Progress in Engineering Application and Technology Vol. 2 No. 1 (2021) 444–452
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PEAT

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

Numerical Analysis of Senggarang Embankment Constructed Cement-CSP Stabilised Sandy Gravel

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DOI: https://doi.org/10.30880/peat.2021.02.01.044
Received 13 January 2021; Accepted 01 March 2021; Available online 25 June 2021

Abstract: A problematic embankment in Senggarang, Johor is being observed due to its excessive seepage happens from the wave impact by the sea that might lead to the instability of the embankment. Therefore, this paper aims to analyze the seepage characteristic of the embankment constructed with cement and cockle shell powder stabilized sandy gravel and to evaluate the load-bearing capacity of the cement-CSP-stabilised sandy gravel embankment with the 'prescribed displacement approach'. PLAXIS 8 software was used to simulate the embankment that is made from sandy gravel with homogenous clay footing. The parameters needed for PLAXIS 8 simulation are gained from literature review made from past works. As a result, the seepage loss for sandy gravel mixed with cement-CSP is lower than untreated sandy gravel. Therefore, the objective of the simulation is as expected, because the parameters for treated sandy gravel are better than the untreated sandy gravel. Somehow, the parameters data for the cement-CSP sandy gravel need to be done in laboratory for more precise value in the future.

Keywords: Embankment, Sandy Gravel, Stabilization, PLAXIS 8

1. Introduction

Dams are mainly made of earth and rock-filled materials and are therefore generally referred to as embankment dams or fill-type dams. Embankment is an economical hydro-engineering structure and are built for various purposes, such as protecting human and animal beings, properties and others from flooding; storing water for irrigation, providing water and producing energy [1]. A study by [2] confirmed that, there are three major categories to describe an embankment failure: (i) hydraulic failure (ii) structural failure and (iii) seepage failure. According to the report too, 35.00 % happened due to hydraulic failure, 20.00 % failed due to structural failure, 38.00 % of embankment failure causes by seepage failure and the rest 7.00 % failed because of other reasons.

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As stated earlier, seepage failure contributes to majority of embankment failures; therefore, it is alarming and requires further study. Therefore, soil stabilization needed to be done in order to improve the strength of the embankment and reduce seepage. Improving an on-site (in situ) soil's engineering properties is referred to as either "soil modification" or "soil stabilization". Some benefits from soil stabilization include reducing plasticity, lower permeability, eliminating excavation or handling material and controlling the potential of soils for change in volume, and even improving soil strength [3].

There are a number of soil stabilization procedures, such as the use of reinforcement, such as geosynthetic products, undercutting and replacement, grazing, soil mixing with natural stabilizers to alter chemical and physical properties, and many more. The use of natural stabilizers attracts worldwide attention in research due to their ability to increase strength, reduce environmental impact and reduce material costs. Other than that, the benefits from soil stabilization include reducing plasticity, lower permeability, eliminating excavation or handling material and controlling the potential of soils for change in volume, and even improving soil strength [3].

Therefore, this study highlighted the use of Cockle Shell Powder (CSP) as natural stabilizer. This is because cockle shell contains calcium carbonate ($CaCO_3$) and Calcium Oxide (CaO), which is similar to cement an additive which is lime [4]. This study aims to mix sandy gravel soil with cockle shell powder and cement in order to stabilize the embankment. Sandy gravel soil can be achieved by the mixture of sand and gravel. Gravel can be identified by particle size. The particles may have an angular, rounded, or sub rounded shape. Sand can also be identified by particle size. Gritty grains that can easily be seen and felt. They are therefore strongly influenced by other components.

In recent years, various techniques have been introduced by many researchers to study about the behavior of soils such as experimental, analytical and numerical simulation. Therefore, this research used PLAXIS 8 software to simulate the embankment. Brinkgreve [5] explained that PLAXIS 8 is designed with features to deal with different elements of challenging geotechnical structures. The severe seepage that happened might lead to the instability of the embankment or even a critical flooding. Besides, the problems also lead to causing flood and water inundation of agricultural plots and dwellings and it also affects livelihood and safety of approximate 12000 population of Senggarang town. The 40-year-old Earth Bund shows signs of aging that this problem happens due to both climate change and rising sea levels. As shown in Figure 1, the earth bund is facing problems such as potholes with visible deep reaches that might cause tyres from the passing through vehicles stuck in the mud.

