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Formulation of a Slope Protection Scheme for Senggarang Coastal Embankment Subjected to Tidal Assault

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Abstract: The seaward slope of embankment that experience erosion due to washing of soil particles from the wave action might resulting the slope become steeper by time and posing a threat to the closest residents. The objective of this research is to examine the existing slope protection methods for Senggarang Coastal Embankment (SCE) in terms of functionality and performance. This paper explores the possible success and failure factors of the slope protection methods by performing the stability analysis of the slope. Desk research were conducted to identify the potential slope protection scheme for SCE then simulated with PLAXIS 2D to refine the proposed solution. Embankment was simulated using silty clay with different water level at 1 m, 2 m and 3 m to see the total displacement, effective stress, excess pore pressure and discharge of seepage. As a result, the deformation for embankment with innovative method is 10% lower than embankment without any slope protection. Meanwhile, the discharge of seepage for embankment with innovative slope protection has reduced by 40% compared to the embankment in the absence of slope protection. In summary, this study has found the water level effect on the displacement and stability of the embankment. The higher the water level, the higher the displacement of the embankment.

Keywords: Embankment, erosion, slope protection, PLAXIS 2D

1. Introduction

Coastal embankment is commonly used to property and safeguard human life from harsh environmental conditions like long-term wave loading, sea level rise, rainfall and storm [1]. One of the common problems faced at the embankment sites is erosion at the seaward slope. Erosion takes place mainly due to two types of reason which are natural forces and human interferences [2].

There are several types of slope protection against embankment failure. One of the slope protection tools that can be adopted is riprap. Riprap is widely used as underwater structures protection that approach embankments [3]. Fig. 1 shows riprap in Senggarang, Johor that is a kind of big and angular stone which is used to armor or protect the soil surface against erosion and scour in locations where there is concentrated flow or wave activity.

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Fig. 1 - Riprap in Senggarang, Johor

SCE has a great concern on embankment slope failure due to erosion and washing of soil particles from the seaward slope area. This event invites severe seepage problems in inland area to be happened as shown in Fig. 2. This leads to cause damage of service roads, inland floods at high tide, and possibility of embankment to failure. Both seaward and inland slopes of SCE are under high threat, especially the seaward slopes which are exposed to the tidal assault and can invite the settlement of slope to happen as can be seen in Fig. 3.

Fig. 2 - Inland side of SCE that occur seepage [4]

Fig. 3 - Seaward slope of SCE that occur settlement

Therefore, this study is intended to explores the existing alternative of slope protection via desk research while aiming in providing the industry with a general overview of the potential slope protection scheme for SCE. Besides, the objective of this study is to analyse the characteristic of SCE constructed with selected slope protection methods and different sea water level via PLAXIS 2D. This study is also to propose a comprehensive slope protection scheme for SCE to counter the tidal assaulting effect. The data gathered from the comparative study will be analyzed and discussed, with the most relevant approach being chosen as the most desirable slope protection for SCE. By using PLAXIS 2D, it can be used to run the simulation of the SCE to see the slope protection performance in term of its stability and safety factor.

2. Materials and Methods

Fig. 4 shows the methodology flow chart of this study. PLAXIS 2D Version 2015 was used to simulate the embankment. The coordinate of the location is latitude 1˚ 43’ 57” to 1˚ 42’ 48” N, longitude 103˚ 01’ 00” to 103˚ 03’ 26” E, where the research area is about 5 kilometers which passed through Parit Aman, Parit Besar and Parit Kongsi.

