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Full Scale Model Test of Consolidation Acceleration on Soft Soil deposition with Combination of Timber Pile and PVD (Hybrid Pile)

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Abstract— This research aims to analyze the effect of composite pile-PVD (hybrid pile) as the reinforcement in embankment on soft soil by the means of numerical simulation and Full-Scale Trial Embankment. The first phase cunducted by numerical analysis and obtained 6-8 meters hybrid pile length effective. Full-Scale trial embankment. was installed hybrid pile of 6 m and preloading of 4,50 height. Full-scale tests were performed to investigate the performances of Hybrid pile reinforcement. This research observed vertical displacement, lateral displacement, and pore water pressure. Observation were taken for each stage construction in 3 months. The result of full-scale observation validated with numerical method. Reinforced with hybrid pile able to increase the bearing capacity and accelerate the rate of consolidation.

Keywords— Bearing Capacity, Consolidation, Full-Scale, Hybrid Pile, Numeric, Soft Soil.

I. INTRODUCTION

Embankment construction is one of method employed to adjust the elevation of the ground surface. Embankment on soft soil imposes additional stress that is resulted in deformation and consolidations as well as an increase of shear strength.

For the case of embankment on soft clay, it needs method to solve the problem of bearing capacity. The increase of bearing capacity can be achieved by staged construction and soil reinforcement, while the hydraulic conductivity problem can be dealt with using PVD that accelerate the dissipation of pore water pressure. Hybrid pile, as one of new innovation in soil improvement, is the combination between timber pile and PVD. This technology is expected to increase the bearing capacity of soil and accelerate the rate of consolidation.

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.

II. SUB-SOIL PROPERTIES AND MATERIAL CHARACTERISTIC

The sub-soil properties on field, full scale location, determine by deep boring and laboratory test. According to visualisation and soil test, sub-soil defined as soft clay over the top 18 m. The silty sand was found between the depths of 18 and 30 m. The result of soil test each layers presented in Table 1.

Pile reinforcement of soft soil made from galam timber 6 meter length and 10 cm of diameter. Galam timber characteristic are presented in Table 2.

Testing of PVD mterial was conducted to determine the permeabilty of PVD used in the full scale test location. Permeability of PVD was found $2x10^{-3}$ cm/det. In this research also used geotextile with a tensile strength of 52 kN/m.

TABLE I
SUB-SOIL LAYER PROPERTIES

Constitutive Models	Soil Type		γ_{unsat} [kN/m]	γ_{sat} [kN/m]	k_x [m/day]	k_y [m/day]	E [kN/m]	v [-]	Cc [kN/m]	Cs [kN/m]	e_0 [-]	j [°]	c [kN/m]
Soft Soil	Layer 1 (00,00 - 04,00) m	Soft Clay	12	14,5	1,38E-03	6,89E-04	-	-	0,9	0,13	2,2	5	10
	Layer 2 (04,00 - 06,00) m		12	14,5	1,38E-03	6,89E-04	-	-	0,9	0,11	2,2	8	12
	Layer 3 (6,00 - 12,00) m		13	15	1,38E-03	6,89E-04	-	-	0,85	0,13	2	12	20
	Layer 4 (12,00 - 18,00) m		15	16	1,38E-03	6,89E-04	-	-	0,6	0,09	1,8	14	25
	Layer 5 (18,00 - 25,00) m	Silty Sand	16	18	1,38E-03	6,89E-04	-	-	0,4	0,09	1,5	16,5	30
Mohr Coulomb	Layer 6 (25,00 - 30,00) m		16,5	20	2	1	8000	0,35	-	-	-	30	1
	Fill	Slected Sand and Gravel	19	20	2	1	10000	0,35	-	-	-	33	1

TABLE II
CHARACTERICTIC OF TIMBER (GALAM)

