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STUDY OF SOFT SOIL REINFORCEMENT USING HYBRID PILE-PVD

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ABSTRACT

Recently due to the high demand of construction road need the construction in short period. The problem of construction on soft clay is the low bearing capacity and total as well as differential settlements. Therefore, innovation in soil improvement is needed. Soft soil improvement by geotextile and rigid piles is an interesting method to provide and economic and effective solution, which reduces settlements, construction time and cost. Full-scale tests were performed to investigate the performances of Pile-PVD (Hybrid pile), geotextile reinforcement and conventional pile. This study consisted of pore water pressure monitoring by piezometer, ground settlement monitoring by settlement plates and lateral movement by inclinometer. Preloading with a trial embankment of 4.5 m height was used in this study. Measurements were taken for each stage of embankment construction in 3 months. Monitoring results show that Hybrid pile has effectively increased stability and the time of consolidation. Consolidation settlements of Hybrid pile were found to be relatively faster compared to conventional pile reinforcement.

Keywords: soft clay, soil improvement, hybrid pile, settlement, consolidation, timber pile.

INTRODUCTION

The constructions of road embankment over a soft soil pose challenging problems in its development. Generally, the strength of soft clay is not strong enough for supporting embankment stability. Recently, the use of Prefabricated Vertical Drain (PVD) has been gaining popularity to overcome the problem of very thick compressible soft soil. Moreover, the development of new method/technique of soil improvement is needed due to the increasing demand in advanced technology of soil improvement. Some studies reported using various type of technique for dewatering and stabilizing soft soil (e.g. Mitchell and Wan, 1977; Bergado *et al*., 2000; Shang *et al*., 1998). Poulos (2004) conducted a numerical analysis for pile raft model applied to normally consolidated clay and showed that the safe bearing capacity of the piled raft decreases with increase ground improvement. Practical application of the piled raft to normally consolidated clay was performed in Malaysia (Tan *et al*., 2004, 2005). Han *et al*. (2012) reported that the construction of a long railway embankment supported by the piled raft on clay deposits. Vacuum-PVD combination with embankment loading in the Suvarnabhumi airport project was conducted as an innovative soil improvement technique (Saowapakpiboon *et al*., 2009). Ma *et al*. (2009) reported that a case history of the performance of high sensitive Ariake clay under stage constructed embankment.

The undrained shear strength increased to twice of the original value. In this study, three full scale trial embankments and numerical analysis were conducted. The first embankment constructed with geosynthetics reinforcement and installed at the surface of soft soil. Timber pile with 6 m length was inserted to the soft soil for the second trial embankment type. For the the third embankment, an innovative integrated pile-PVD combination (Hybrid pile) was installed with 6 m depth. Observation by using settlement plates, inclinometer and piezometer was conducted continuously for a period of 3 months. This paper describes the detail of pile-PVD construction and discussion the observed behavior from monitoring and observation results.

SOIL LAYERS AND MATERIAL PROPERTIES

The borehole test was carried out to collect and determine the soil properties of full-scale location. The subsoil properties are presented in Table-1. The general soil properties consist of very soft clay over the top 18 m. The silty sand is found between the depths of 18 and 30 m. This layer is underlain by medium stiff clay down to about 70 m depth. The engineering properties were obtained by performing index properties and consolidation test. Moreover, the property of timber pile (galam) which is used in this study was presented in Table-2.

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Table-1. Mechanical properties of soil layer.

Soil Type	Layer 1 (0,00 - 4,00) m	Layer 2 (4,00 - 6,00) m	Layer 3 (6,00 - 12,00) m	Layer 4 (12,00 - 18,00) m	Layer 5 (18,00 - 25,00) m	Layer 6 (25,00 - 30,00) m	Fill
	Soft Clay					Sand	Slected Sand and Gravel
γ_{unsat} [kN/m³]	12	12	13	15	16	16.5	19
γ_{sat} [kN/m³]	14.5	14.5	15	16	18	20	20
k_x [m/day]	6.89E-04	6.89E-04	6.89E-04	6.89E-04	6.89E-04	2	2
k_y [m/day]	1.38E-03	1.38E-03	1.38E-03	1.38E-03	1.38E-03	1	1
E [kN/m²]	-	-	-	-	-	8000	10000
v [-]	-	-	-	-	-	0.35	0.35
Cc [kN/m²]	0.9	0.9	0.85	0.6	0.4	-	-
Cs [kN/m²]	0.13	0.11	0.13	0.09	0.09	-	-
e_0 [-]	2.2	2.2	2	1.8	1.5	-	-
φ [°]	5	8	12	14	16.5	30	33
c [kN/m²]	10	12	20	25	30	1	1

Table-2. Characterictic of Galam timber.

