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Numerical Analysis of Senggarang Embankment Constructed with Cement-CSP Stabilised Sandy Clay

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Abstract: Embankment is a structure constructed covering a water body which can be natural water retaining storage like lakes, pond, or artificially constructed water storage structure likes dams. However, there are some failures that can occur in the embankment caused by seepage, piping and foundation instability. The Senggarang embankment is facing severe seepage phenomena which could lead to collapse and critical flooding risk. The seepage problem has severely compromised the stability and safety of the embankment, especially where the inland area is flooded during tide. The objectives of this research are to analyze the seepage characteristics of Senggarang embankment constructed with cement-CSP-stabilised sandy clay and to evaluate the load-bearing capacity of the cement-CSP-stabilised sandy clay embankent with the 'prescribed displacement approach'. In summary,it was found that discharge of seepage for embankment constructed with cement-CSP stabilised sandy clay was lower than untreated sandy clay embankment. The discharge of seepage using PLAXIS also has been compared with manual calculation using flownet analysis. The average difference was only 22.00 %. Futhermore, the tide level or water level effect on the seepage and stability of the embankment. The higher the water level, the higher the discharge of seepage. Therefore, mixture of cement-CSP found to be an excellent way to reduce seepage problem in Senggarang embankment.

Keywords: Embankment, Sandy Clay, Seepage, Cement-CSP

1. Introduction

Embankment is a structure constructed covering a water body which can be natural water retaining storage like lakes, pond, or artificially constructed water storage structure likes dams. However, there are some failures that can occur in the earth bund or coastal embankment caused by seepage, piping and foundation instability. Based on the study conducted by [1], most of the recorded failures around the world are related to seepage problem.

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Soil improvement technique or soil stabilization has been widely used to reduce soil deformability and to increase the shear strength of soft soil [2]. Soil stabilization involves the treatment for the soil by adding stabilization agents like cement to increase the soil's durability and strength [3]. Cement is considered the oldest method for soil stabilization as it was introduced as soil stabilizer in 1960's [4]. However, cement has been found to be non-economical and unsustainable because the manufacturing process emits large quantities of carbon dioxide which contribute to environmental pollution. Therefore, reducing the use of cement with other waste materials such as cockle shell powder (CSP) could reduce the impact of pollution to the environment. The use of cockle shell powder (CSP) ground from shells as a natural stabilizer is possible as the shells contain calcium carbonate ($CaCO_3$) and calcium oxide (CaO), similar to the main contents in cement as a binding agent [5].

In addition, numerical simulation is gaining popularity and wider usage in geotechnical and structural analysis [6]. This is mainly because numerical analysis provides immediate, probable solutions for various field problems which can be used when similar cases arise in the future. Owing the fact that safety against seepage is one of the most important steps for checking the possibility of failure of embankment dam, PLAXIS is an alternative software that can be used for evaluating safety of embankment dam due to seepage condition [7].

In this research study, Senggarang embankment is facing severe seepage phenomena which could lead to collapse and critical flooding risk. Some parts of the 40-year-old embankment (Figure 1) suffer potholes which caused extensive seepage paths within earth structure. The seepage problem has severely compromised the stability and safety of the embankment, especially where the inland area (Figure 2) is flooded during tide. In the collaboration with JPS Batu Pahat, a feasible alternative is to utilize the cockle shell powder (CSP) admixture with cement as stabilising agents to provide adequate stiffness for seepage control. PLAXIS 8 will be used to simulate a numerical simulation of cement-CSP stabilised sandy clay embankment. This analysis to analyze the seepage characteristics of Senggarang embankment constructed with cement-CSP-stabilised sandy clay and to evaluate the load-bearing capacity of the cement-CSP-stabilised sandy clay embankent with the 'prescribed displacement approach'.