Characteristic	No. Sample					Average
	1	2	3	4	5	
Water Content (MPa)	21,62	23,68	23,53	-	-	22,95
Tensile Strength (MPa)	18,63	18,83	19,52	17,06	15,30	17,87
Tensile Elasticity (MPa)	690,10	710,52	780,61	609,41	536,79	665,48
Compressive Strength // (MPa)	24,88	22,06	24,15	21,08	24,52	23,34
Compressive Elasticity // (MPa)	1244,22	767,48	1073,28	674,70	980,67	948,07
Compressive Strength ⊥ (Mpa)	13,65	15,53	14,63	15,20	13,08	14,42
Compressive Elasticity ⊥ (MPa)	467,92	776,36	566,25	675,57	412,91	579,80
Bending Strength (MPa)	97,45	99,89	107,20	99,89	102,33	101,35
Split Strength (MPa)	26,97	28,19	27,46	26,97	27,70	27,46

III. EMBANKMENT STRUCTURE DESIGN

Embankment structure was analyzed with a length variations of composite pile – PVD (Hybrid Pile) to obtain a composite pile - PVD effective length. The Test results of trial embankment reinforced with hybrid pile compared with other reinforcement (geotextile reinforcement and conventional pile reinforcement conducted by Suheriyatna et al.). Vertical displacement obtained by settlement plate monitoring, lateral displacement obtained by inclinometer monitoring, and pore water pressure obtained by piezometer monitoring. The result of field monitoring validated with numerical analysis by Plaxis 8.x. Embankment structure design are shown in Fig. 1.

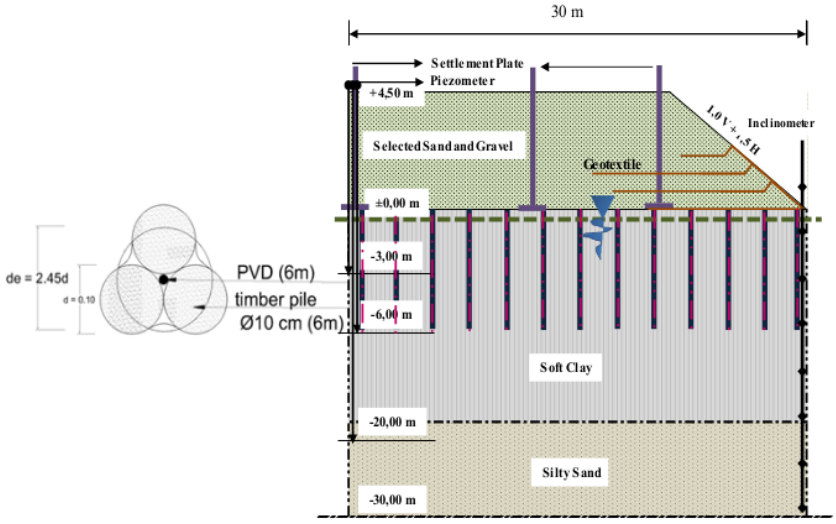

Fig. 1 Embankment Structure that reinforced with composite pile – PVD

IV. RESULT AND ANALYSIS

A. *Effect Hybrid Pile Length to Consolidation Degree*

The Effect of hybrid pile length to consolidation settlement compered with length variations of composite pile – PVD (Hybrid Pile) for degree of consolidation U_{R60}, U_{R80}, U_{R90}. U_R defined as total settlement at t time (δ_t) divided by final settlement $(\delta_\sim)$. The result of analysis obtained 6-8 meters hybrid pile length effective, as presented in Table 3 and Fig. 4.

$$U_R = \frac{\delta_t}{\delta_\sim}$$

TABLE III
EFFECT HYBRID PILE LENGTH TO CONSOLIDATION DEGREE

Reinforcement type	Total Settlement (m)			Time Consolidation (day)		
	(u_{R60})	(u_{R80})	(u_{R90})	(u_{R60})	(u_{R80})	(u_{R90})
Un-Reinforcement	-1.87	-2.5	-3.12	650	737	3918
Hybrid Pile, 2 m	-1.57	-2.09	-2.61	400	665	2855
Hybrid Pile, 4 m	-1.15	-1.77	-2.33	232	513	2614
Hybrid Pile, 6 m	-1	-1.32	-1.67	200	498	2038
Hybrid Pile, 8 m	-0.86	-1.16	-1.45	145	281	1065
Hybrid Pile, 10 m	-0.65	-0.89	-1.11	114	227	848
Hybrid Pile, 12 m	-0.49	-0.69	-0.86	106	216	802
Hybrid Pile, 15 m	-0.36	-0.48	-0.6	69	113	333
Hybrid Pile, 20 m	-0.22	-0.27	-0.33	62	65	200
Hybrid Pile, 22 m	-0.19	-0.21	-0.27	43	59	128

