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PERFORMANCE EVALUATION OF THE HYBRID GEOBAGS AND PU FLATBED SYSTEM AS A SOFT GROUND IMPROVEMENT WORK

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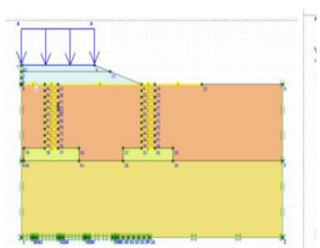
Graphical abstract



Abstract

Soft ground is commonly known as a problematic soil foundation, thus required a ground improvement work to be executed. This research was carried out to evaluate the performance of the Hybrid Geobag PU flatbed as a proposed remedial work for the failed embankment founded on soft ground in Pulau Betong. Back-analysis of existing embankment was executed using PLAXIS 2D in order to investigate the failure mechanism of the existing embankment. The cause of the embankment failure is due to the excessive consolidation settlement which causes both vertical and horizontal displacements of the soil. Performance of the proposed remedial works was compared with the conventional design solution of bored pile embankment. Existing embankment has an extreme vertical displacement of 1.87m and horizontal displacement of 0.259m. With the Hybrid Geobag PU flatbed method, the vertical and horizontal displacement reduced to 0.879m and 0.098m respectively. The vertical and horizontal displacement further reduced to 0.099m and 0.030m respectively with bored pile method.

Keywords: Geobag, PU flatbed, soft ground, consolidation settlement, PLAXIS

Abstrak

Tanah lembut biasanya dikenali sebagai asas tanah yang bermasalah, oleh itu kerja pembaikan tanah perlu dilaksanakan. Penyelidikan ini dijalankan untuk menilai prestasi alas rata PU Geobeg Hibrid sebagai cadangan kerja pembaikan bagi tambak yang gagal yang diasaskan di atas tanah lembut di Pulau Betong. Analisistambak sedia ada telah dilaksanakan menggunakan PLAXIS 2D untuk menyiasat mekanisme kegagalan tambak sedia ada. Punca kegagalan benteng adalah disebabkan oleh mendapan pengukuhan yang berlebihan yang menyebabkan kedua-dua anjakan tanah secara menegak dan mendatar. Prestasi kerja-kerja pembaikan yang dicadangkan telah dibandingkan dengan reka bentuk konvensional tambak cerucuk. Tambak sedia ada mempunyai anjakan menegak yang melampau 1.87m dan anjakan mendatar 0.259m. Dengan kaedah alas rata PU Geobeg Hibrid, anjakan menegak dan mendatar dikurangkan kepada 0.879m dan 0.098m masing-masing. Anjakan menegak dan mendatar terus berkurangan kepada 0.099m dan 0.030m masing-masing dengan kaedah cerucuk..

Kata kunci: Geobeg, flatbed PU, tanah lembut, mendapan pengukuhan, PLAXIS

4.0 INTRODUCTION

A failure of embankment founded on soft soil is a common problem in geotechnical engineering field. Many options of ground improvement have been applied for embankments founded on soft soil including excavate and replace the soft soil with backfill material, surcharging, prefabricated vertical drain (PVD), pile foundation, geofoam and etc. The use of high-strength geosynthetic reinforcement also able to improves embankment stability, permits controlled construction over soft soils, ensures more uniform settlement of embankment and results in cost effective solutions. Most of geotechnical issues have been caused by consolidation settlement, particularly for buildings on soft soils. Ground improvement works would reduce the consolidation settlement of soft soil while causing the least degree of severe displacement. However, most of the ground improvement works need a lot of resources and expensive machinery to carry out.

A development of road construction at Kampung Pulau Betong, Balik Pulau, may be halted due to cost concerns. The road in Kampung Pulau Betong requires an embankment along the proposed route to offer enough quality to the driving experience for the residents and road users. This created an issue when the embankment collapse at a height of less than 0.8m, resulting in erosion. Subsurface investigation revealed that the soil components of the stretch consist primarily of soft clay with a little quantity of sand.