Characteristic of Galam	Value
Water content	22.95%
Compressive strength //	23.3 Mpa
Compressive strength ⊥	14.4 Mpa
Tensile strength	17.9 Mpa
Bending strength	101.4 Mpa

PVD properties

Investigation on PVD was conducted to determine the permeability of PVD materials used in the field. Permeability of PVD was found higher than $2x10^{-3}$ cm/det.

CONSTRUCTION OF HYBRID PILE AND INSTRUMENTATION HYBRID PILE DESIGN

The arrangement of full-scale trial embankment with Hybrid pile reinforcement is shown in Figure-1. The full-scale test is constructed on 16.5 m width and 20 m length (half of cross section) of each type of reinforcement with 4.5 m of embankment high. A layer of geotextile was placed and beneath the embankment a. The piles and PVD were driven with 6 m length. Piles together with PVD were driven with a spacing of 1.0 m by 1.0 m. The schematic arrangement of Hybrid pile design is shown in Figure-2.

The geotextile was installed between embankment and subsoil. The embankment was founded on a soft soil; several instruments were installed on the soft soil. The instrumentation was installed prior to the construction of embankment and consisted of the surface settlement plates, inclionometer and piezometer. The instrumentation in the subsoil for each type of reinforcement {i.e. geotextile, conventional and inclined pile} is shown in Figure 3, 4 and 5.

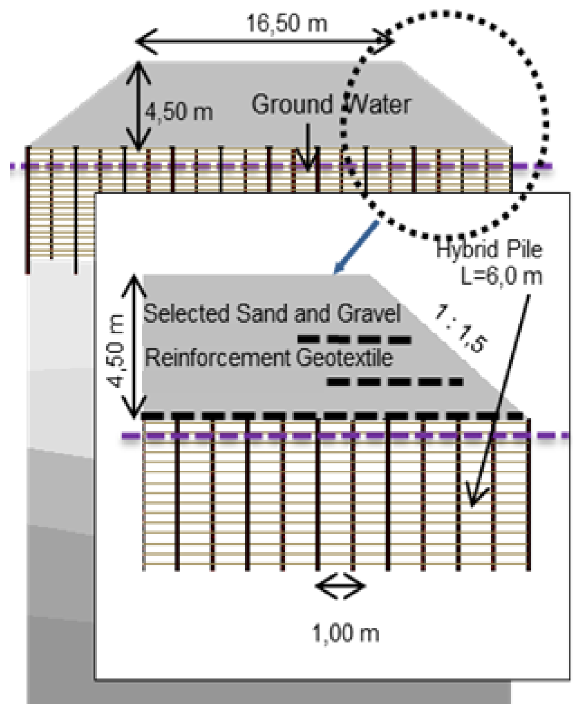

Figure-1. Typical cross section.

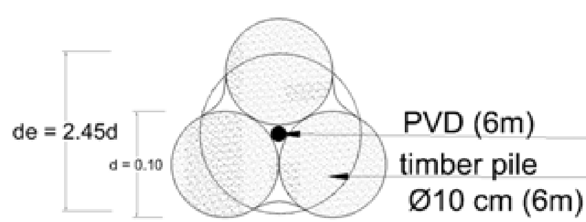

Figure-2. Schematic design of Hybrid pile.