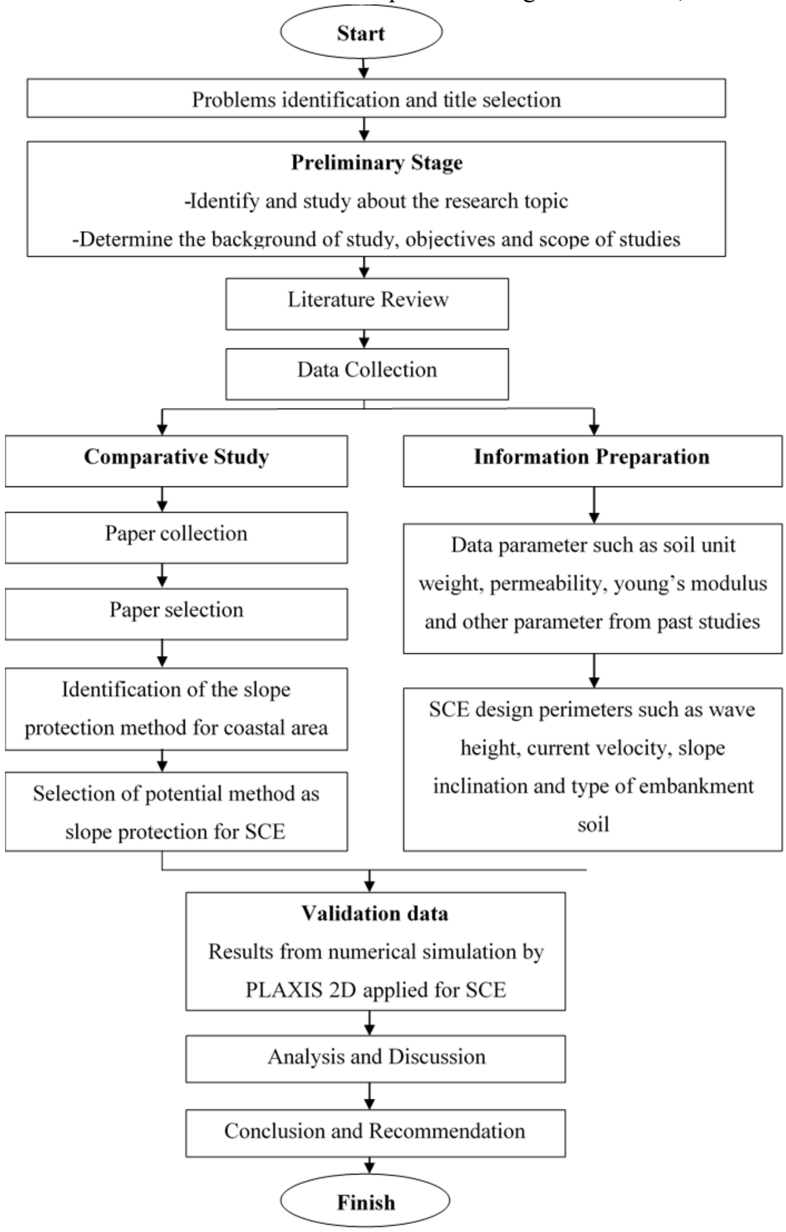

Fig. 4 - Research activity flow chart

2.1 Embankment Details

Based on the study area which is SCE, type of soil for the embankment consist of clay. However, in this study, the first layer which is the foundation of the embankment was modelled as bedrock to avoid any major settlement at the foundation. This is because this study is only focus on the performance of the embankment slope and not its foundation. Then, the top layer of the embankment which is the slope is made of silty clay. The embankment that consisted of bedrock and silty clay then modelled with 6 m and 3 m height respectively for each type of soil as can be seen in Fig. 5. The data parameters for SCE simulation was inputted as Table 1. Meanwhile, Table 2 and Table 3 shows the data parameters of geotextile model and slope protection for simulation, respectively.