Geotextiles are the most widely used geosynthetics (Zhao at al, 2018) which is used as a ground improvement work. Geosynthetics are products made of synthetic or natural polymeric materials, which are used in contact with soil or rock and other geotechnical materials. Geosynthetics mainly include geotextile, geogrid, geocell, geonet, geomembrane, erosion control mat, geosynthetic clay liner, and geo-composite (Park et al, 2013). The first reported employment of geotextiles can be considered to be the nylon bags filled with sand used in the Dutch Delta Works in 1956 (Koerner et al, 2016). In the last 60 years, geotextiles were widely used in geotechnical engineering. Geotextiles can be used for at least one of the following functions in geotechnical engineering: Separation, filtration, drainage, reinforcement, stabilization, barrier, and erosion protection (Agrawal et al, 2011). Geobags on the other hand, are small soil containers made of either woven or non-woven geotextile, it is the best geosynthetic product used for slope protection and river engineering. Geobags, also known as Geotextiles Bags, Geotextile Sand Containers, or Woven / Non-Woven Geobags, are filled with locally available sand and stitched manually on-site to form a bag (Fibromat, 2021)

With the increasing demand of geotextiles, the geotextiles have also been innovated. With the development of green concept, the natural geotextiles made of natural fibers are worth considering. Intelligent geotextiles are also the trend of geotextile development. At present, the integration of optical fiber sensors into geotextiles can make geotextiles have the functions of reinforcement, structural safety monitoring and early warning. The latest development of natural geotextile, intelligent geotextile and high-performance geotextile are discussed by Wang et. Al. (n.d.), Voet et. Al. (2005) and Benjamin et. Al. (2007).

2.0 METHODOLOGY

here were 15 boreholes drilled at the site. These soil samples have been tested in the field and in the laboratory. Borehole, Mackintosh Probe test and ground water measurement were among the field exploration experiments that have been carried out. Natural moisture content test, Atterberg limit test, particle distribution for coarse and fine-grained size, liquid limit test, plastic limit test, plasticity index test, linear shrinkage test, specific gravity, bulk density, and dry density test were performed in the lab.

Finite element model, PLAXIS was executed to determine the stability of existing ground as well as improved ground with the proposed remedial works. The analysis was carried out for the cross-section of soil with the lowest shear strength. The most essential cross-section was analyzed in order to give the most effective solution for the overall embankment project. There are two alternative solutions proposed for the remedial works of the failed embankment and these solutions are compared further with the conventional ground improvement method using bored pile. The flatbed is made up from polyurethane foam which is produced from exothermic reaction between polyol and isocyanate that is casted as a slab

2.1 Solution 1 (2 Hybrid Geosynthetic Geobags)

In this solution (Figure 1), a geotextile, HS400 was laid at the bottom of the embankment covering the entire embankment height. The bottom of the embankment was installed with Geobags that covers a portion of the total soil formation which is estimated to be 7m-10m deep along with a Hycomp flatbed at both sides.

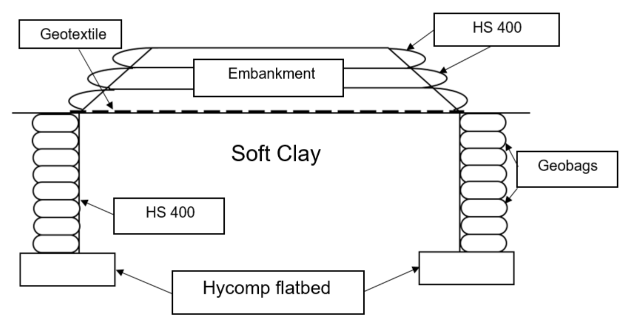


Figure 1 Solution 1: Hybrid of geosynthetic geobag embankment

The model aims to reduce lateral displacement, increase the stability of soil and reduce settlement of the soil. The geotextile able to prevent both inward and outward lateral sliding. HS400 geosheet is proved to prevent circular failure while the Geobags will prevent any sort of squeezing failure mode to happen and give the soil a bit more strength. This method however required a longer construction installation phase as excavation is needed.