Figure 1: Overlying service road of coastal embankment in Senggarang Batu Pahat

Figure 2: Seepage happened at the inland area

2. Materials and Methods

Methodology flow chart explain the workflow that will be conducted starting from the selection of final year project (FYP) titles to the conclusions and recommendations of the study. Figure 3 shows the flow of studies that will be conducted.

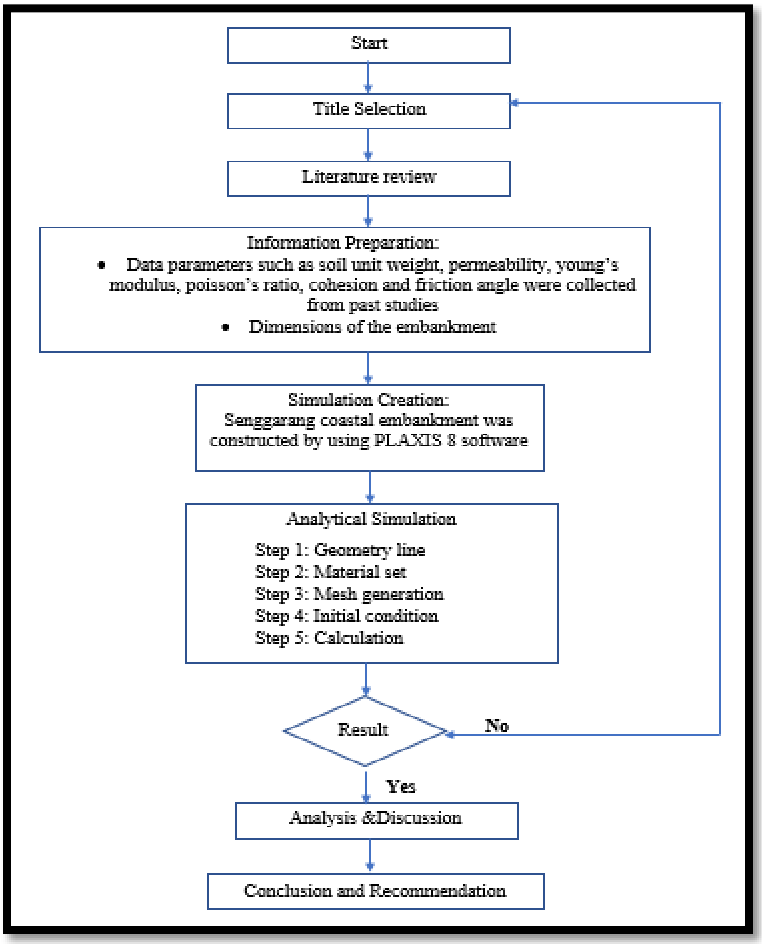

Figure 3: Methodology flowchart

2.1 Sandy clay soil

The embankment was modelled with two layer of soil which is sandy clay as foundation soil with 6 m height and above it was clay with 3 m height. The type of soil that were stabilised with cement-CSP was sandy clay. That is because the foundation soil found to be problematic which cause extensive seepage path within the embankment. hence, Hence, in order to improve the strength and reduce the seepage of embankment over sandy clay, the sandy clay soil need to be stabilised. The soil parameters of sandy clay were inputted in the simulation. Then, PLAXIS will simulate the seepage analysis of the embankment.

2.2 Material properties

In order to simulate the behaviour of soil, a suitable model and appropriate material parameters must be assigned to the geometry. In PLAXIS, soil properties are collected in material data sets and the various datasets are stored in a material database. Two material layers are adopted for the soil. Table 1 show the material properties use in PLAXIS simulation.