Figure 1: The potholes with visible deep reaches along the earth structures

2. Materials and Methods

In this research, PLAXIS 8's software is used in order to identify the result of the whole project. The collection and preparation of the input information including the simulation steps that included geotechnical properties of related type of soils, and engineering properties of the soils are presented. Figure 2 shows the methodology flow chart that will explain the process of work to be conducted in order to complete this paper.

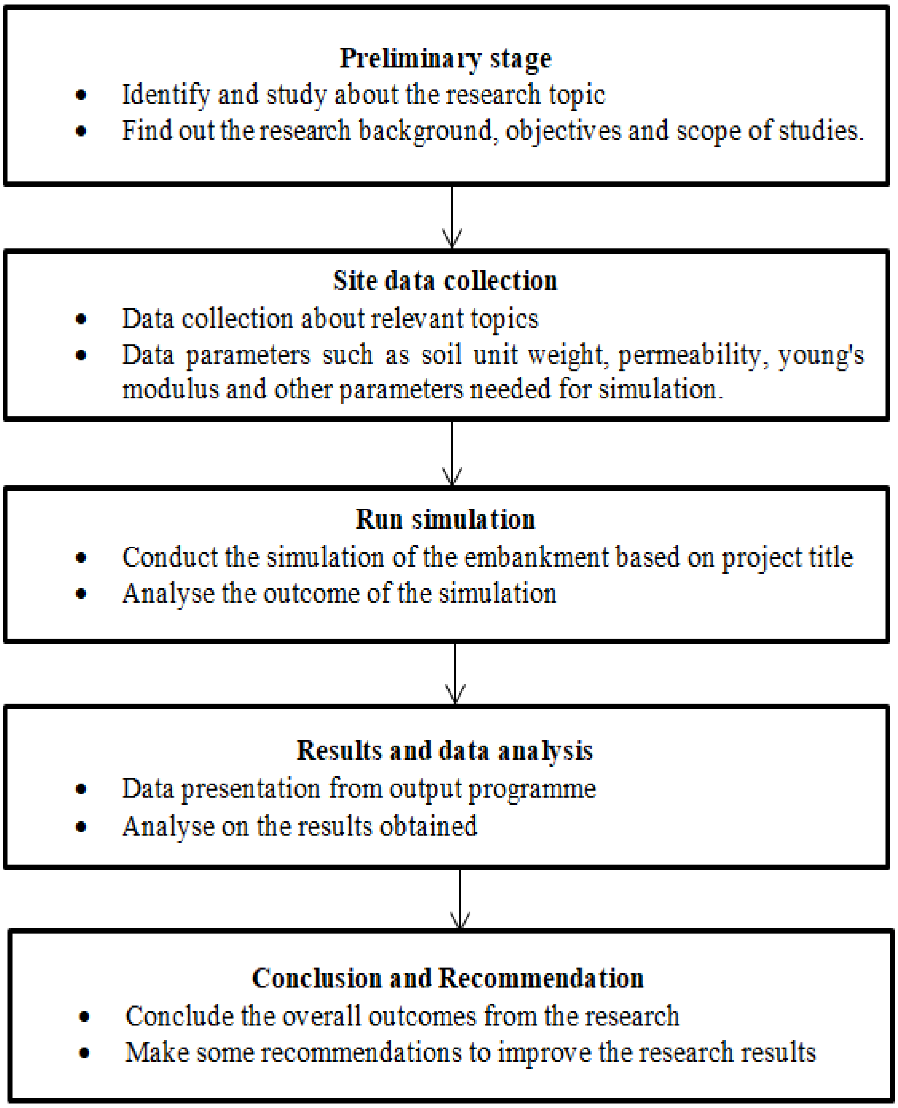

Figure 2: Methodology flow chart of the research

The problematic embankment was built along the seaside at Senggerang, Batu Pahat, Johor. The embankment co-ordinate is 1°43'01.7"N 103°02'59.1"E according to Google Map. Since the embankment has been built for more than 40 years, it shows the sign of aging where one of the sign showing is excessive seepage that happened along the inland area.