2.2 Solution 2 (4 Hybrid Geosynthetic Geobags)

This solution (Figure 2) is the same as the 1st solution but instead of installing 2 sets of Geobags and Hycomp flatbed, there will be 4 of the sets. The purpose of doing so is to identify the effectiveness of the set of Geobags and PU flatbeds to resist settlement and lateral loading and keep the displacement low. If the solution proves to enhance the stability of the embankment, then future design enhancements could be made to improve this solution to become more viable.

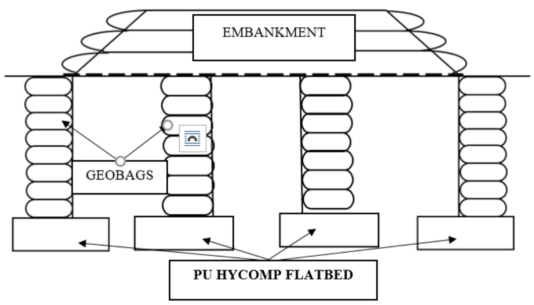


Figure 2 Solution 2: Double Hybrid of Geosynthetic Geobag embankment

2.3 Solution 3 – Conventional Method (Bored piles)

For the 3rd solutions (Figure 3), bored piles will be placed under the embankment for stability. This model aims to compare the two alternative models with the conventional method. Embankment load is supported by the geotextile and pile, thus the reduce of settlement and displacement as well as the stability of the ground can be expected.

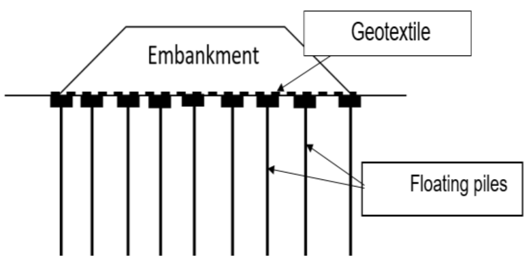


Figure 3 Bored Pile Embankment

2.4 Material properties

Soil layer material properties for the finite element model are based on the site investigation that was carried out at this area and shown in Table 1. The tensile strength of geotextile is 400kN/m whilst the pile properties using pile stiffness of pile, EA is $2x10^6$ kN. The PU flatbed is modeled as linear elastic, non-porous materials, with density of $1.5kN/m^3$ and Young's Modulus of $15{,}000kN/m^2$. The geobag is a soil encapsulated with geotextile. Figures 4 to 7 show the finite element model for existing condition as well as the proposed remedial works for different solutions 1, 2 and 3.

Table 1 Soil properties for FEM

Material	Sandy Silty CLAY	Silty SAND
Model	Soft soil model	Soft soil model
Thickness(m)	12m	12
Dry Density(kN/m³)	11.97	11.68
Saturated Density(kN/m³)	16.64	14.67
Cohesion(kN/m²)	34	41
Friction Angle(degree)	25	30
Dilation angle(degree)	1.0	1.0
Kx	$1.00x10^3$	$1.00x10^3$
Ky	$1.00x10^3$	$1.00x10^3$
Cc	0.258	0.663

