is the slope exposure to the high seawater tide's impacts hitting on the embankment while having riprap as the only slope protection. Weak structural and reinforcement of the embankment along the Senggarang Coastal Embankment causes it to be eroded over time while inducing other major problems and ended up experiencing failure.

Figure 1: The condition of SCE during high tide

This study focuses on Senggarang Coastal Embankment located in Batu Pahat, Johor with the width of 3m average and 3m height. Approximately 1150m length from the whole embankment has been chosen for the data collection purposes starting from coordinates (1.715661°N, 103.052365°E) to (1.720049°N, 103.043563°E). The whole structure of the SCE is in risk of failure after soil erosions happens on the seaward side of the embankment. Thus, a proper slope protection helps SCE to maintain their structure by protecting the seaward slope from exposed to the tidal assault especially during high tide. There are several types of slope protection that can be used to prevent or control erosion on a coastal embankment slope, including geotextile, sea wall, gabion retaining wall, and cantilever retaining wall [2].

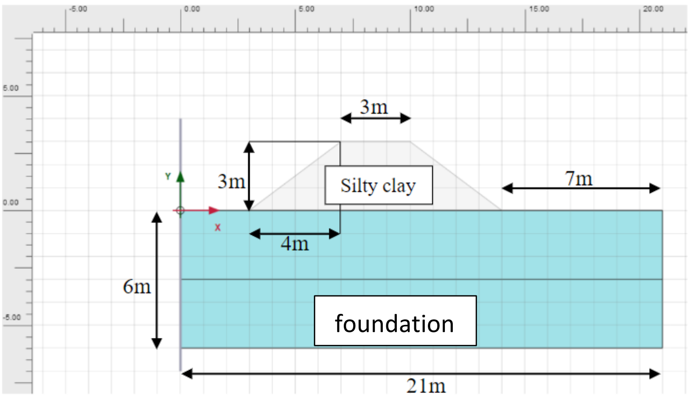

Figure 2: The measurement of SCE

Appropriate with eleventh sustainable development goals list that is making cities and human settlement safe, inclusive, resilient, and sustainable by preventing the erosion process from causing any further disruption to the embankment[3]. Therefore, these studies will examine the existing slope protection methods which is riprap for SCE in terms of their functionality and performance. Then, an effective slope protection scheme against erosion will be proposed for SCE with sustainability considerations.

2. Plaxis 2D Simulation

Before working on the embankment simulation process, characteristics of the soil are needed as data parameter in creating the model of the embankment in PLAXIS 2D. In order to obtain the characteristics of soil, on-site testing and laboratory testing are to be done by using disturbed samples from the site. The Mackintosh probe test is a field test used to determine the bearing capacity of soil while the vane shear test is famous for estimating the undrained shear strength (Cu) of fully saturated clays and slits without disturbance[4]. For laboratory testing, the plastic limit test is used to determine the moisture content at which soil transitions from a plastic to a crumbly state. The liquid limit test is used to determine the moisture content at which soil transitions from a solid to a liquid state[5]. The specific gravity of a soil is an important property for determination of void-ratio, degree of saturation and others that can be used to evaluate the consistency and compaction characteristics of the soil[6]. The sieve analysis test is a laboratory test used to determine the percentage of various size particles in a soil sample, and to classify the coarse-grained soil[7]. While for shear box test, it is to determine the ultimate shear resistance, peak shear resistance, cohesion, angle of shearing resistance and stress-strain characteristics of the soils[8]. The soil sample is subjected to a series of shear stresses, and the resulting deformation of the soil is measured.

2.1 Embankment Model with Slope Protection Method

The structure of the embankment will be designed with 6m and 3m height respectively consisting of foundation as the lower layer of the embankment. The simulation will also run in two ways of slope protection application which are using geotextile underneath the slope protection structure or without the absence of geotextile. Data from previous testing are now tabulated into a material set as shown in table 1 which users need to assign types of materials according to the structure required in the project because different types of soil have different behavior projected in the structure.

Table 1: Data parameters to be applied in PLAXIS 2D

Parameter	Symbol	Silty clay	Foundation
Material model	-	Mohr-Coulomb	Mohr-Coulomb
Behaviour type	-	Undrained (A)	Non-porous
Soil unit weight above p.I (kN/m^3)	$\gamma unsat$	16	26
Soil unit weight below p.I (kN/m^3)	γsat	17	26
Horizontal permeability (m/day)	k_x	3.499	-
Vertical Permeability (m/day)	k_y	3.499	-
Young’s Modulus (kN/m^2)	E_{ref}	1300	85400
Poisson’s ratio	υ'	0.34	0.1
Cohesion (kN/m^2)	c'_{ref}	14	-
Friction angle (°)	φ'	34	-

Dilatancy angle (°)	ψ	0	-

Simulations of slope stability analysis are to be done in PLAXIS 2D with the implementation of slope protection method according to Table 2. The cantilever retaining wall which has the backfill is going to be filled with the same silty clay material as the embankment. While for geotextile parameters will use elastic material model with axial rigidity of 5000kN/m [9].