2.1 Sandy gravel soil

In this study, the foundation of the embankment is modeled with sandy gravel soil. With 6m and the embankment was made from homogenous clay with 3 m height. As the seepage happened at the foundation of the soil. Therefore, it needs to be stabilized with cement-CSP, in order to reduce the seepage problem and to improve the strength of the embankment at a time.

2.2 Material and simulation properties

The full geometry model of the embankment were created with the finite element mesh is based on the 15-node elements. This study is conducted using the modeling of Mohr Coulomb on PLAXIS, which uses the finite element method by dividing the embankment structure into small nodal-related dots (meshing). In this case, the settlement of the bank is simulated by prescribed displacements at the top of the embankment. By considering the self-weight of 1 meter per cubic of sandy gravel soil and load of a truck, the load that will be simulated on top of the embankment is 8.97 m.

After the geometry is done, the materials set for the soil will be adopted in the material sets input. Fill in all the data and parameters for the soil properties such as permeability, soil unit weight, friction angle, cohesion, young's modulus and Poisson's ratio based on the data collected from literature reviews of other authors before starting this simulation as shown in Table 1.

Table 1: Data and parameter for embankment simulation on Plaxis 8

Parameter	Name	Unit	Clay	Clay	Sandy Gravel	Treated Sandy Gravel
Material model	Model	-	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb
Type of behaviour	Type	-	Undrained	Undrained	Drained	Drained
Soil unit weight above p.I	γunsat	kN/m^3	16	16	17	22.5
Soil unit weight below p.I I	γsat	kN/m^3	18	18	21	23.0
Horizontal permeability	k_x	m/day	0.001	0.001	6912	691.2
Vertical permeability	k_y	m/day	0.001	0.001	6912	691.2
Young’s Modulus	E_{ref}	kN/m^2	2000	5000	170240	1700000
Poisson’s ratio	υ	-	0.35	0.35	0.33	0.25
Cohesion	c_{ref}	kN/m^2	2.0	5	5	20
Friction angle	φ	°	24	25	32	47
Dilatancy angle	Ψ	°	0	0	0	0

2.3 Boundary condition

According to PLAXIS manual, there are two types of boundary conditions for deformation problems prescribed for displacement and prescribed forces (loads). In principle, all boundaries must have one boundary condition in each direction. The natural condition shall apply if no explicit boundary condition is given to a particular boundary. Natural condition means a prescribed force equal to zero and a free movement. The prescribed displacement is assigned at some points to avoid situations where the geometry displacement is undetermined. Fixity is the simplest form of prescribed displacement (zero displacement). In this case, the settlement of the bank is simulated by prescribed displacements at the top of the embankment as in Figure 3.

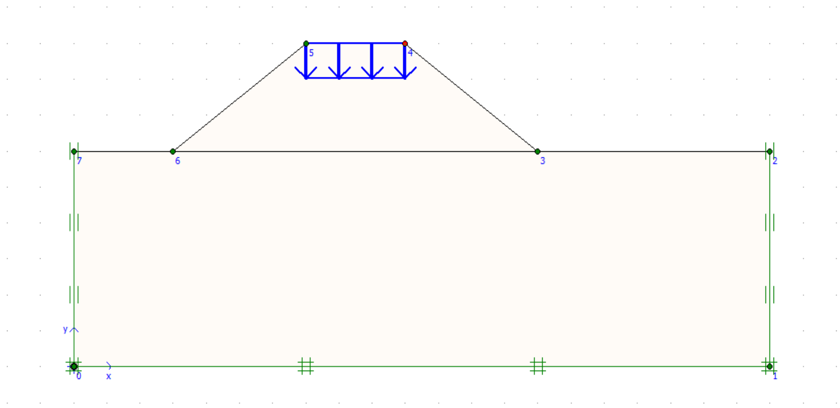

Figure 3: Prescribe displacement at the top of the embankment

3. Results and Discussions

The embankment undergoes numerical simulation process by applying the same parameter for each material, meshing and groundwater calculation which is in steady state with different water level depth and 8.97 m load applied on it through prescribed displacement approach.