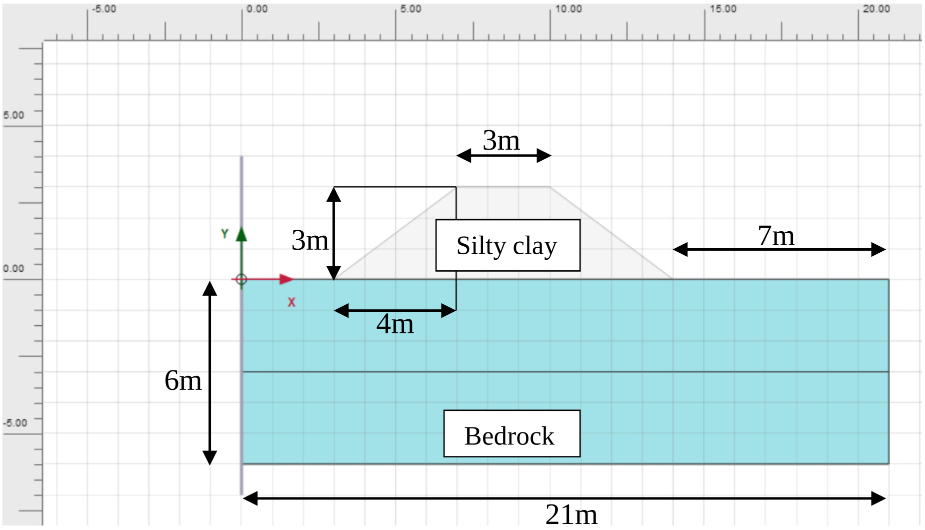

Fig. 5 - Model of the SCE that was be inputted in PLAXIS 2D software

Table 1 - Data parameters of embankment model for SCE simulation on PLAXIS 2D

Parameter	Symbol	Silty Clay	Bedrock
Material model	-	Mohr-Coulomb	Linear elastic
Behavior type	-	Undrained	Non-porous
Soil unit weight above p.I (kN/m^3)	γunsat	16	26
Soil unit weight below p.I (kN/m^3)	γsat	17	26
Horizontal permeability (m/day)	k_x	0.778	-
Vertical Permeability (m/day)	k_y	0.864	-
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	-

Table 2 - Data parameters of geotextiles model for SCE simulation on PLAXIS 2D

Parameter	Symbol	Geotextile
Material model	-	Linear elastic
Axial rigidity (kN/m)	EA	5000

Table 3 - Data parameters of slope protection model for SCE simulation on PLAXIS 2D

Parameter	Symbol	Limestone for Riprap	Sand for Geo-bag
Material model	-	Linear elastic	Mohr-Coulomb
Behavior type	-	Non-porous	Drained
Soil unit weight above p.I (kN/m^3)	γunsat	26.00	17
Soil unit weight below p.I (kN/m^3)	γsat	26.42	20
Horizontal permeability (m/day)	k_x	-	7.128
Vertical Permeability (m/day)	k_y	-	7.128
Young's Modulus (kN/m^2)	E_{ref}	58577500	100000
Poisson's ratio	υ'	0.923	0.4
Cohesion (kN/m^2)	c'_{ref}	-	5.49
Friction angle (°)	φ'	-	31.49
Dilatancy angle (°)	ψ	-	3.0

2.2 Riprap

Riprap is widely used as technical reinforcement to protect banks of the river since it is flexible, durable, easy to build and looks natural [5]. In this study, the riprap that was designed in PLAXIS 2D is assumed to have the same parameters as limestone. The model of riprap is designed as structure using the polygon lines as illustrates in Fig. 6. In this study, the load of 1.9 kN/m^2 was applied in the PLAXIS 2D software.

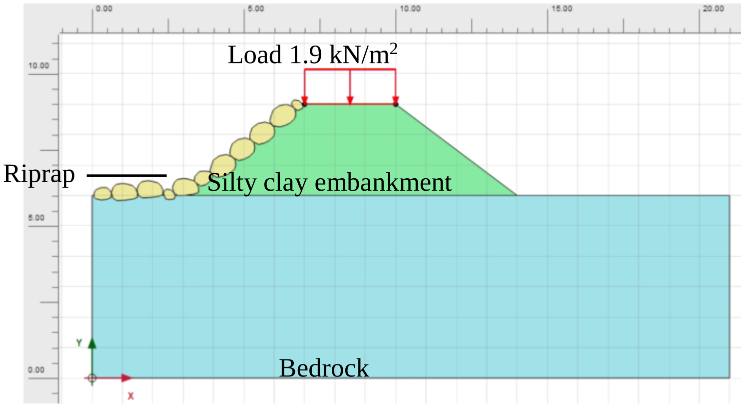

Fig. 6 - Example model for slope protection of the riprap in the PLAXIS 2D

2.3 Calculation

The different phases of the embankment construction area used to run the simulation at different water level. In the modelling analysis for each slope protection method consist of 5 phases. The first phase was calculated as the initial condition. Then, followed with phases for water level at 1 m, 2 m and 3 m. Lastly, the phase 5 is to define the factor of safety.