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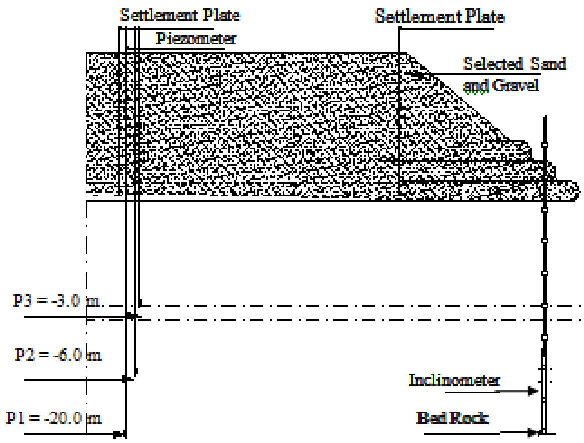

Figure-3. Geotextile reinforcement.

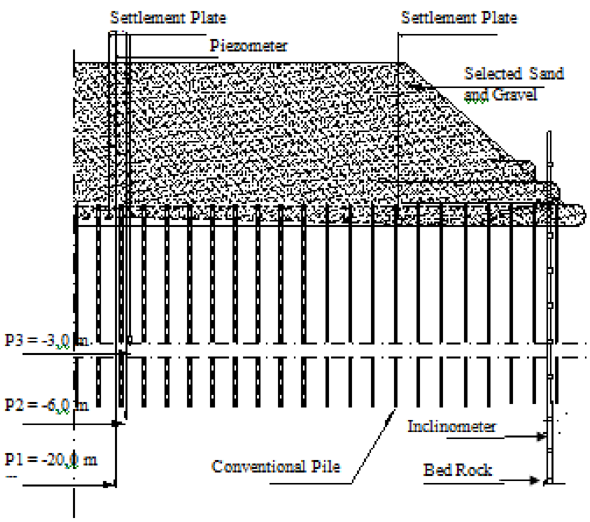

Figure-4. Conventional pile reinforcement.

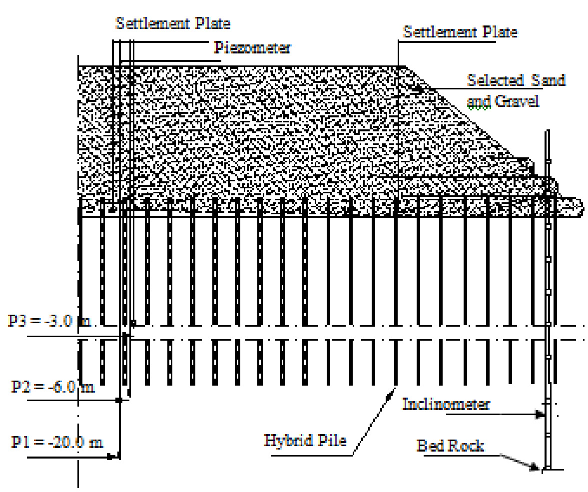

Figure-5. Hybrid pile reinforcement.

During the construction period, the elastic settlements were observed periodically. Digital piezometers were installed near the settlement plate and the lateral movement of the soil and embankments were measured by using a digital inclinometer which is installed vertically at the edge of embankment.

CONSOLIDATION BEHAVIOR OF FULL-SCALE TEST

The performance of geotextile reinforcement is shown in Figure-6. During the stage construction period, immediate elastic settlements were observed. The rate of settlement was low near the surface, but after construction the rate of settlement increase. In this study, the settlement increased with increasing embankment high until reach approximately 4.5 m. The result shows that larger settlement was observed in this type of reinforcement. Initially small amount of settlement was recorded (250 mm) with 1.5 m embankment height. Increasing the high of embankment up to 3.0 m show a larger settlement occurred in the subsoil. For the final stage, the final level of embankment was set to 4.5 m and according to monitoring result, the total settlement was found around 1.1 m.

According to recorded data for the conventional galam pile reinforcement, initially at the lower high of embankment, similar settlement behavior with geotextile reinforcement was found. Increasing high of embankment (4.5 m) tend to increase the settlement of the subsoil up to 0.55 m. It is indicated that the presence of pile in the reinforcement system will reduce the amount of settlement by 52%. The observed data for pile reinforcement is shown in Figure 7. Miki and Nozu (2004) reported that significant improvement on soft ground surface settlement (more than 60%) from the construction completion when using floating piles compared to without piles (settelement without piles is about 1.1m)..