3.1 Total displacement

Total displacement is the total cumulative displacement, coupled with horizontal (x) and vertical (y) displacement components at all nodes at the end of the current measurement stage, seen on the geometry map. Sari et al. [6] claimed that when the water level increases, the settlement in embankment also increases. Table 2 and Figure 4 show the comparison of total displacement gained between treated sandy gravel and untreated sandy gravel with different depth by using PLAXIS 2D. It can be seen that the untreated sandy gravel have a slightly higher total displacement compared to treated sandy gravel that consisted the mixture of cement and cockle shell powder. However, it can be seen that the total displacement of both untreated sandy gravel and treated sandy gravel increase when the depth of water level increase. This happen due to the dissipation of excess pore pressure in soft soil layer which causes consolidation in soils.

Table 2: Total displacement of different water level untreated sandy gravel and treated sandy gravel (cement-CSP)

Type of soil	**Untreated Sandy Gravel**			**Treated Sandy Gravel (Cement+CSP)**		
Water level (m)	1	2	3	1	2	3
Horizontal displacement, Ux (m)	11.26	13.19	15.09	7.90	8.77	9.64
Vertical displacement, Uy (m)	8.97	8.97	9.18	8.97	8.58	8.97
Total displacement (m)	11.29	13.21	15.11	8.97	9.08	10.02

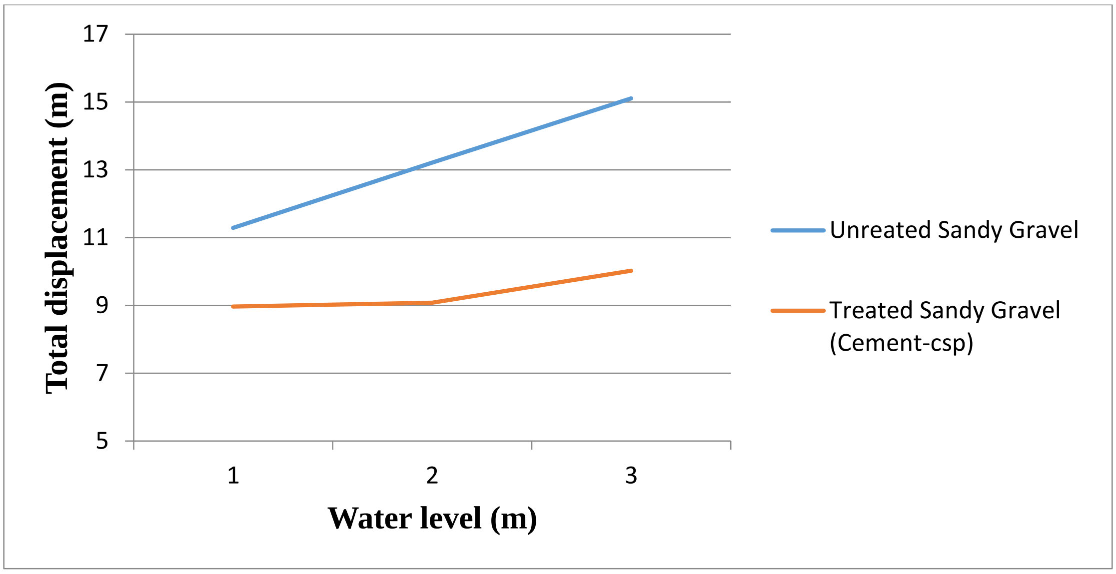

Figure 4: Graph of water level (m) vs total displacement (m)

3.2 Effective stress

As per geotechnical studies, an undrained condition which is nothing but the total stress analysis is used for the short term stability check, and drained condition which is the effective stress analysis is used for the long term stability evaluation. Table 3 and Figure 5 show the trend of effective stress for both untreated sandy gravel and treated sandy gravel. It can be seen that the effective stress of treated sandy gravel in lower than the effective stress for untreated sandy gravel. The flow change does not directly affect the stresses but with increased flow there is a lowering of pore pressure that increases the effective stress.