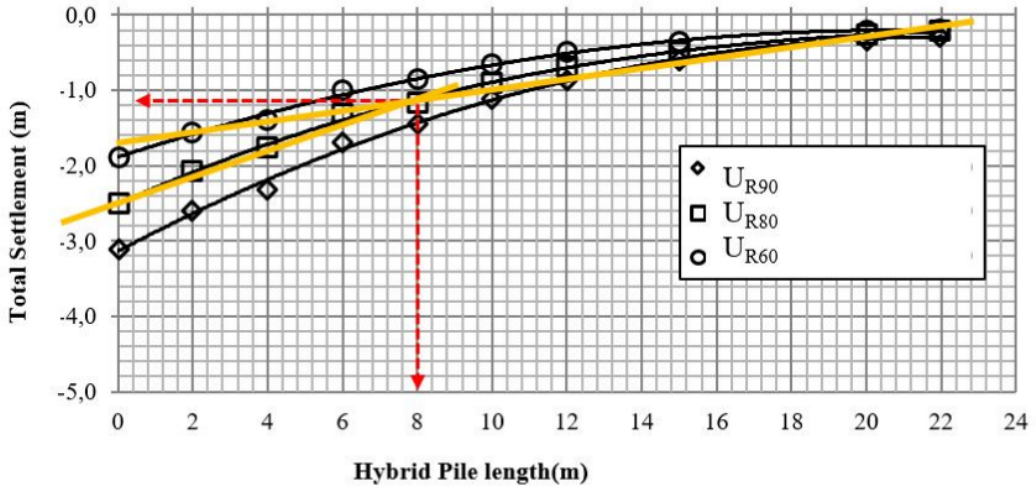

Fig. 2 Relationship Between Total Settlement and Hybrid Pile Length

B. *Trial Embankment Test and Numerical Validation*

Lateral displacement increased significantly at a depth 6-8 m and not occur by the deep layers. That caused by effect of embankment weight gets smaller. The result of settlement observation and numerical analysis show that heaving behaviour on toe embankment reinforced with hybrid pile only occur in the first month, be continued gradually decrease until the 3rd month. Heaving behaviour relatively smallest compared with other reinforcement system. Trial embankment reinforcement with hybrid pile can be able to reduced settlement (Fig. 5) comprared with trial embankment reinforcement with geotextile and trial embankment reinforcement with conventional micro pile (Fig. 6, and Fig. 7, respectively).