For the Hybrid pile reinforcement, the total settlement of soil reaches 0.48 m for 3 months observation time after the end of embankment construction and it is stabilized. Soil settlement is slightly lower than the settlement of pile reinforcement. The reduction of settlement was found 56% compare to geotextile reinforcement. However, the time for consolidation taking place is much faster for hybrid pile reinforcement system (65 days) as shown in Figure-8.

The observed settlement results for each reinforcement type are plotted in Figure-9. The settlements of the reinforcement system (conventional pile and hybrid pile) were almost identical (97 days). Furthermore, the result of total settlement (3 months) is summarized in Table 3. However, although the settlement observation up to 97 days for both conventional pile and Hybrid pile indicated very small difference as shown in Figure 9, but the degree of consolidation of Hybrid pile was found almost 90%. It indicates that the consolidation process of Hybrid pile is almost finished. While the settlement of conventional pile still underway with the same period of observation (97 days).

The deformation behavior of 3 (three) types of reinforcement as shown in Figure 10, 11 and 12. The numerical analysis shows that the installation of Hybrid pile tends to reduce the amount of deformation. This result has a good agreement with the results of field observation.

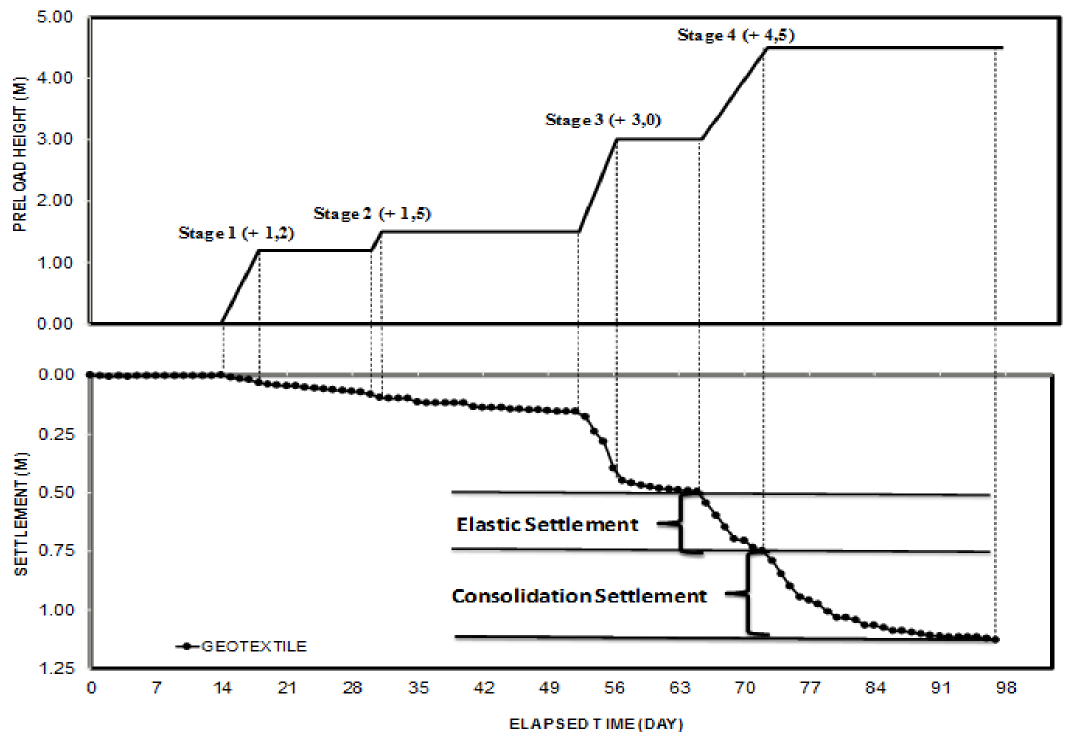

Figure-6. Settlement observation of geotextile reinforcement.

