Geotechnical and Geophysical Site Characterisation 5 – Lehane, Acosta-Martínez & Kelly (Eds)

Field Investigation of the Performance of Soft Soil Reinforcement with Inclined Pile

A. T. Harianto & L. Samang
Geo-environmental Laboratory, Department of Civil Engineering, Hasanuddin University, Indonesia
B. Suheriyatna & Y.Sandyutama
Department of Public Works, Agatis, Tanjung Selor, Indonesia

ABSTRACT: A full-scale test of inclined timber pile was conducted to observe the effectiveness of this soil reinforcement in reducing the settlement with various types. A series of reinforcement method were applied in the field under a trial embankment with 4,5 m high. Field instrumentation was set up on the site to observe the movement and settlement behaviour of reinforced soil under embankment load. Pile reinforcement of soft soil made from galam timber with 6 m length and 10 cm in diameter. The settlement monitored by using settlement plate during the construction stage and the lateral displacement measured by using inclinometer. Piezometer was used in order to monitor the change of pore water pressure during the preloading test. It was concluded that construction of embankment using inclined pile as reinforcement on soft soil can reduce the settlement and lateral movement significantly and can be used as an alternative soil reinforcement material.

1 INTRODUCTION

Construction of road embankment over a soft soil poses challenging problems in its development. Generally, the strength of soft clay is not strong enough for supporting embankment stability. The problem of construction on soft clay is the low bearing capacity and differential settlement, therefore innovation in soil improvement is needed. Recently, many researchers conducted field observation of full-scale model (e.g. Falorca et al., 2011; Won and Kim, 2007; Hatami and Bathurst, 2005, 2006; Bergado et. al., 1995, 2000, 2003; Ling and Leshchinsky, 2003; Varuso et al., 2005). Nunes et al. (2013) reported that the settlement efficacy of pile-supported embankment is a reliable parameter to assess the overall performance of the rigid inclusion technique.

An experiment of full-scale trial embankment constructed on soft soil reinforced by several reinforcement methods is conducted in this study. Due to the limitations of construction materials especially in East Kalimantan Island (Indonesia), most of the construction materials for road construction were imported from outside the Kalimantan Island causing inefficiency (very high costs) in construction. Moreover, the trees (melalucea lencadendron linn/galam) are a local timber and easily found in Kalimantan and have long life if buried in the swamp. This timber is considered as an alternative material for soil reinforcement over soft clay. The performance of inclined pile compare to construction of conventional pile and geotextile reinforcement was observed.

Table 1. Soil properties

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

2 MATERIAL PROPERTIES AND METHODS

2.1 Soil and timber properties

In order to collect and determine the soil properties of experimental study location, deep borehole test was carried out. The soil 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. Moreover, the property of timber pile (galam) that is used in this study was presented in Table 2.

Table 2. Galam timber characteristics

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

2.2 Instrumentation

A Full-scale test of trial embankment was constructed on 16.5 m width and 20 length of each type of reinforcement with 4.5 m of embankment high. The piles were installed with 6 m length and beneath the embankment a layer of geotextile was installed. The arrangement of pile reinforcement is shown in Figure 1. Typical cross section showing soft soil, piles and geotextile is shown schematically in Figure 2a. A series of instruments were installed on the embankment in order to monitor the deformation behavior such as settlement plate, inclinometer and piezometer. The instrumentation in the subsoil for each type of reinforcement {i.e. geotextile, conventional and inclined pile} was installed prior to the construction of the embankment as shown in Figure 2b.