Table 2: Data parameters for the cantilever retaining wall [10] and gabion retaining wall [11] slope protection method

Parameter	Symbol	Cantilever retaining wall	Gabion retaining wall
Material model	-	Mohr-Coulomb	Mohr-Coulomb
Behaviour type	-	Non-porous	Non-porous
Soil unit weight above p.I (kN/m^3)	$\gamma unsat$	24	26
Soil unit weight below p.I (kN/m^3)	γsat	24	26
Horizontal permeability (m/day)	k_x	-	-
Vertical Permeability (m/day)	k_y	-	-
Young's Modulus (kN/m^2)	E_{ref}	22720	85400
Poisson's ratio	υ'	0.2	0.1
Cohesion (kN/m^2)	c'_{ref}	513	1
Friction angle (°)	φ'	35	25
Dilatancy angle (°)	ψ	0	-

Referring to the first objective of this project is to examine the existing slope protection methods for SCE in terms of functionality and performance. A simulation of embankment model with the existing slope protection which is riprap is built in the PLAXIS 2D for the analysis of the total displacement, effective stresses, excess pore pressure, and seepage analysis.

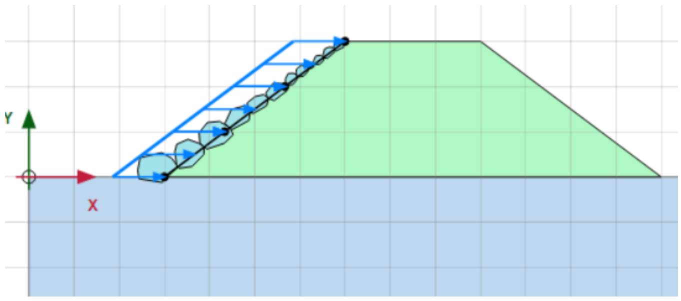

Figure 3: Boundary condition of embankment with riprap

Table 3: Data parameters of slope protection model for SCE simulation in PLAXIS 2D [9]

Parameter	Symbol	Limestone for Riprap
Material model	-	Linear Elastic
Behaviour type	-	Undrained (C)
Soil unit weight above p.I (kN/m^3)	$\gamma unsat$	26
Soil unit weight below p.I (kN/m^3)	γsat	26.42
Horizontal permeability (m/day)	k_x	-
Vertical Permeability (m/day)	k_y	-
Young's Modulus (kN/m^2)	E_{ref}	58577500
Poisson's ratio	υ'	0.923
Cohesion (kN/m^2)	c'_{ref}	-
Friction angle (°)	φ'	-
Dilatancy angle (°)	ψ	-

A horizontal line load is added to the structure with 6 kN/m as substitute for seawater at three different level shows the boundary conditions of the structure. Then, the generation of mesh is done with mesh refinement enhance set into medium. The initial conditions refer to the state of stress and strain in the embankment material mass at the start of an analysis. These conditions can have a significant effect on the behaviour of the soil or rock mass during the analysis, especially if the soil or rock mass is expected to undergo large deformations or changes in stress. Before the calculation process begins, the element nodes must be appointed for the curve of the model, therefore point (14,0) is chosen for the element node. The calculation is considered done when all checklist in phase explorer has turned green, then we can view the calculation result in the next chapter.

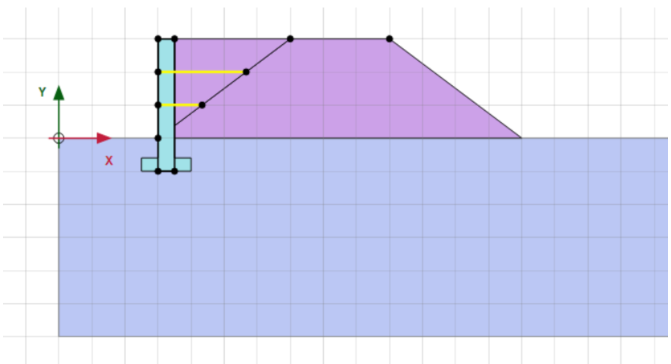

Figure 4: embankment model of cantilever retaining wall with geotextile.