Table 1: Material properties of the embankment and subsoil [8] &[9]

Parameter	Name	Unit	Clay	Clay	Sandy Clay	Treated Sandy Clay
Material model	Model	-	Mohr-Coulumb	Mohr-Coulumb	Mohr-Coulumb	Mohr-Coulumb
Type of behaviour	Type	-	Undrained	Undrained	Drained	Drained
Soil unit weight above p.I	γunsat	kN/m^3	16	16	16	18
Soil unit weight below p.I I	γsat	kN/m^3	18	18	20	22
Horizontal permeability	k_x	m/day	0.001	0.001	0.1	0.001
Vertical permeability	k_y	m/day	0.001	0.001	0.1	0.001
Young's Modulus	E_{ref}	kN/m^2	2000	5000	3700	16000
Poisson's ratio	υ	-	0.35	0.35	0.3	0.2
Cohesion	c_{ref}	kN/m^2	2.0	5	2.5	60
Friction angle	φ	°	24	25	30	43
Dilatancy angle	Ψ	°	0	0	0	0

2.3 Calculation

These calculations are generally used to define the different phases of embankment construction. Figure 4 presents a print-screen of different phases of the construction process as implemented in FEM program. In the modelling analysis, the calculation consists of 5 phases. First the initial stress field has to be calculated since this has not been done during the input of the initial conditions.

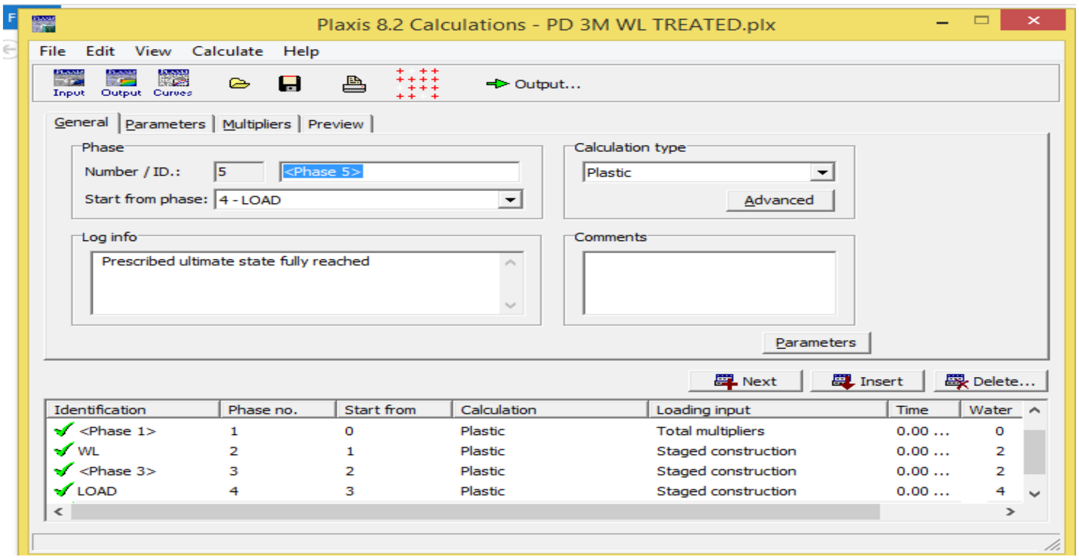

Figure 4: Calculation Steps using FEM program

The second calculation phase is the increase of the river water level, and the pore pressure, in the foundation soil layer. This calculation phase is done in the *Stage construction* mode. The 'Ultimate' situation will be defined in this phase. The third phase is to define the loading. In the 'prescribed displacement' dialog box the magnitude and direction of the prescribed displacemnet can be specified, as indicate in Figure 5. In this research the load apply was 80 kN/m^2 or 8 m.