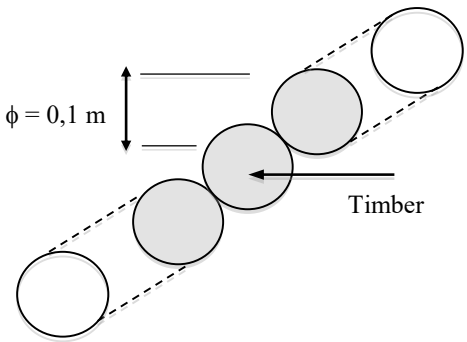

Figure 1. Inclined pile setting

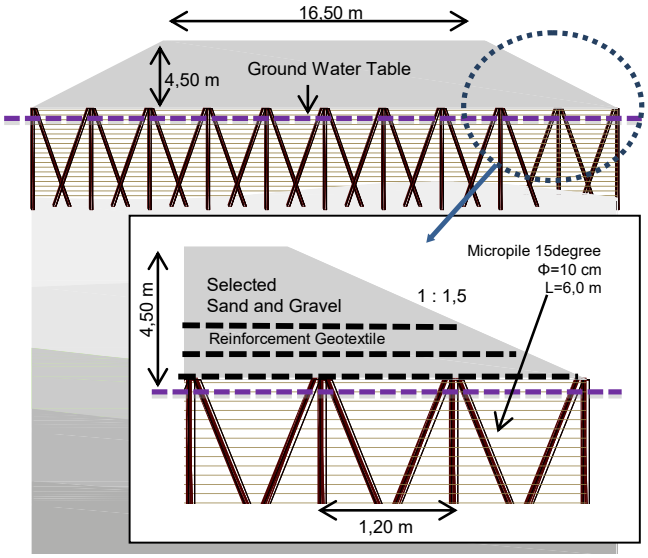

Figure 2a. Cross section of embankment

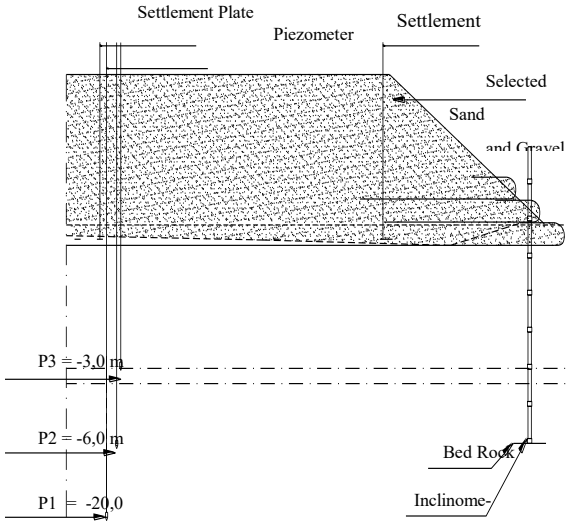

Figure 2b. Placement of instrumentation

3 RESULT AND DISCUSSION

The trial embankment observation was conducted in 3 months. Based on the observation results, the settlement of geotextile reinforcement was found about 1.1 m. It is indicated that the geotextile reinforcement inadequate in supporting the trial embankment with 4.5 m height. The bearing capacity also very low which indicate by huge amount of lateral displacement observed in the field.

For conventional pile reinforcement, the settlement was found lower than geotextile reinforcement. The total settlement reduces about 52%. It is indicated that the presence of piles tends to increase the bearing capacity of subsoil in supporting the embankment.

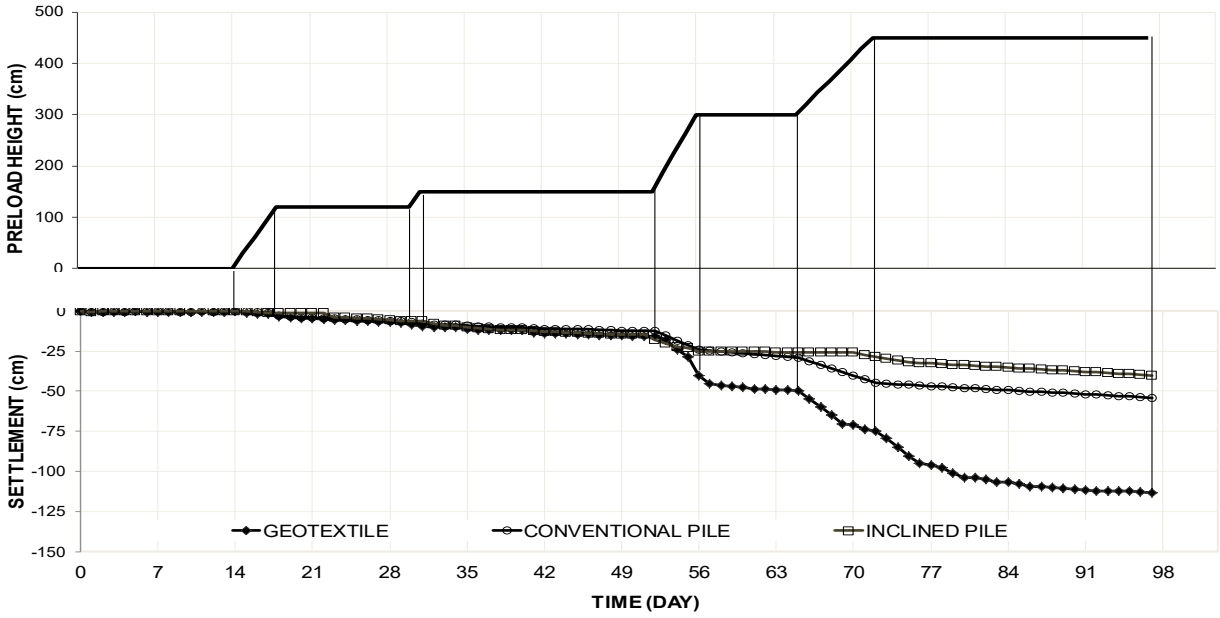

Figure 3. Summary of time versus settlement observations

Similar result obtained with the inclined pile reinforcement method. Reduction of settlement was found around 65% compare to geotextile reinforcement. The bearing capacity of this type of reinforcement has a highest value compare to other reinforcement method. The results of total settlement (3 months) are summarized in Table 3. The combination of all reinforcement method conducted in this study is shown in Figure. 3.