3. Results and Discussion

3.1 Total Displacement

Fig. 7 shows the comparison graph of water level versus total displacement for five types of model which one of it is model without slope protection and the rest are model with slope protection method that had been selected in previous section. From the graph, it depicted that the value of total displacement for model without slope protection has the highest value at each water level of 1 m, 2 m and 3 m with value of 5.12 mm, 14.27 mm and 27.11 mm respectively. At water level of 3 m, the innovative slope protection method showed the lowest total displacement which is 22.19 mm. This indicates that the settlement for the embankment with slope protection is lower than the embankment without any slope protection. These was due to the high cohesion value for the innovative slope protection that has increased the strength of the soil slope which allows the embankment to withstand the load applied on top of the embankment through prescribed displacement approach.

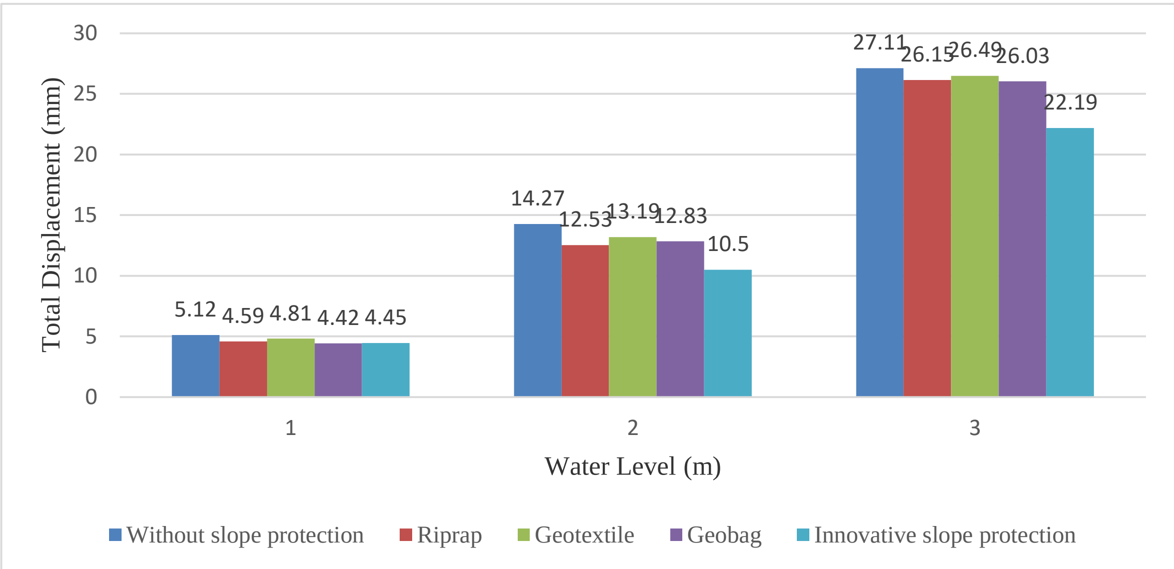

Fig. 7 - Graph of water level versus total displacement

3.2 Excess Pore Pressure

The results projected by the graph in Fig. 8 shows the value pattern of excess pore pressure for each water level of 1 m, 2 m and 3 m was not much different between every model of slope protection in PLAXIS 2D. However, for water level at 1 m and 2 m, the innovative slope protection methods had the lowest excess pore pressure with value 0.033 kN/m^2 and 0.074 kN/m^2 respectively. This indicate the stability of embankment with this slope protection techniques were higher compared to the embankment with another slope protection.