Table 3: Effective stress of different water level untreated sandy gravel and treated sandy gravel (cement-CSP)

Type of soil	Untreated Sandy Gravel			Treated Sandy Gravel (Cement+CSP)		
Water level (m)	1	2	3	1	2	3
Effective stress (kN/m^2)	-94.51	-91.85	-95.83	-107.17	-103.46	-106.86

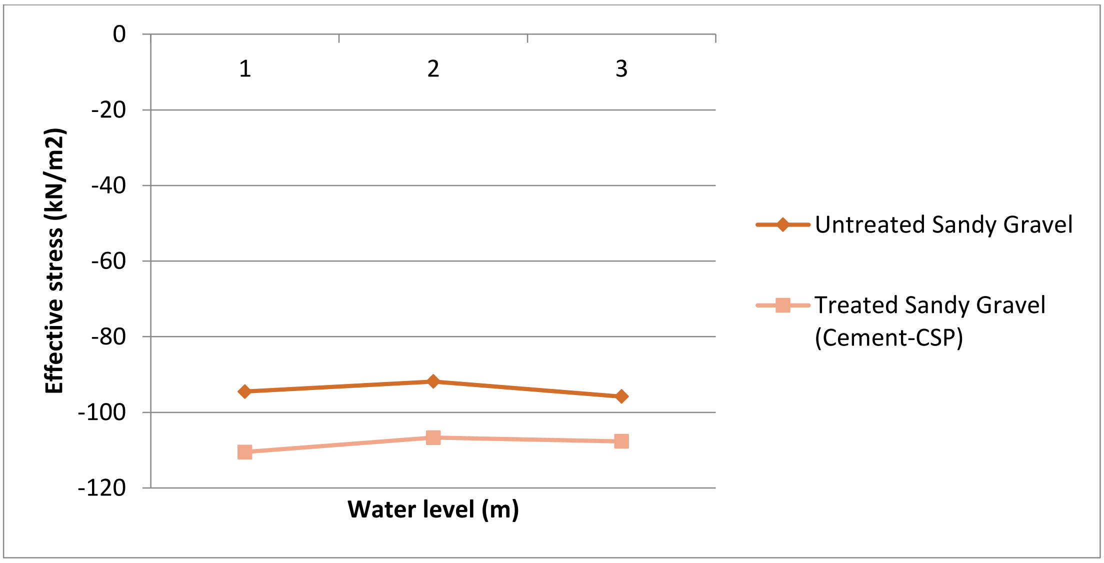

Figure 5: Graph of water level (m) vs. Effective stress (kN/m^2)

3.3 Excess pore pressure

As the soil is saturated under compression in an undrained state, the device resists compression by producing excess pore-water pressure which contributes to a reduction in effective stress [7]. Hubler et al. [8] argued that excessive pore pressures are increasing during undrained loading due to shearing, which reduces productive container tension and thus loss of soil stiffness. Figure 6 and Table 4 demonstrate the pattern of excess pore pressure with differences in depth for untreated sandy gravel and processed sandy gravel. It can be shown that the excess pore pressure at a depth of 1 m for both untreated and handled sandy gravel is negative. Theoretically, negative pore water pressure means that the soil above the groundwater level is unsaturated and therefore the pore pressure is weaker than the ambient pressure. If the voids are partly filled with water in the event of surface tension, they act to achieve a suction impact on the particles contained in the surrounding environment, which contributes to an increase in the shear intensity of the soil.

Table 4: Excess pore pressure of different water level untreated sandy gravel and treated sandy gravel (cement-CSP)

Type of soil	Untreated Sandy Gravel			Treated Sandy Gravel (Cement-CSP)		
Water level (m)	1	2	3	1	2	3
Excess Pore Pressure (kN/m^2)	-19.95	38.37	24.42	-44.19	-26.59	-25.44