Table 3. Result of settlement plate observation

No	Construction Type	Settlement (cm)	Reduction of settlement compare to geotextile reinforcement (%)
1	Geotextile	113	-
2	Conventional Pile	54	52
3	Inclined Pile	40	65

Figure 4 shows the inclination pattern of three types reinforcement tested in this study. The displacement versus time at specific depth is useful to determine the rate of movement at that depth. It is found that the shear zone located near the surface (0-4 m depth). Installation of inclined pile significantly reduces the amount of lateral movement about 75% compared to geotextile reinforcement. This phenomenon mainly due to the presence of pile up to 6 m depth that provide the lateral resistance in the zone with pile reinforcement.

There were three piezometer points monitored in the field. Piezometer levels are shown plotted as a pore water pressure with various depth in Figure 5 (3, 6 and 20m). It was observed that with increasing height of embankment, the pore water pressure increase. The initial pore water pressure was increased to a depth of 20 m due to the stresses induced by the application of the embankment fill and construction equipment.

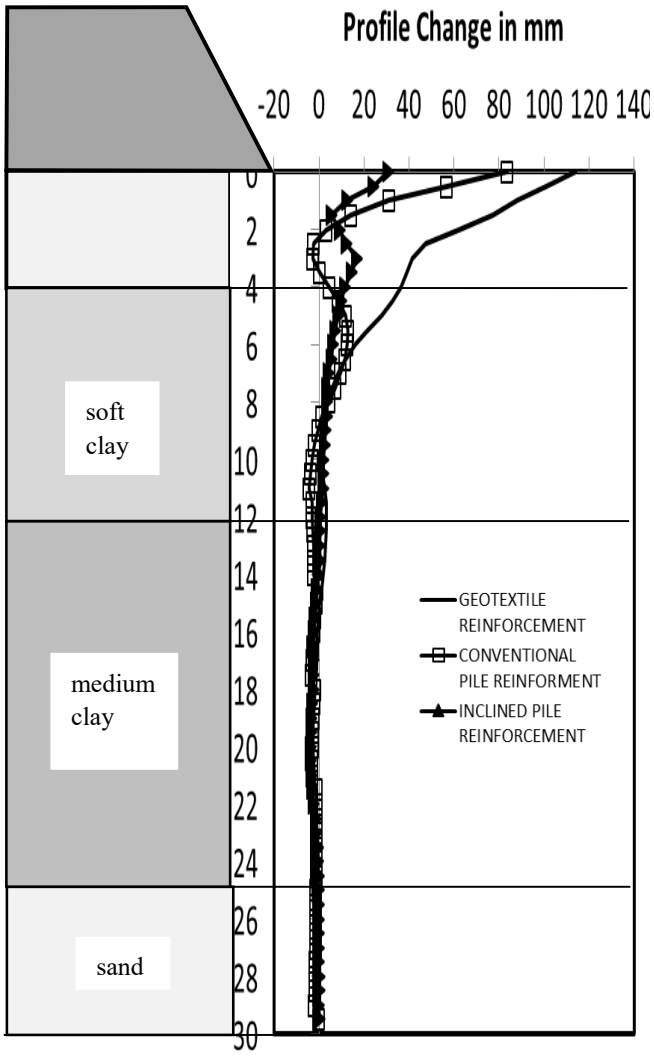

Figure 4. Inclination of various reinforcement

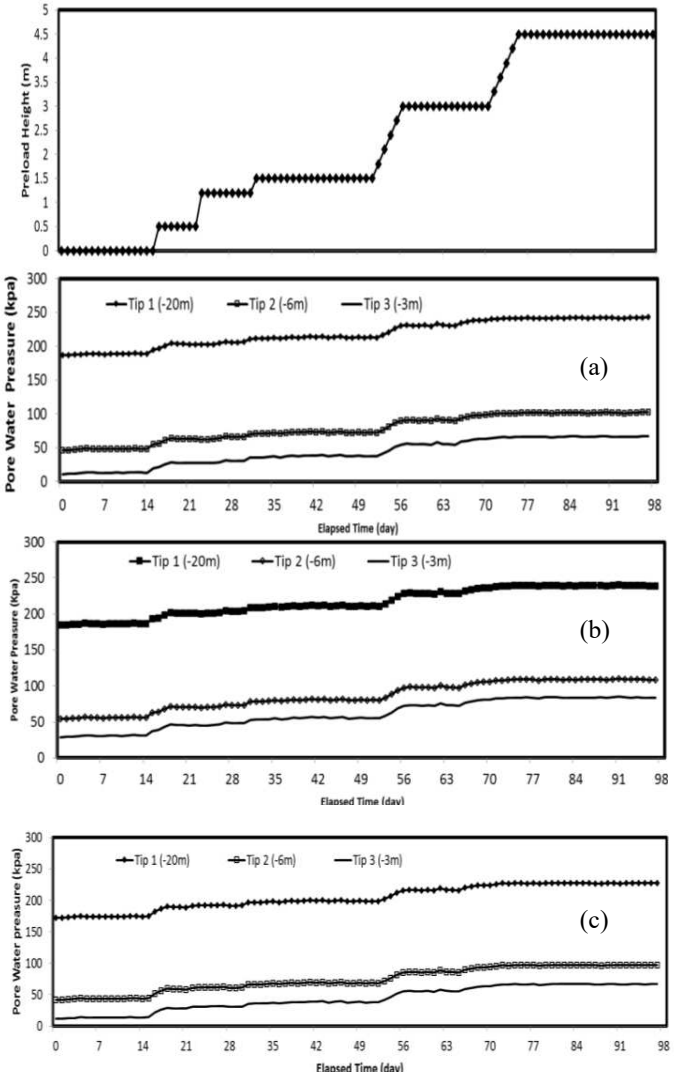

Figure 5. Pore water pressure profile (a) geotextile, (b) conventional pile, (c) inclined pile

4 CONCLUSIONS

The bearing capacity of reinforced soil with conventional and inclined pile is sufficient to support the trial embankment (4,5 m). The small amount of lateral movement was observed for both pile reinforcement, which is indicated that the sufficient slope stability of trial embankment, occur with the installation of pile reinforcement. The initial pore water pressure was increased to a depth of 20 m due to the stresses induced by the application of the embankment fill and construction equipment. The total settlement reduction for both conventional and inclined pile compared to geotextile reinforcement was found 52% and 65% respectively. Therefore, the inclined pile reinforcement has a potential application for road construction on soft soil as an alternative construction method.