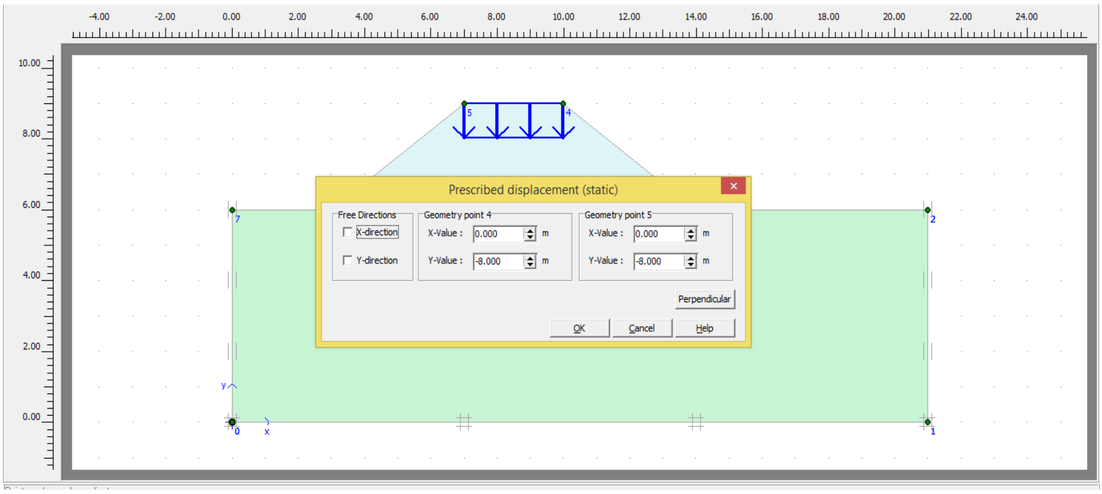

Figure 5: The prescribed displacements dialog box in the staged construction window

3. Results and Discussion

The embankment was modelled with two different type of soil which was untreated sandy clay and treated sandy clay (cement-csp). The simulation was simulated with different water level and by applying 80 kN/m^2 load through prescribed displacement approach.

3.1 Total displacement

Table 2 shows the results of horizontal displacement (U_x) and vertical displacement and (U_y) from numerical simulation of embankment with untreated and treated (cement-CSP) sandy clay. From the graph (Figure 5), it can be seen that the value of total displacement for untreated sandy clay is higher than treated sandy clay (cement-CSP) For examples, for 3 m water level, the total displacement of untreated sandy clay was 38.28 mm while treated sandy clay (cement-CSP) was 12.54 mm. This indicates that the settlement at the embankment with untreated sandy clay is higher than embankment with treated sandy clay. These was due to the cohesion value for treated sandy clay (cement-CSP) were higher than untreated which was 60 kN/m^2 and 30 kN/m^2 respectively. The high cohesion value for treated sandy clay has increased the strength of the soil which allows the embankment to withstand the 80 kN/m^2 load apply on top of the embankment through prescribed displacement approach. Cementation properties of treated sandy clay (cement-CSP) enhanced the performance of the embankment against shear failure.

Table 2: Horizontal displacement (U_x) and vertical displacement and (U_y) from numerical simulation of embankment with untreated and treated (cement-CSP) sandy clay

Type of soil	Untreated Sandy Clay			Treated Sandy Clayl (Cement+CSP)		
Water level (m)	1	2	3	1	2	3
Horizontal displacement, Ux (mm)	7.67	10.46	36.86	2.31	5.24	10.99
Vertical displacement, Uy (mm)	6.64	8.00	16.97	2.00	8.00	6.37
Total displacement (mm)	8.83	10.48	38.28	2.75	8.00	12.54