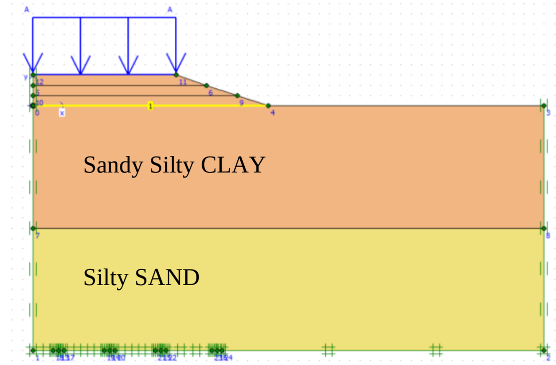


Figure 4 Finite element model for existing condition

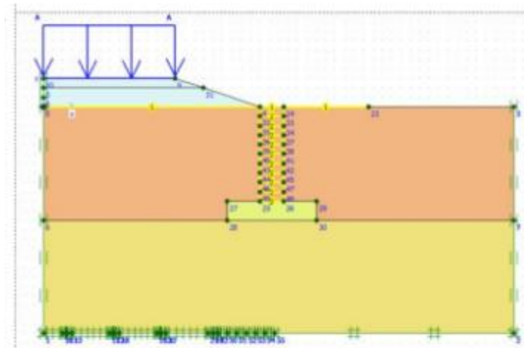


Figure 5 Finite element model for solution 1

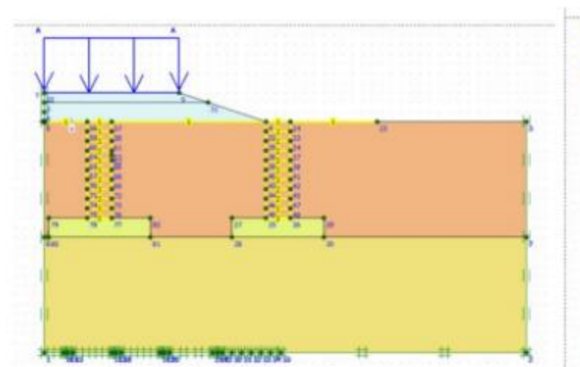


Figure 6 Finite element model for solution 2

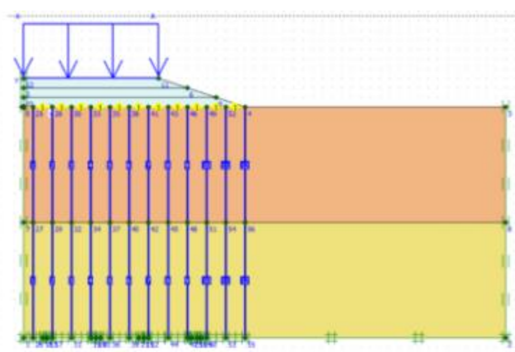


Figure 7 Finite element model for solution 3

3.0 RESULTS AND DISCUSSION

This section discusses on the results obtained from the simulation using finite element model. The data comparison is focusing on the vertical and horizontal displacement. The traffic load that was applied was 20kN/m^2 during this simulation. This simulation is carried out for 5 years duration in order to investigate the ultimate displacement of the embankment after 5 years.

3.1 Settlements and Lateral Displacements Before Rehabilitation Methods

As seen in the data obtained from PLAXIS FE as shown in Figures 8 and 9, the unreinforced embankment has an extreme total displacement of 1.87m and horizontal displacement of 0.259m. This is due to the soil strata itself which is 24m of soft soil before reaching the hard stratum. These values are quite high which may affect the road that need to be maintained frequently as the soil can cause cracking to the road.

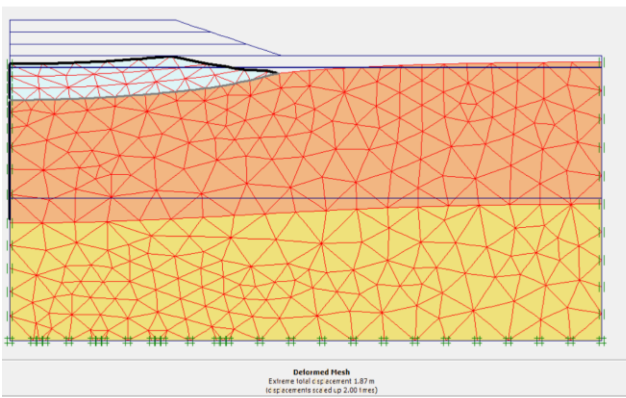


Figure 8 Deformed mesh of unreinforced embankment after 3m consolidation and addition of traffic load.