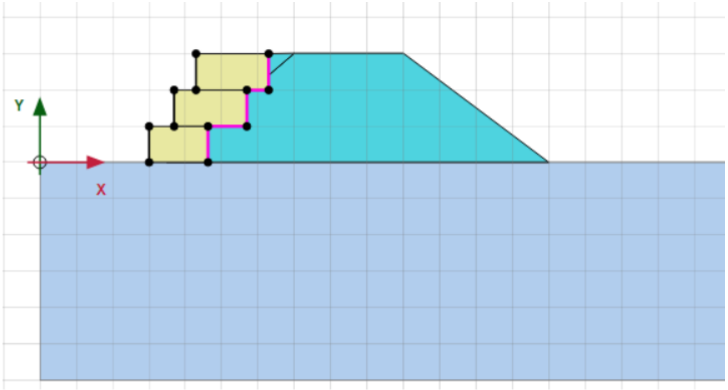

Figure 5: embankment model of gabion retaining wall with geotextile.

3. Results and Discussion

In the calculation process of riprap embankment model, only three phases are analyzed up until 3m of water level because there is no geotextile application in this model. It is found that the total displacement of the structure can be from 8.916×10^{-3}m during low tide until 2.218×10^{-2}m during high tide while the effective stress of the structure is between 474.30kN/m^2 to 2840kN/m^2. The excess pore pressure of the embankment ranged from 83.52kN/m^2 to 146.6kN/m^2 and lastly the seepage discharged which is 2.035m^3/day/m from 0.1723m^3/day/m. Lastly, the safety factor of SCE with current riprap slope protection has safety factor of 2.339, 2.054, and 1.551 respectively with the increasing water level.

3.1 Total Displacement

As shown in figure 6, the calculation shows that cantilever retaining wall with geotextile has the least total displacement with 5.201 $\times 10^{-6}$ m at 1m water level, but gabion retaining wall with geotextile model has improve with 5.846×10^{-5} m displacement at 2m water level and 8.469 $\times 10^{-5}$ m total displacement at 3m water level. Control model has the highest total displacement at 3m water level with value of 2.672×10^{-2} m.

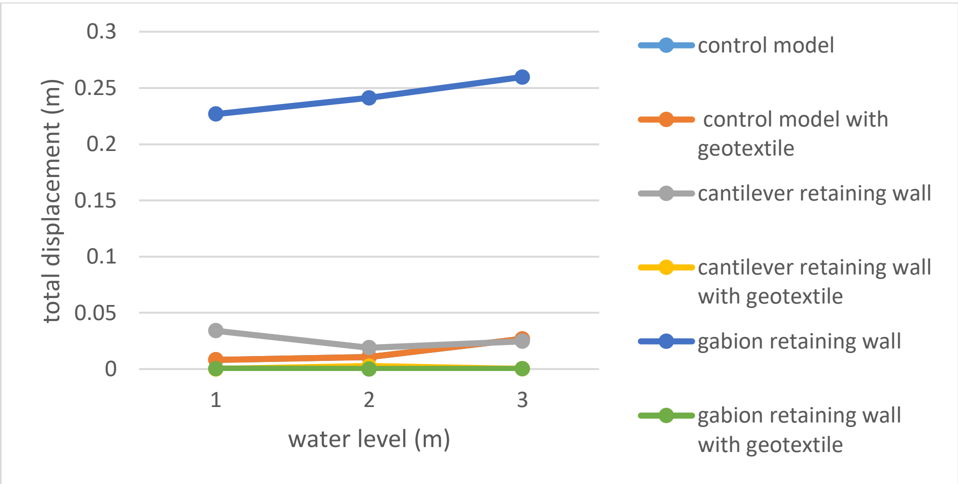

Figure 6: Trend between water level and effective stresses

3.2 Effective Stress

From the result, it can be concluded that all the simulation values of effective stress increase following the increase of water level. At 1m depth, the lowest effective stress was the control model with 9.441kN/m^2. Then, gabion retaining wall with geotextile shows the highest effective stress at all three different water levels with minimum value of 277.1kN/m^2 at 1m water level with geotextile on.