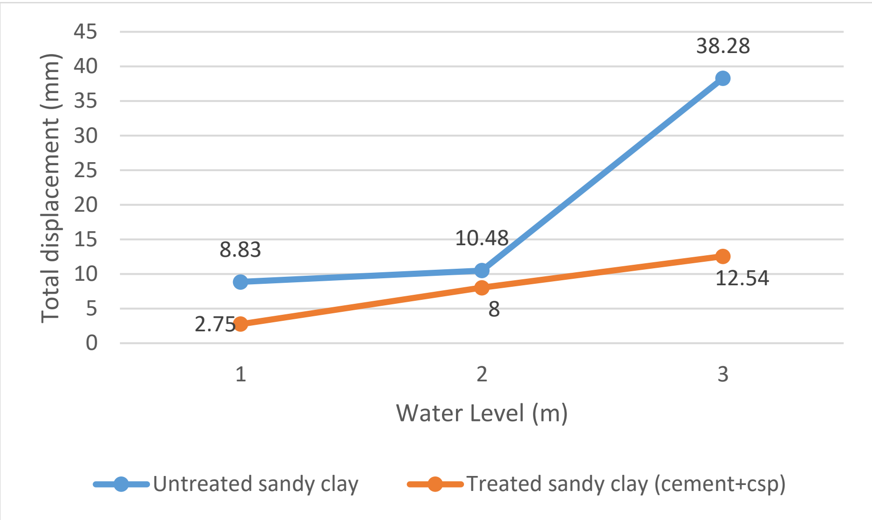

Figure 6: Graph of water level vs total displacement

3.2 Effective stresses

Table 3 shows the results of effectives stresses from numerical simulation of embankment with untreated and treated (cement-CSP) sandy clay. In soils, it is the combined effect of pore pressure and total stress that keeps it together. Hence, when pore pressure is positive, the effective stress will be negative. According to [10], changes in water level below ground (water table changes) results in changes in effective stresses below the water table. From the Figure 6, the effectives stresses were decreased from 1 m water level to 3 m water level which was -87.62 kN/m^2 to -102.82 kN/m^2. If the pore pressure in a soil increases, effective stresses will be reduced by Ds' and the critical strength of soil will reduced by Dt.

Table 3: Effective stresses of embankment with untreated sandy clay

Type of soil	Untreated Sandy Clay			Treated Sandy Clay (Cement+CSP)		
Water level (m)	1	2	3	1	2	3
Effective stress (kN/m^2)	-87.62	-87.81	-102.82	-100.59	-97.11	-100.87

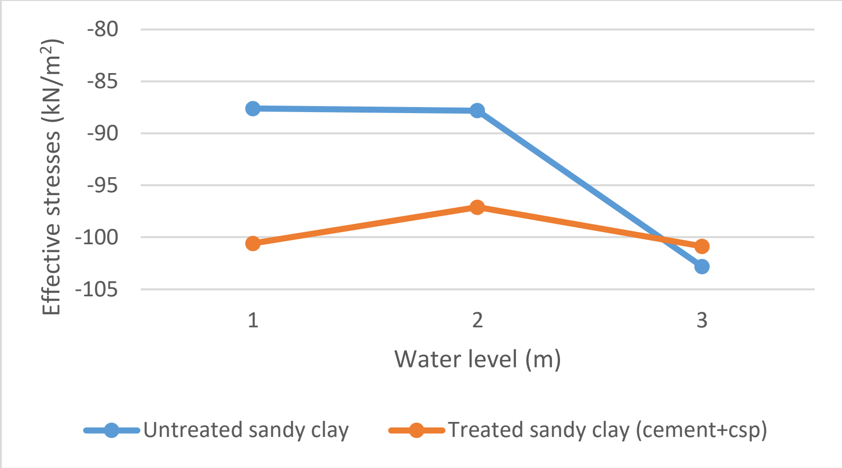

Figure 7: Graph of water level vs effective stresses

3.3 Excess pore pressure

Table 4 shows the results of excess pore pressure from numerical simulation of embankment with untreated and treated (cement-CSP) sandy clay. From the results, it can be concluded that when the water level increase, the excess pore pressure will also increase. Increasing water level can cause an increase excess pore pressure because the material is in the saturated condition resulting from the flow of water seepage into the body of the embankment [7]. Saturated material will increase the excess pore pressure especially for 3 m water level because the embankment is saturated by the rising water.

The difference in value of pore pressure of untreated and treated sandy clay can be seen in Figure 8. It shows that treated sandy clay gave a smaller value of pore pressure compared to untreated sandy clay. This indicated that the stability of embankment with treated sandy clay was higher than embankment with untreated sandy clay. Owing to the fact that the admixture of cement-csp has decrease the value of permeability of sandy clay soil from 1.00 x 10^{-3} to 1.00 x 10^{-4}. Hence, the lower the value of permeability the higher the strength of soil.