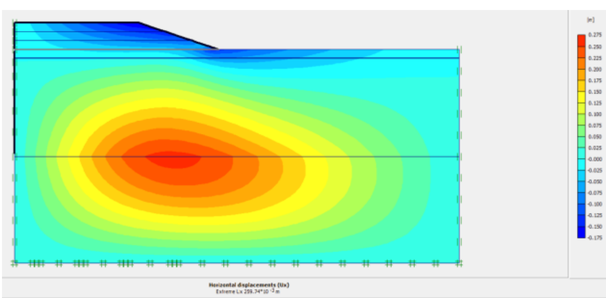


Figure 9 Shading indication of horizontal displacements (Ux) of unreinforced Embankment after 3m consolidation and addition of traffic load.

3.2 Settlement and Lateral Movement for 2 Hybrid Geobag PU Flatbed Method

As shown in Figures 10 and 11, the Hybrid Geobag PU flatbed embankment method reduce the settlement to 0.879m which increases the settlement resistance of the cross-section quite significantly. The Hybrid Geobag PU Flatbed embankment also reduces the lateral displacement to 0.098m. These values however are not good enough to ensure the road is viable to be used with this method. There will still be constant cracks appearing on the road and also possible embankment failure which can be harmful and unsafe.

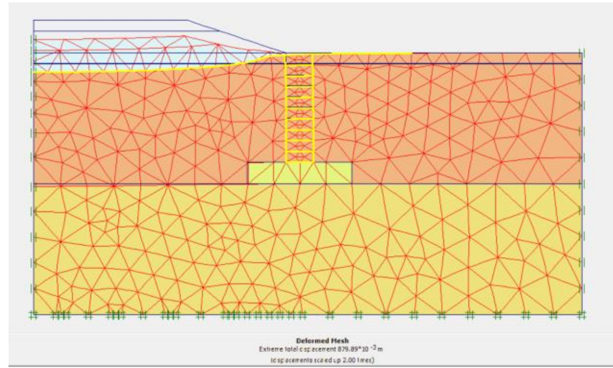


Figure 10 Deformed mesh of 2 Hybrid Geobag PU Flatbed embankment after 3m consolidation and addition of traffic load.

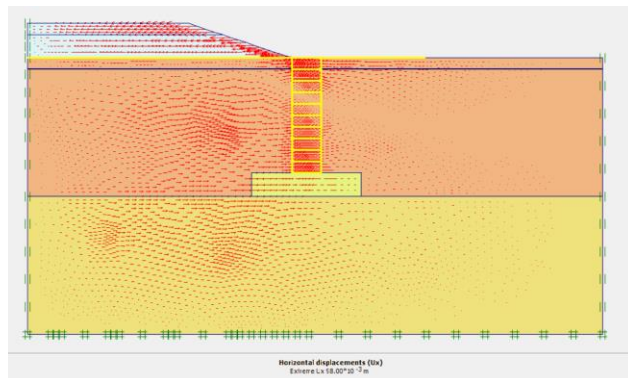


Figure 11 Arrow indication of horizontal displacements (Ux) of 2 Hybrid Geobag PU Flatbed embankment after 3m consolidation and addition of traffic load.

3.3 Lateral Movement and settlement for 4 Hybrid Geobag PU Flatbed Method

As predicted, the addition of an additional Hybrid Geobag PU flatbed embankment technique decreases the settlement to 0.570m as shown in Figures 12 and 13. The use of Hybrid Geobag PU Flatbed Embankment decreases lateral displacement to 0.061m, which is within acceptable limits. The road may be proved to be feasible, but it will need to be maintained on a regular basis. The embankment, on the other hand, has to be enhanced further by incorporating more geosynthetics, such as prefabricated vertical drains, to drain the pore water pressure.