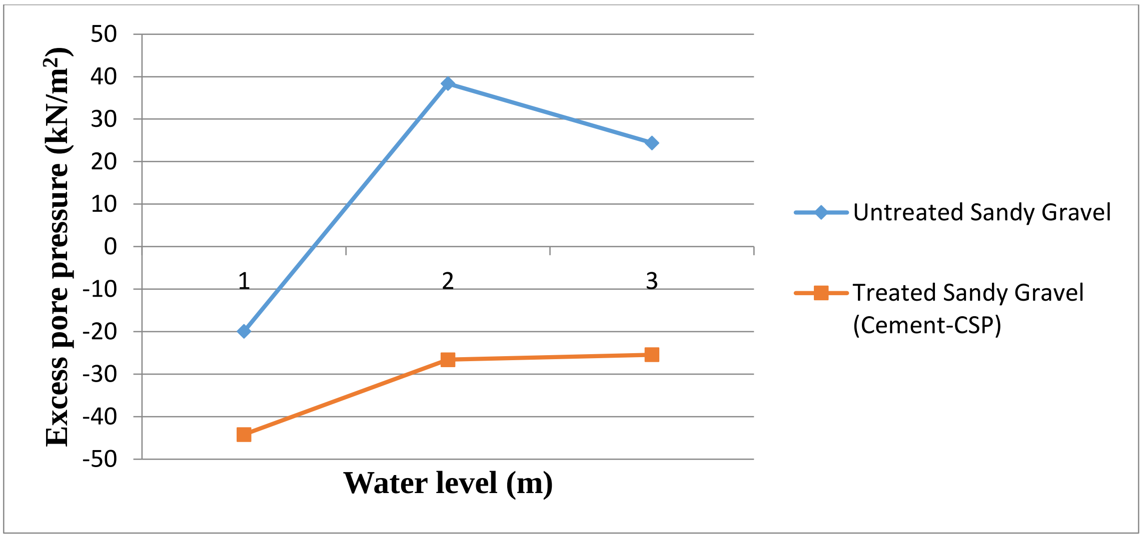

Figure 6: Graph of water level (m) vs. Excess pore pressure (kN/m^2)

3.4 Seepage loss

Safety against seepage is one of the most important steps for checking the possibility of failure of embankment. Sari et al. [6] agreed that the seepage that occurred within embankment is affected by water level height. Table 5 shows the discharge of seepage between numerical analysis and flow net analysis. Table below described that, the seepage loss value between numerical simulation and flow net analysis method have different values. However, the seepage loss values will increase if the water level increases. From the graph, it can be seen that the value of seepage loss using PLAXIS 2D and flow net analysis for both untreated sandy gravel and treated sandy gravel have a very least difference. This shows that the seepage loss comparison using PLAXIS 2D does not give big difference compared to manual calculation. Figures 7 and 8 show more accurate and clear difference of seepage loss using PLAXIS 2D and manual calculation in graphical form.

Table 5: Seepage loss difference using PLAXIS 8 and Flow net analysis of different water level untreated sandy gravel and treated sandy gravel (cement-CSP)

Water level (m)	Soil type	Seepage loss using PLAXIS 2D (m^3/day)	Seepage loss using flow net analysis (m^3/day)
1	Untreated sandy gravel	$3.84x10^3$	0.69×10^3
	Treated sandy gravel	381.69	69.12
2	Untreated sandy gravel	$8.22x10^3$	3.84×10^3
	Treated sandy gravel	819.80	384
3	Untreated sandy gravel	$12.48x10^3$	23.33×10^3
	Treated sandy gravel	$1.23x10^3$	1.04×10^3