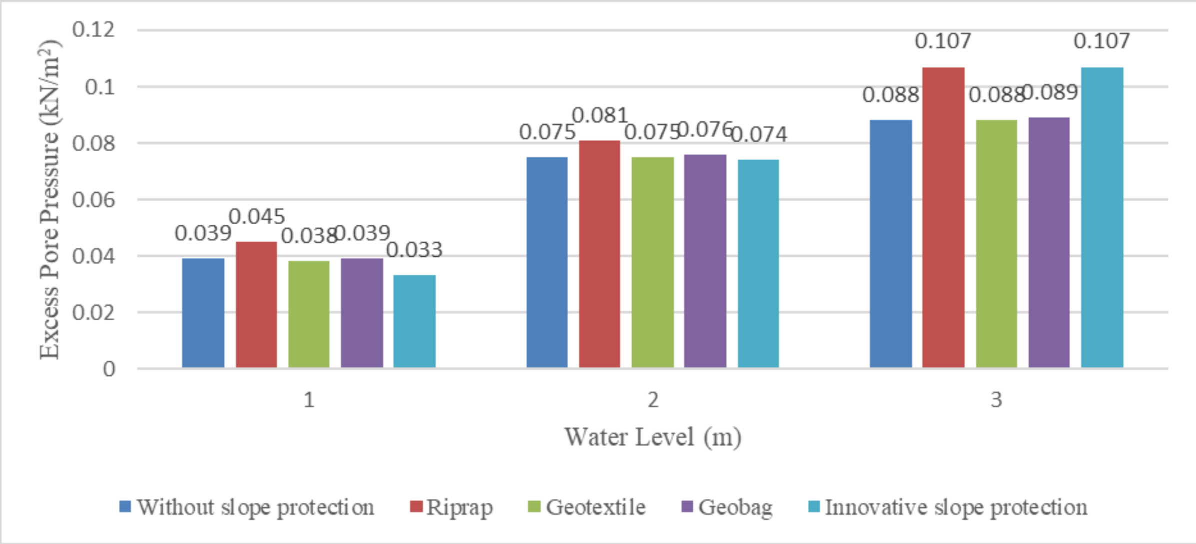

Fig. 8 - Graph of water level versus excess pore pressure

3.3 Effective Stress

The results of effective stress simulated in PLAXIS 2D is illustrated by the graph in Fig. 9. From the graph, it can be seen that the embankment model without slope protection showed the highest effective stress at water level of 1 m, 2 m and 3 m where the value was 12.75 kN/m^2, 21.86 kN/m^2 and 40.91 kN/m^2 respectively. Meanwhile, the geotextile slope protection method had the lowest effective stress for water level at 2 m and 3 m with value of 15.61 kN/m^2 and 18.09 kN/m^2 respectively. When the pore pressure in soil is decrease, the effective stress is reduced.