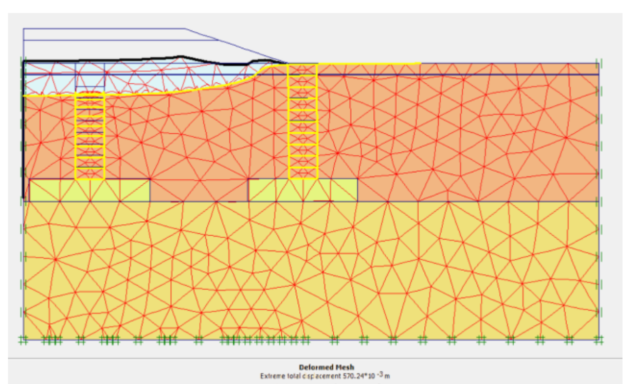


Figure 12 Deformed mesh of 4 Hybrid Geobag PU Flatbed embankment after 3m consolidation and addition of traffic load.

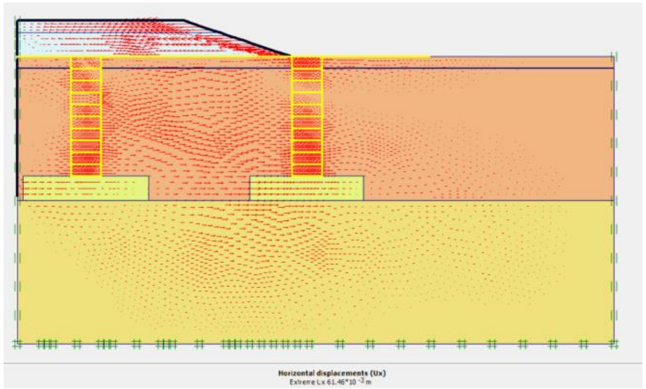


Figure 13 Arrow indication of horizontal displacements(Ux) of 4 Hybrid Geobag PU Flatbed embankment after 3m consolidation and addition of traffic load.

3.4 Lateral Movement and settlement for Bored Pile Method

The bored piles proved to be the most stable among the 3 solutions to resist settlement and lateral movement. As shown in Figures 14 and 15, the extreme vertical displacement is 0.099m while the extreme horizontal is 0.030m respectively. This is because the bored pile method is known to guarantee a minimum settlement and deformation for high compressible soil.

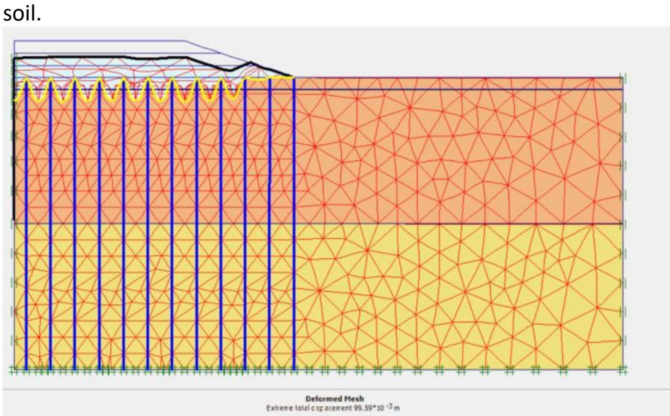


Figure 14 Deformed mesh of Bored Pile Embankment after 3m consolidation and addition of traffic load.

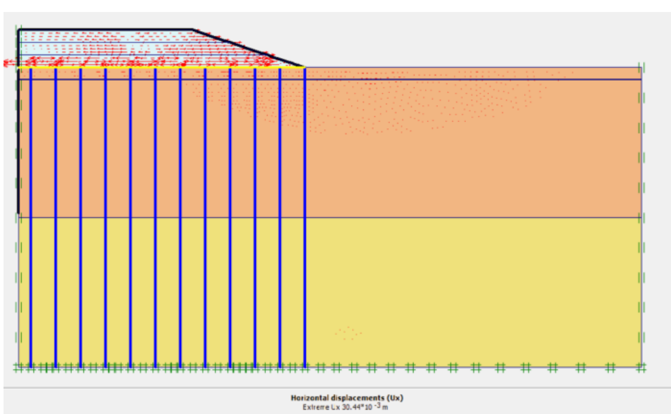


Figure 15 Arrow indication of Horizontal displacements (Ux) of Bore Pile embankment after 3m consolidation and addition of traffic load.