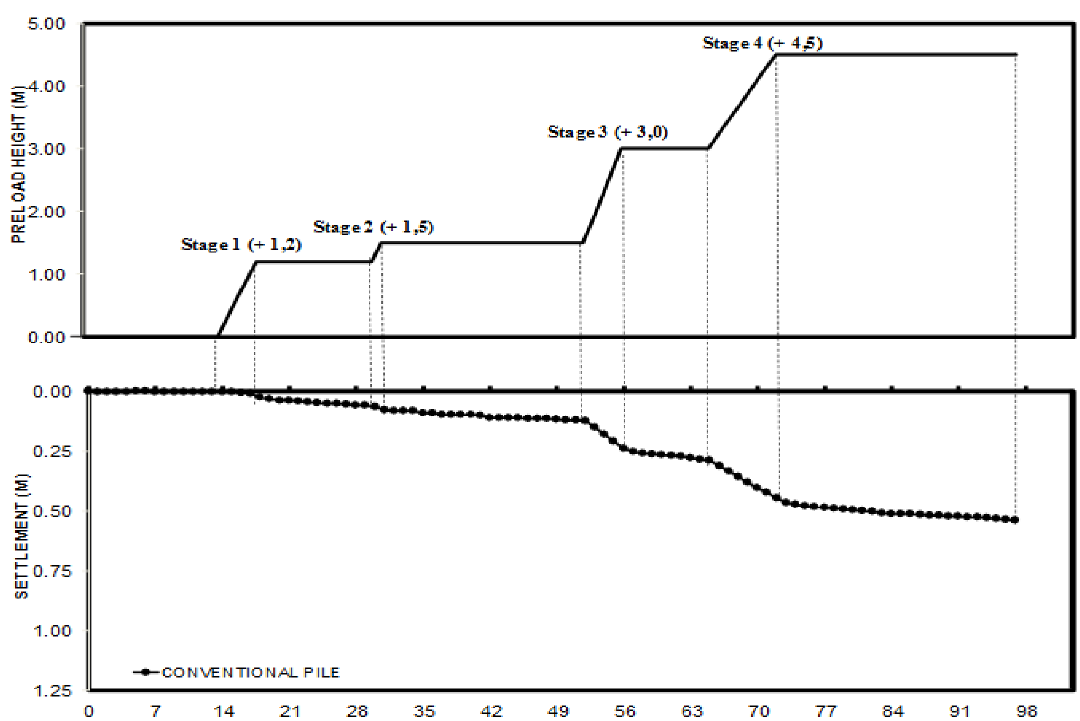

Figure-7. Settlement observation of conventional pile reinforcement.

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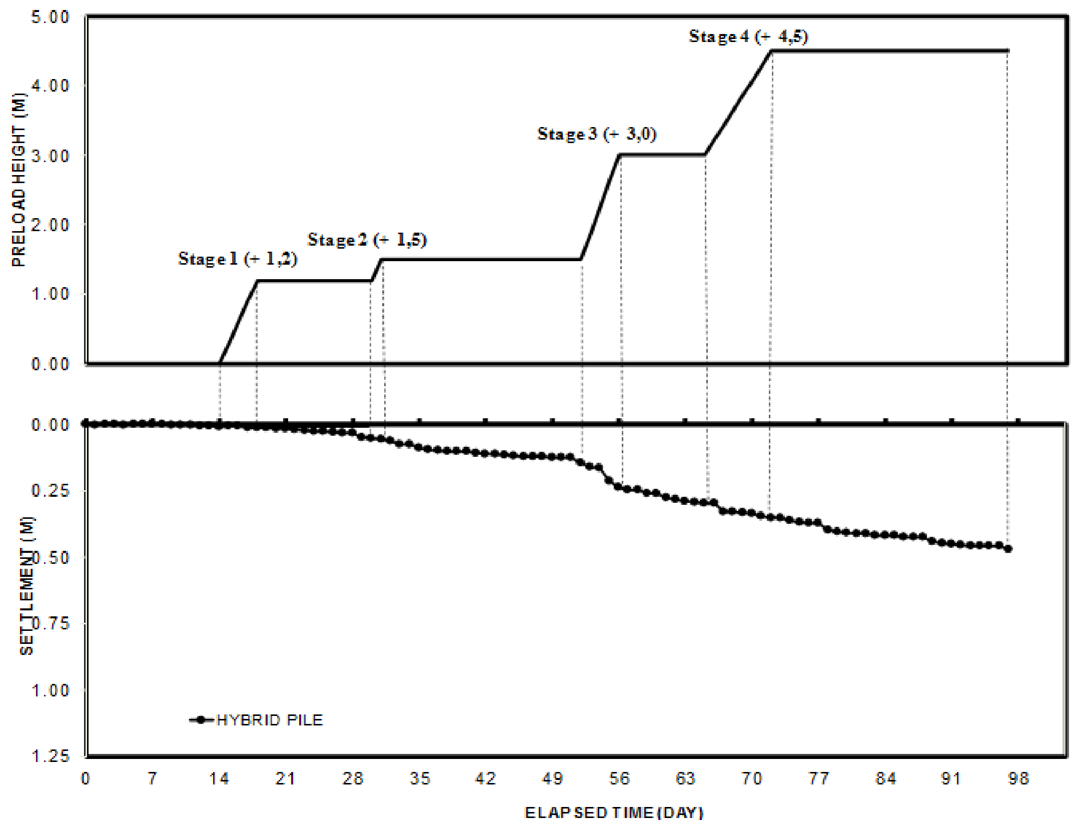