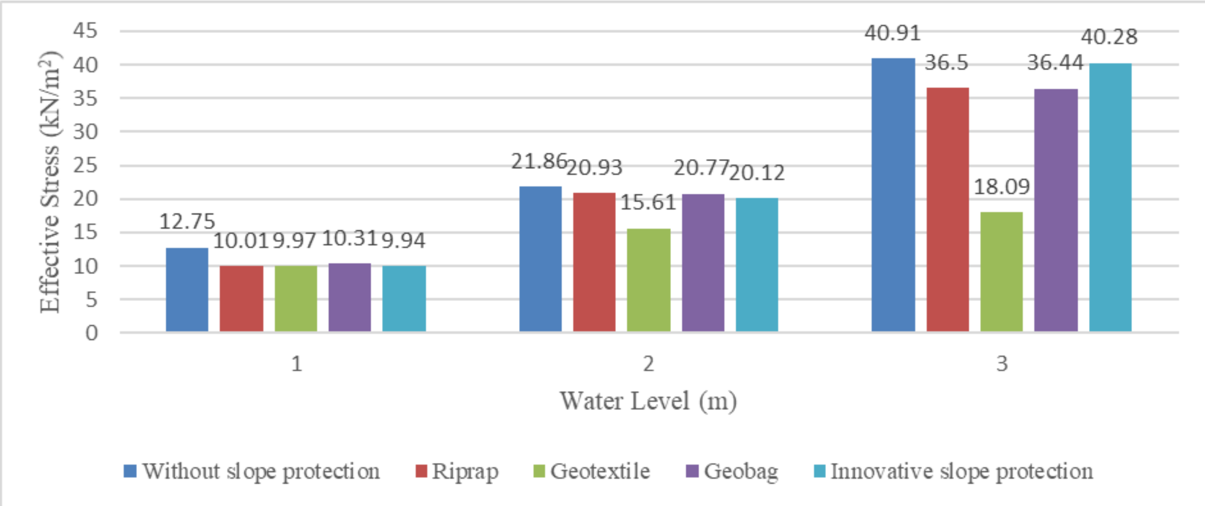

Fig. 9 - Graph of water level versus effective stress

3.4 Discharge of Seepage

Referring to the graph of water level versus discharge of seepage in Fig. 10, the discharge of seepage for model without slope protection at 1 m water level was 9.99 m^3/day while 30.29 m^3/day for the 3 m water level. Meanwhile for model with innovative slope protection showed the lowest value of discharge of seepage at every water level which was 6.14 m^3/day for 1 m water level, 15.34 m^3/day for 2 m water level and 17.75 m^3/day for 3 m water level. It can be seen that embankment with innovative slope protection can helps in lowering the discharge of seepage compared to embankment without any slope protection. Seepage can cause slope failure where the high pressures may happen in the soil pores or by the saturation of the slope.

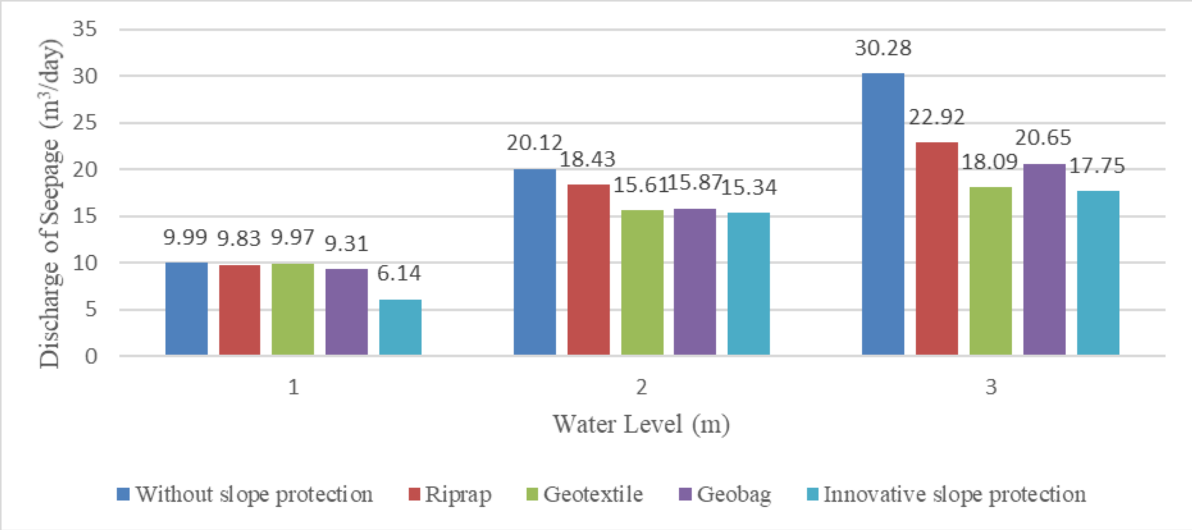

Fig. 10 - Graph of water level versus discharge of seepage

3.5 Factor of Safety

The results interpreted by the graph in Fig. 11 shows the value pattern of factor of safety for every model of embankment in PLAXIS 2D. The highest value of safety factor was obtained by the innovative slope protection method which was 3.9. The factor of safety for embankment without slope protection had reduced to 2.7 which it was the lowest value. Meanwhile, the riprap slope protection had the factor of safety with value of 3.4. Besides, the geo-bag method showed the factor of safety with 3.7 which is slightly lower than model with geotextile which had the value of 3.8. It can be seen that all methods meet the minimum requirement for safety factor, where any values that are greater than 1.5 are acceptable safety factors [6]. This section concluded that as the settlement of the embankment had been increased, the factor of safety value has gone down [7].