Table 4: Excess pore pressure of embankment with untreated and treated sandy clay

Type of soil	Untreated Sandy Clay			Treated Sandy Clay (Cement-CSP)		
Water level (m)	1	2	3	1	2	3
Excess Pore Pressure (kN/m^2)	7.98	14.87	25.15	7.18	13.33	20.21

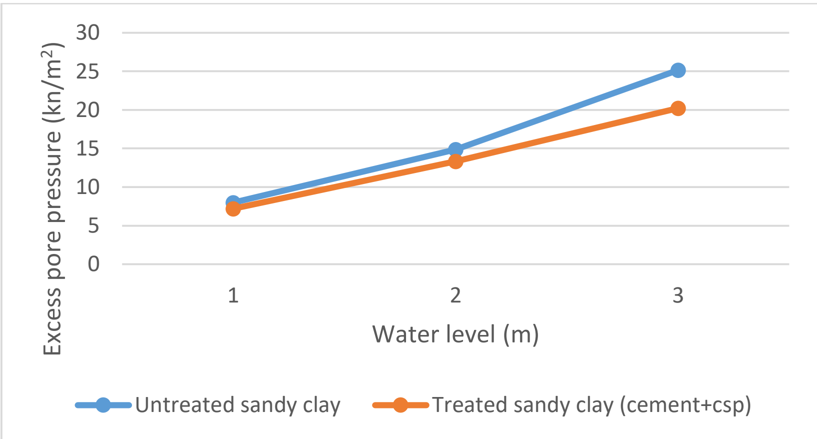

Figure 8: Graph of water level vs excess pore pressure

3.4 Seepage analysis

The comparison discharge of seepage from PLAXIS with manual calculation of seepage was to observe the difference in the value and to determine the accuracy value of seepage by using PLAXIS. The manual calculation was calculated using flow net analysis. The flow of the water through a soil can be represented graphically by a flow net, a form of curvilinear net made up of a set of flow lines intersected by a set of equipotential lines.

It can be concluded that discharge of seepage using PLAXIS does not give a bigger difference with manual calculation as shown in Table 5. The average difference between PLAXIS and flow net analysis was only 22.00 %. The seepage value from manual calculation found to be bigger than from PLAXIS. That is because, calculation from PLAXIS considered parameter such as cohesion, friction angle, young modulus and poisson ratio. Furthermore, it can be seen that treated sandy clay has lower discharge of seepage compare to untreated sandy clay. Hence the mixture of cement-CSP stabilised sandy clay has successfully reduced the discharge of seepage. The comparison discharge of seepage using PLAXIS, and flow net analysis can be seen more clearly in Figures 8 and 9.

Table 5: Comparison of discharge of seepage using PLAXIS and manual calculation using flow net analysis

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 clay	57.41×10^{-3}	86.4×10^{-3}
	Treated sandy clay	1.11×10^{-3}	8.64×10^{-3}
2	Untreated sandy clay	119×10^{-3}	384×10^{-3}
	Treated sandy clay	34.08×10^{-3}	38.4×10^{-3}
3	Untreated sandy clay	952×10^{-3}	1067×10^{-3}
	Treated sandy clay	80.21×10^{-3}	106.7×10^{-3}