Figure-8. Settlement observation of pile-PVD (Hybrid pile) reinforcement.

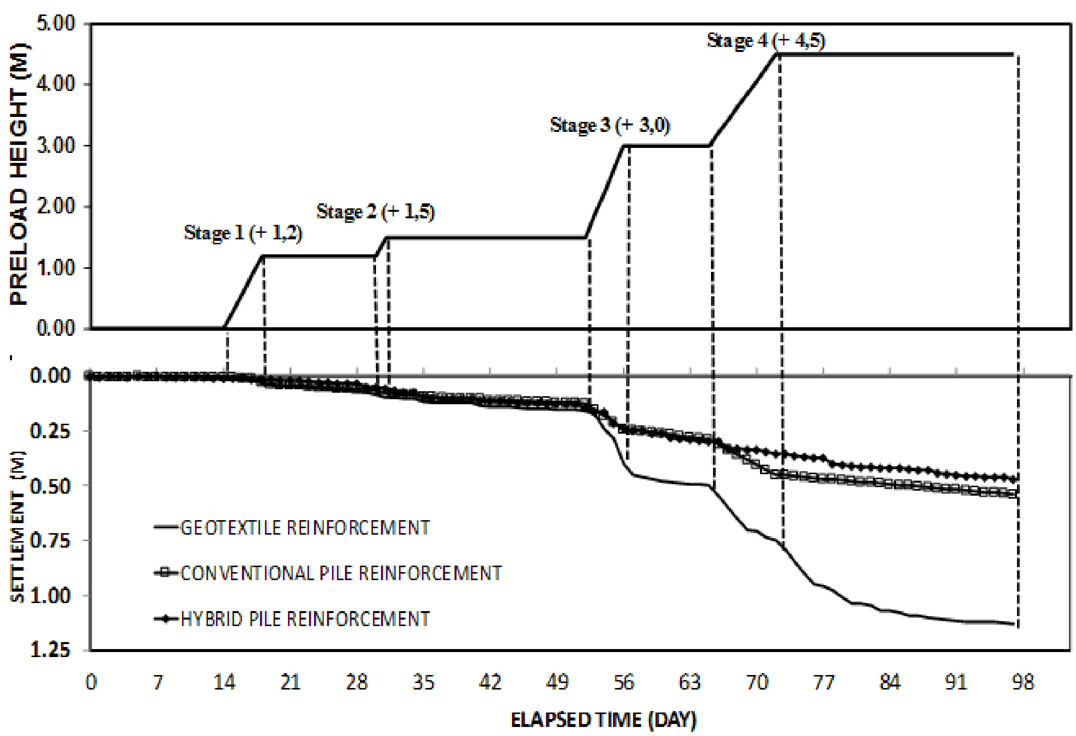

Figure-9. The observed settlement for each reinforcement type.