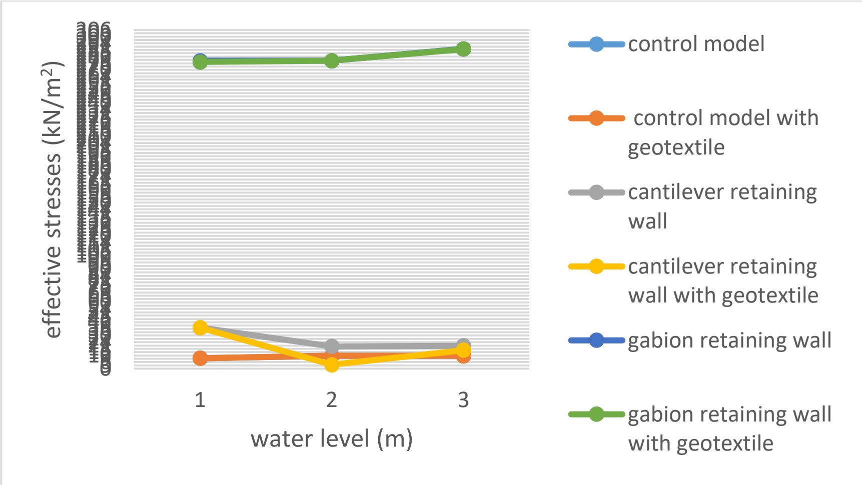

Figure 7: Trend between water level and effective stresses.

3.3 Excess Pore Pressure

The strength of the soil will rise as the pore pressure decreases and the effective stresses are reduced. From Figure 8, it can be concluded that as the water level increases, the excess pore pressure will also increase. For example, the pore pressure for the control model is 8.403kN/m^2 at 1m water level and it increased to 15.84kN/m^2 at 2m water level. As the water level increased to 3m, the excess pore pressure rose to 24.41kN/m^2 yet it is the lowest value among all three types of models.

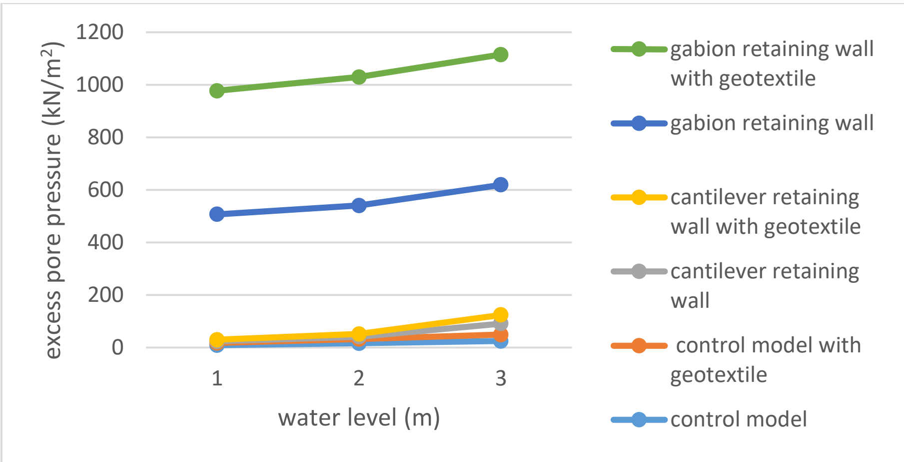

Figure 8: Trend between water level and excess pore pressure

3.3 Seepage Analysis

From figure 9, it can be concluded that as the water level increases, the seepage discharge will also increase. For example, the seepage discharge for cantilever retaining wall method has the highest seepage discharge at all three water levels with 0.1046 m^3 /day/m at 1m water level and it increased to 0.2481 m^3 /day/m at 2m water level. As the water level increased to 3m, the seepage discharge rose to 0.5198 m^3 /day/m. It is noticeable that the seepage analysis for all applied geotextile is not in the graph, because the value for the model with the application of geotextile is the same value with the model without geotextile.