5 REFERENCES

Bergado, D.T., Chai, J.C., Miura, N., 1995. FE analysis of grid reinforced embankment system on soft Bangkok clay. Computers and Geotechnics 17: 447-471

Bergado, D.T., Teerawattanasuk, C., Youwai, S., Voottipruex, P., 2000. FE modelling of hexagonal wire reinforced embankment on soft clay. Canadian Geotechnical Journal 37 (6): 1-18.

Bergado, D.T., Youwai, S., Teerawattanasuk, C., Teerawattanasuk, C., Visudmedanukul, P., 2003. The interaction mechanism and behaviour of hexagonal wire mesh reinforced embankment with silty sand backfill on soft clay. Computers and Geotechnics 30: 517-534.

Falorca, I., Gomes, L. and Pinto, M., 2011. A full-scale trial embankment construction with soil reinforced with short randomly distributed polypropylene microfibers. Geosynthetics International, 18(5) : 280.

Hatami, K., Bathurst, R.J., 2005. Development and verification of a numerical model for the analysis of geosynthetic-reinforced soil segmental walls under working stress conditions. Canadian Geotechnical Journal 42: 1066-1085.

Hatami, K., Bathurst., R.J., 2006. Numerical model for reinforced soil segmental walls under surcharge loading. Journal of Geotechnical and Geoenviromental Engineering, ASCE 136 (6): 673-684.

Ling, H.I., Leshchinsky, D., 2003. Finite element parametric study of the behaviour of segmental block reinforced – soil retaining walls. Geosynthetics International 10 (3): 77-94.

Nunez, M. A., Briancon, L. and Dias, D, 2013. Analyses of a pile-supported embankment over soft clay: Full-scale experiment, analytical ans numerical approaches. Engineering Geology, 153: 53-67.

Varuso, R.J., Grieshaber , J.B., Nataraj, M.S., 2005. Geosynthetic reinforced levee test section on soft normally consolidated clay. Geotextiles and Geomembranes 23 (4): 362-383.

Won, M.S., Kim, Y.S., 2007. Internal deformation behaviour of geosynthetics-reinforced soil walls. Geotextile and Geomembranes 25 (1): 10-22.