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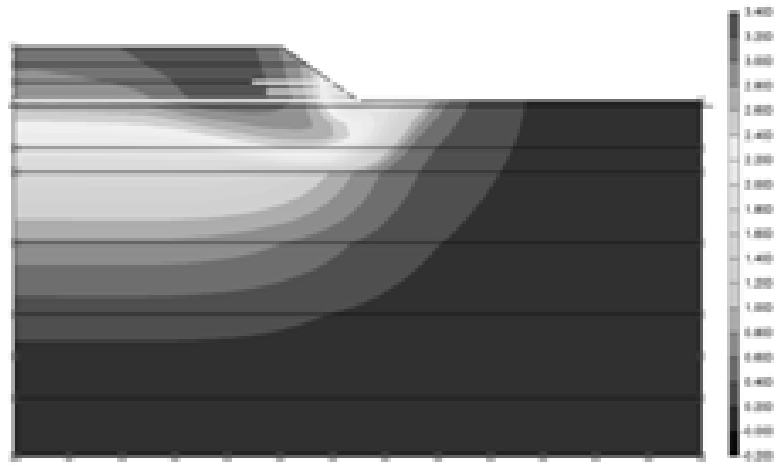

Figure-10. Shading deformation geotextile reinforcement.

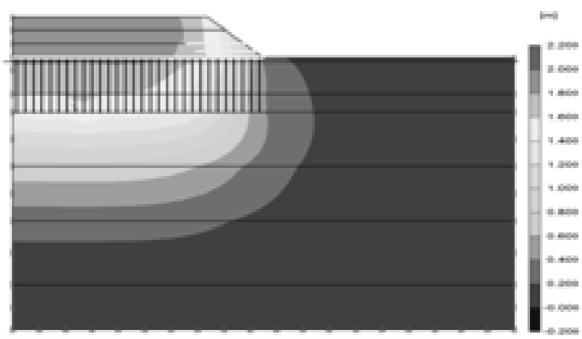

Figure-11. Shading deformation conventional pile reinforcement.

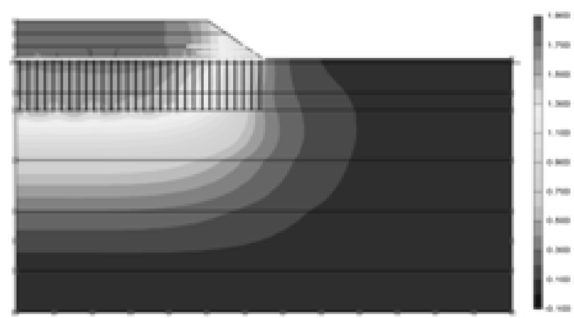

Figure-12. Shading deformation Hybrid pile reinforcement.

Table-3. Result of settlement observation.

No.	Construction type	**Settlement** (cm)	**Reduction of settlement compare to geotextile reinforcement** (%)
1	Geotextile	113	-
2	Conventional Pile	54	52
3	Hybrid Pile	46	60

From piezometers observation shown that the excess pore water pressure is influenced by the lenght of the hybridpile and types of reinforcement. The excess pore water pressure gradually decreases with increasing of hybrid pile depth. Initially, pore water pressure will increase with the addition of loading and will dissipate during the consolidation period take place as shown in Figure 13, 14 and 15. At the lower depth (3 m), time for excess pore water pressure dissipate faster than at the higher depth (6 and 20 m). This is due the water path to dissipate is shorter at the near the surface rather than at the deeper area. Geotextile reinforcement has a longer time for dissipate compare to hybrid pile. The presence of PVD in the center of pile provides a shorter path for water to dissipate. The rate of excess pore water pressure to dissipate for geotextile reinforcement is very slow. This is due to the distance that pore water move out from the certain depth is longer compare to the presence of PVD in the soil.

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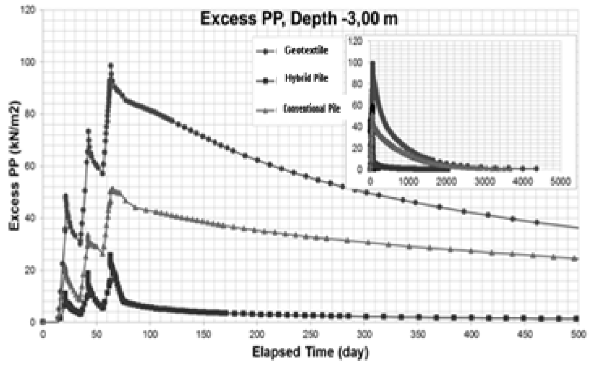

Figure-13. Excess pore water depth 3.0 meters.