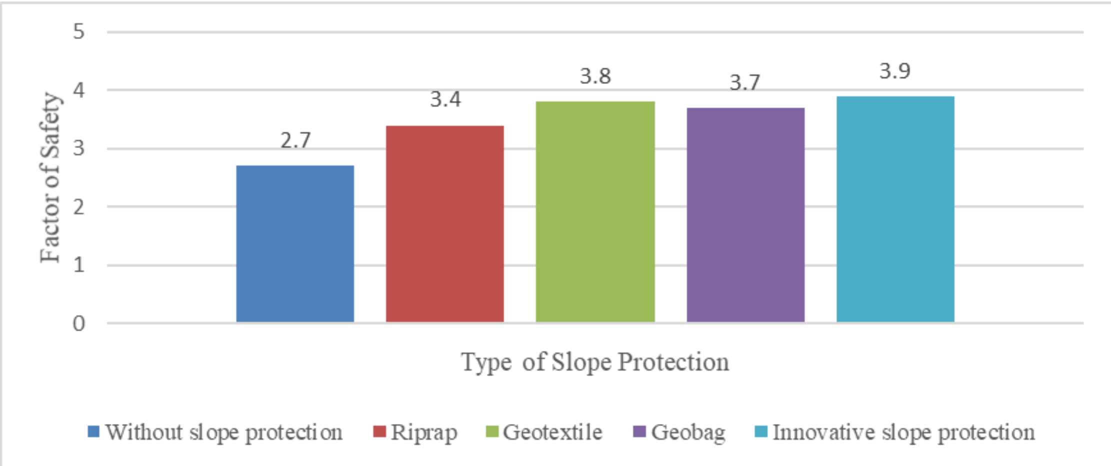

Fig. 11 - Graph of water level versus factor of safety

3.6 Innovative Method

The innovative method is the proposed slope protection method for SCE. As illustrate in Fig. 12, the innovative method consists of geo-bag as the seawall and the geotextile as filter layer. The Fig. also showing the bag friction and the lateral earth pressure applied on the embankment. A revetment was made in this section to improve the gap of methods that had been used in past studies. This revetment involves the innovation of materials and installation procedure to improve the functionality of this innovative method as slope protection. The design of size for the innovative method is proposed by considering the embankment's design parameters obtained from the data collected. The non-woven geotextile was used as an innovative material due to its functionality as abrasion resistance.

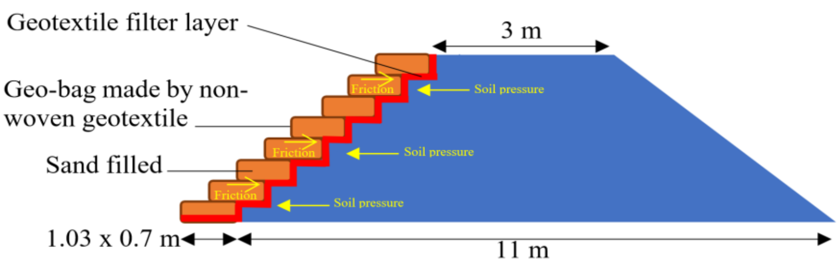

Fig. 12 - Proposed slope protection scheme for SCE

4. Conclusion

From the numerical simulation study, all the objectives were successfully accomplished. In this paper, it can be seen as the water level increase, the total displacement of the soil increased. This study explored the alternative of slope protection that can reduce the settlement of the embankment as the total displacement of the embankment with the selected slope protection method is lower compared to the total displacement of the embankment without any slope protection. The innovative method was found to be the best technique for erosion control and this innovation consists revetments of geo-bag that was made by applying the geotextile as the filter layer. Therefore, this study has concluded that the proposed solution of slope protection meets most of the criteria need for the SCE to control erosion and to reduce seepage problem. One of the remedial actions that are suggested for enhancing improvement to similar study and future works precise data parameters for silty clay and other materials must be obtained by lab verification of the real features of materials.

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