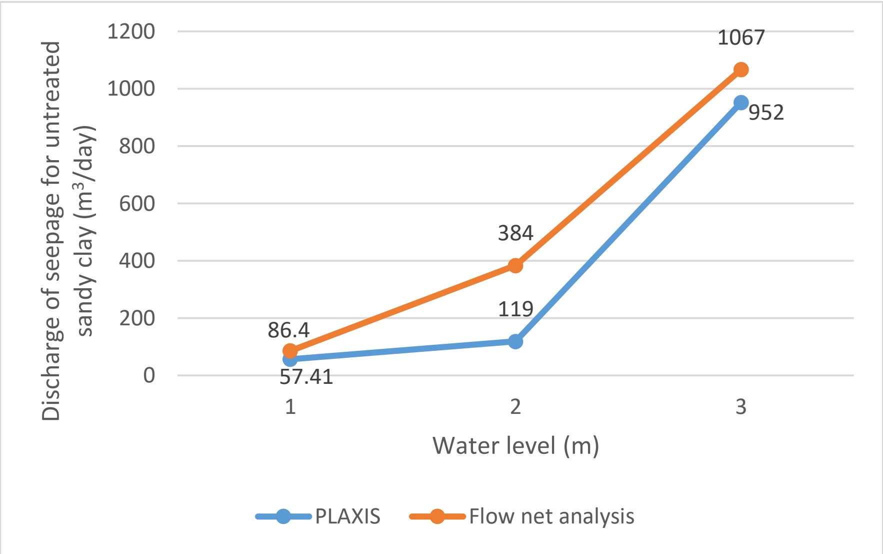

Figure 9: Graph of water level vs discharge of seepage for untreated sandy clay

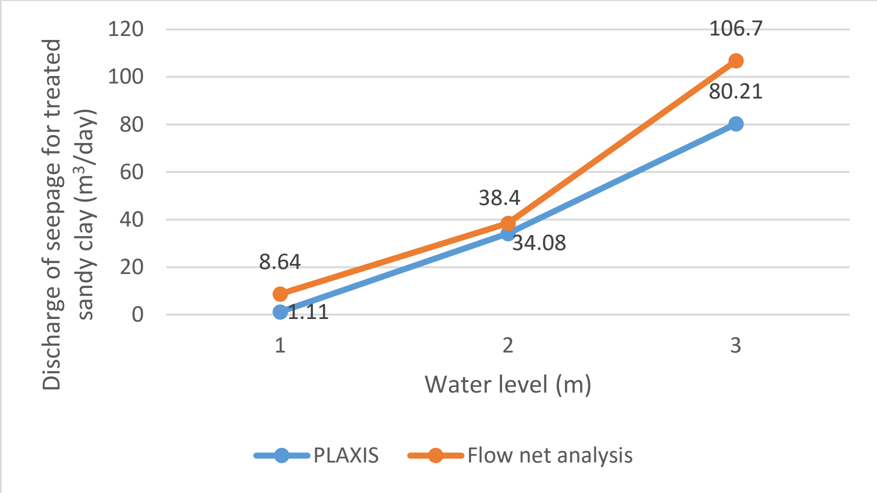

Figure 10: Graph of water level vs discharge of seepage for treated sandy clay

4. Conclusion

From this numerical simulation study, all the objectives were successfully achieved. The numerical simulation of Senggarang embankment was conducted successfully with different type of soil. The first objective was to analyze the seepage characteristic of Senggarang embankment constructed with cement-CSP stabilised sandy clay. The results show the discharge of seepage for embankment constructed with cement-CSP stabilised sandy clay was lower than untreated sandy clay embankment. The mixture of cement-CSP reduce the seepage discharge of the embankment. The discharge of seepage using PLAXIS also has been compared with manual calculation using flownet analysis. The average difference was only 22.00 %.

The second objective was to evaluate the load-bearing capacity of the cement-CSP stabilised sandy clay embankment with the 'prescribed displacement approach'. From the results, the total displacement of cement-CSP stabilised sandy clay embankment was lower than untreated sandy clay embankment. The cementation properties of treated sandy clay (cement-CSP) enhanced the performance of the embankment and increase the shear strength of the embankment. The third objective was to establish the tide level effect on seepage and load-bearing capacity of the cement-CSP stabilised sandy clay embankment. From the results, it shows that the tide level or water level effect on the seepage and stability of the embankment. The higher the water level, the higher the discharge of seepage. Therefore, mixture of cement-CSP found to be an excellent way to reduce seepage problem in Senggarang embankment.

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