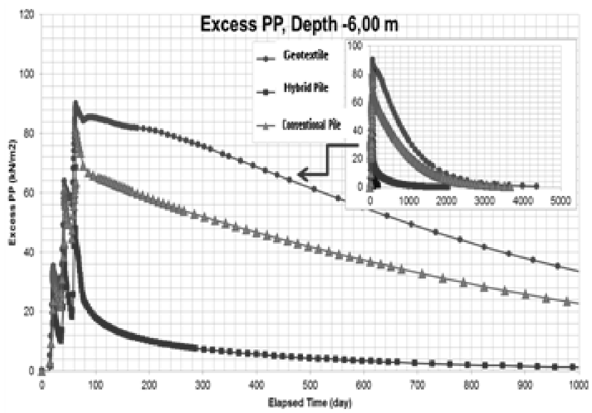

Figure-14. Excess pore water depth 6.0 meters.

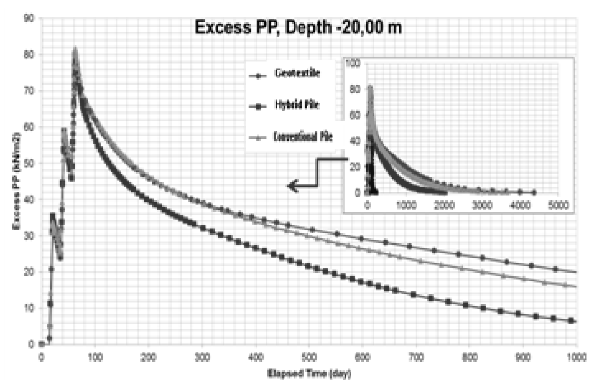

Figure-15. Excess pore water depth 20.0 meters.

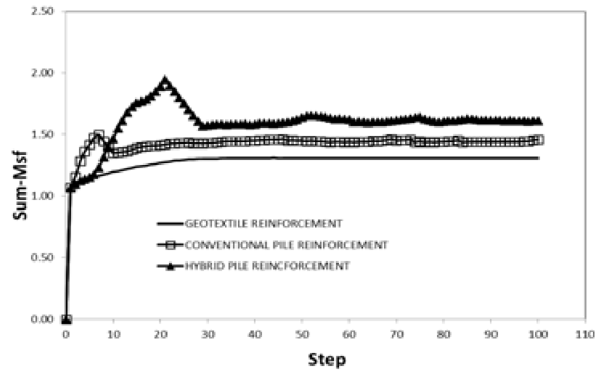

Figure-16. Safety factor.

Figure-16 shows a safety factor comparison of various types of reinforcement. Evaluation of the safety factor is conducted in a critical condition when the heights of loading reach 4.50 m. The analysis showed that with the installation of Hybrid pile reinforcement can increase the safety factor up to 1.56 with the failure mechanisms that occur in the form of sliding slope of the road while geotextile reinforcement only have a safety factor around 1.20. The conventional pile reinforcement indicated that the safety factor increase up to 1.40 but still lower than the Hybrid pile.

CONCLUSIONS

Three full-scale test embankments were investigated on soft clay such as geotextile, conventional pile and Hybrid pile reinforcement. During the stage construction period, immediate elastic settlements were observed. Initially, the rate of settlement was low near the surface. During the next construction stage by increasing the high of embankment, the rate of settlement increase. The settlement observation for both conventional pile and Hybrid pile indicated very small difference, but the degree of consolidation of Hybrid pile was found almost 90%. It indicates that the consolidation process of Hybrid pile is almost finished. While the settlement of conventional pile still underway with the same period of observation (97 days). Significant improvement on soft ground surface settlement (approximately 60%) from the construction completion by using Hybrid pile compared to geotextile reinforcement system. Based on the results of numerical analysis, the safety of embankment increase about 30% compare geotextile reinforcement. It indicates that the potential using of Hybrid pile as an alternative of soil reinforcement on soft soil.

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