3.5 Displacement Comparison

Settlement is caused by soil consolidation, which happens as a result of a reduction in gaps or spaces between soil particles as a result of applied loads or changes in moisture content. The vertical strain in the soil increase as a result of this stress (Balasubramaniam et al., 2010). Consolidation occurs as soils lose moisture. Moisture takes up volume in the soil and as it evaporates, the soil loses volume and consolidates. When moisture builds up in the soils, smaller clays and silts that were previously tilized to fill gaps between bigger soil types and offer additional structural support will drain downwards in the earth when the moisture ultimately subsides(Jeannot & Guezo, 2016).As a result, the supporting soil will lose its load-bearing capacity. As seen in Figure 16, the embankment with no reinforcement seems to have more settlement compared to the Hybrid Geobag PU Flatbed embankment and Bored Pile embankment. This is most likely the cause of compaction of the soil and the consolidation of soil.

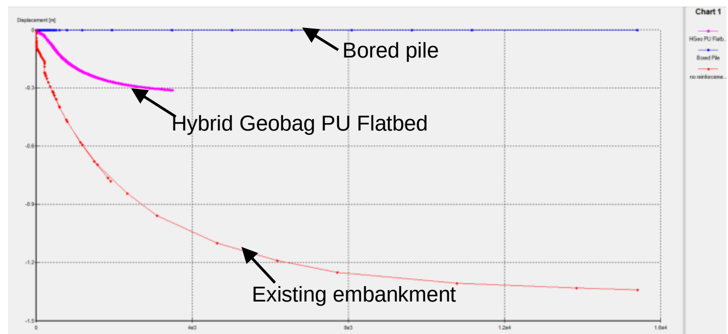


Figure 16 Displacement (m) VS Time Graph (Days)

3.6 Pore Pressure Comparison

The pore water pressure is critical in distinguishing total stress from effective stress in soil. For precise field calculations in a range of engineering trades, a proper depiction of soil stress is required. In this case, the ground water table for the cross-section is 1.3m below ground level. The maximum pore pressure for existing condition, with bored pile and Double Geobags PU flatbed is 162.5kN/m², 61.7kN/m² and 79.5kN/m² respectively. As seen in Figure 17, the pore pressure of the bored pile is the lowest comparing to the other two methods.

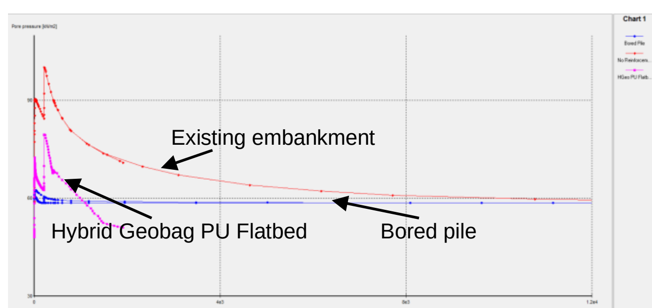


Figure 17 Pore pressure (kN/m²) VS Time Graph (days)

The factor of safety indicates the slope stability of the embankment(Faheem & Hassan, 2014) whereby all the methods have achieved an end factor of safety between the value of 2.1-2.2 which is a satisfactory value for all the slope embankments. The calculation steps do not represent the time of the construction because they iterate the amount of calculation steps that have been done during the whole construction phase.

4.0 CONCLUSIONS

This research used the PLAXIS FE software to analyse rehabilitation method for the road embankment founded on soft ground in Pulau Betong based on subsurface investigation data obtained for this site. This study investigates the failure mechanism of the existing embankment design using PLAXIS FE, simulating the performance of hybrid geobags and geosynthetics system as a proposed solution in PLAXIS FE and to evaluate the performance of the hybrid geobags and geosynthetics solution in comparison to the conventional design solution. Remedial solution 3 which is bored pile method is the best rehabilitation method for the embankment at Pulau Betong as it has the lowest settlement, lateral displacement and pore water pressure. Alternative solutions 1 and 2 are still viable as the cost is lower compared to bored pile method.

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