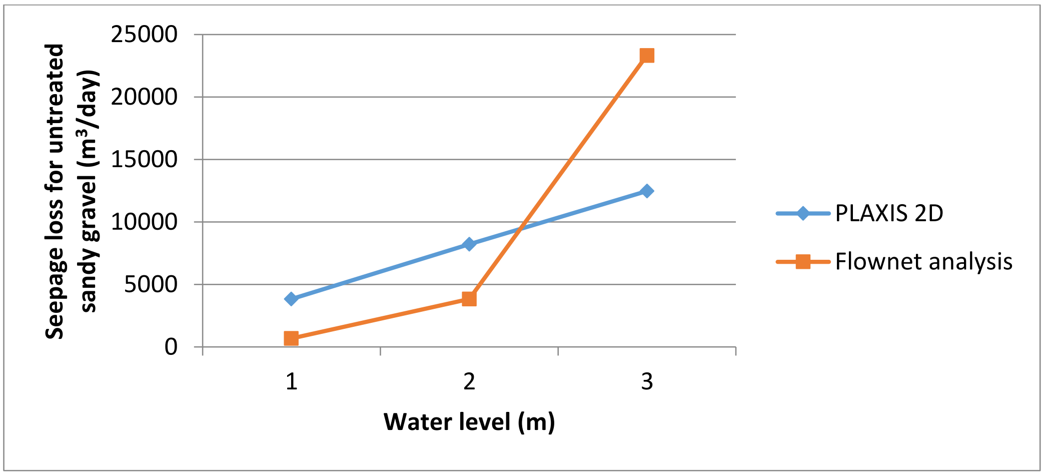

Figure 7: Graph of water level vs. seepage loss for untreated sandy gravel

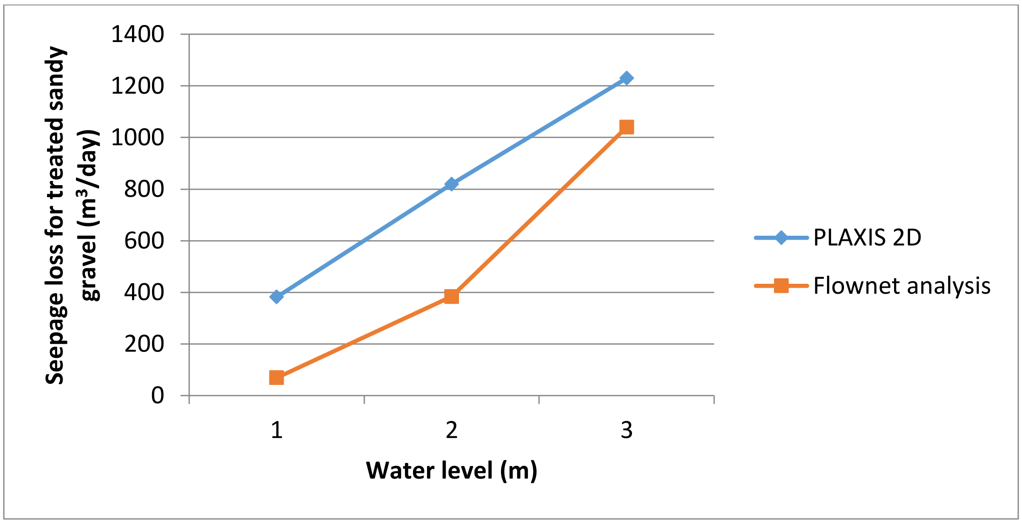

Figure 8: Graph of water level vs. seepage loss for treated sandy gravel

4. Conclusions

From this numerical simulation study, all the objectives were successfully achieved. In this paper, the simulation results of the settlement behavior of a coastal embankment constructed with cement and cockle shell powder stabilized sandy gravel soil using PLAXIS 8 software have been presented.

Based on the results, the seepage behavior of a coastal embankment constructed with cement-CSP is successfully achieved to reduce the seepage loss of the embankment. This can be seen when the values of seepage loss for treated sandy gravel is 10.00 % lower than untreated sandy gravel. As for the second objective was to evaluate the load-bearing capacity of cement-CSP stabilized sandy gravel using 'prescribed displacement approach'. The results shows that the total displacement for treated sandy gravel with cement-CSP mixture is lower than untreated sandy gravel when 8.97 m load was inputted on top of the embankment. The mixture of cement-CSP with sandy gravel was proven to enhance the shear strength of the embankment. As the water level increase, the seepage loss decrease, it means that the strength of the embankment increases. Therefore, the third objective which was to establish the tide level effect on seepage and load-bearing capacity of the cement-CSP stabilised sandy gravel embankment. Therefore, the mixture of cement-CSP and sandy gravel has been an excellent way to reduce the seepage problem happened in Senggarang, Johor embankment.

Acknowledgement

The authors would like to thank and express appreciation to the industrial collaboration JPS Batu Pahat for the collaboration. The author would also like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for guidance and consideration throughout this project.

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