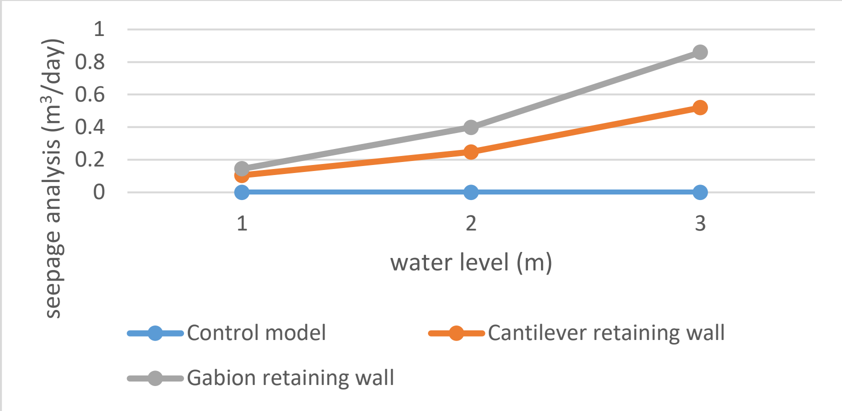

Figure 9: Trend between water level and seepage discharge

3.4 Factor of Safety

All the models simulated in Plaxis 2D have passed the minimum safety factor value of structure of 1.5, except for gabion retaining wall with geotextile model at 3m water level with value 1.497. Based on data observation, the majority of models have decreasing safety factor value in accordance with the increasing water level. The model structure with gabion retaining wall has higher value set off with 2.489 yet decreased to 1.533 at the end 3m water level. Cantilever retaining wall is considered the safest slope protection method with the higher consistency rate for all three different water levels.

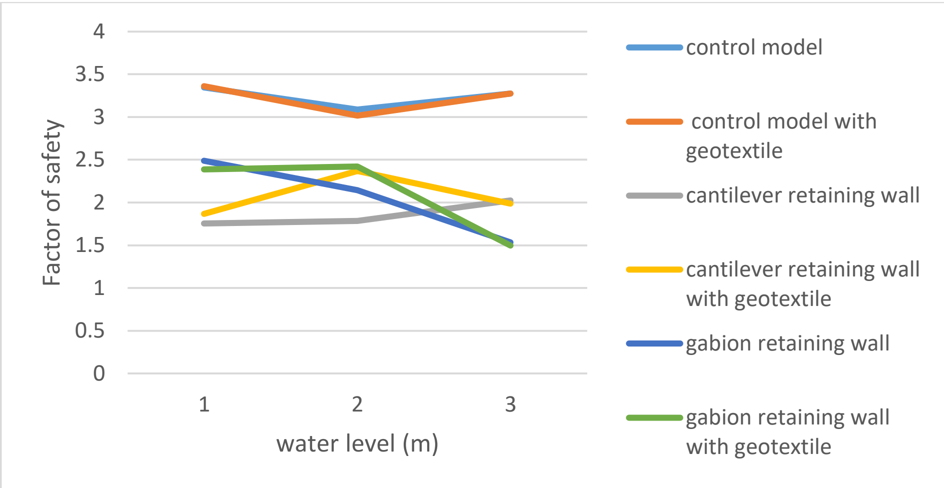

Figure 10: Trend water level and safety factor

3.5 Discussion

It shows that cantilever retaining wall with geotextile will be the most effective slope protection scheme for SCE. Even at 3m water level, cantilever retaining wall with geotextile hold low values in total displacement, total effective stresses and also has low discharge of seepage. It also has the highest safety factor average for the embankment, which is 2.075. The control models in this simulation are not considered in achieving our second objectives, that is developing slope protection method for SCE slope surface.

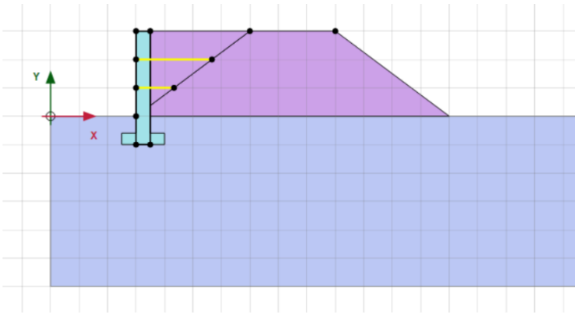

Figure 11: The embankment model with cantilever retaining wall and geotextile.

4. Conclusion

Data findings show that the development of slope protection scheme for Senggarang Coastal Embankment has successfully achieved its objectives of the project. Through the simulation of embankment models in PLAXIS 2D, three types of models are built with and without geotextile application to study the effectiveness of the geotextile uses on slope protection. It is found that the embankment structure with existing riprap slope protection is considered not fully safe, yet cautionaries and reinforcement must be done on the SCE to prevent collapse and further negative impact from the continuous erosion process. The calculation analysis and discussion found that cantilever retaining wall with geotextile has caused less total displacement on the embankment structure while having less seepage discharge even during high tide period. Hence it is the most effective method as a slope protection for the SCE as in both performance and sustainable consideration where the method of application is discussed in previous chapter, so it causes minimal impact to the environment and going towards the sustainable development goals. Even though this study is considered a success, they still have room for improvements that can be referred to and applied for future research such as the process of collecting sample and sample testing must be revised again to get accurate parameter of the embankment.

Acknowledgement

This research was made possible with help and guidance from supervisor and fellow lecturers. The authors would also like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for the opportunity to complete this project.

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