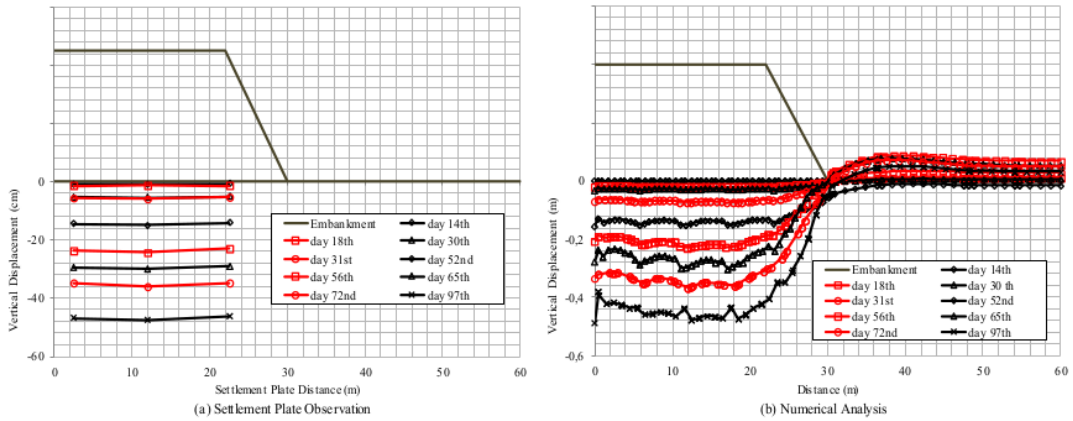

Fig. 3 Vertical Deformation on Reinforcement with Hybrid Pile

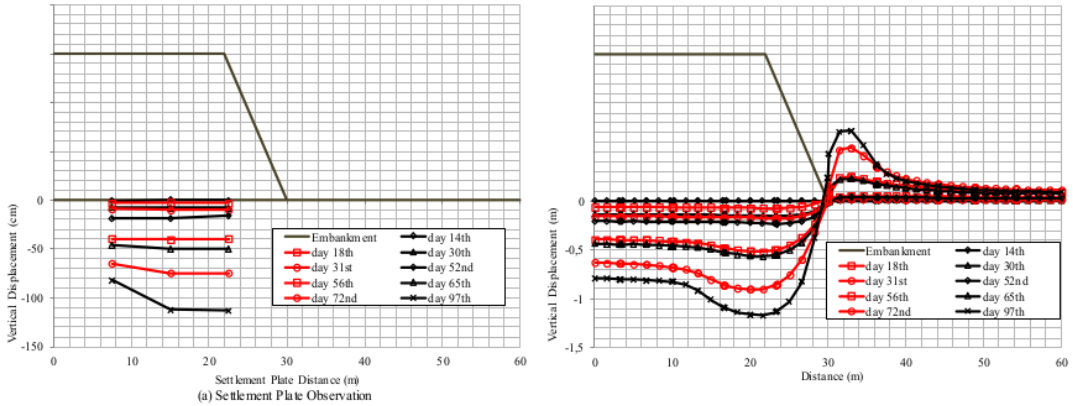

Fig. 4 Vertical Deformation on Reinforcement with Geotextile

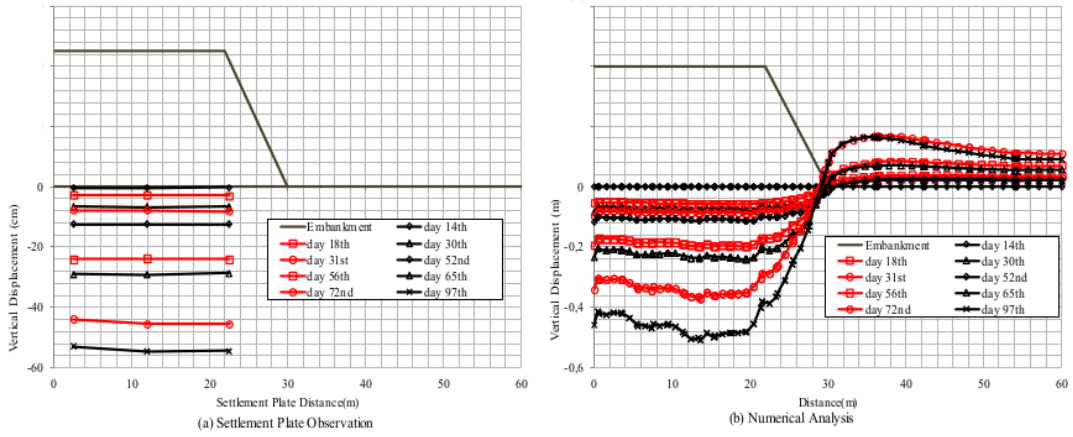

Fig. 5 Vertical Deformation on Reinforcement with Conventional Micro Pile

C. Pore Water Pressure

Pore water pressure based numerical analysis bigger than trial embankment observation. Pore water pressure influenced by type of reinforcement and length of pile. The pore water pressure decreses with increasing depth of soil layer. Compared with geotextile reinforcement (Fig. 9) and conventional micro pile reinforcement (Fig. 10), pore water pressure on reinforcement with hybrid pile (Fig. 8) dissipate faster than other reinforcement.

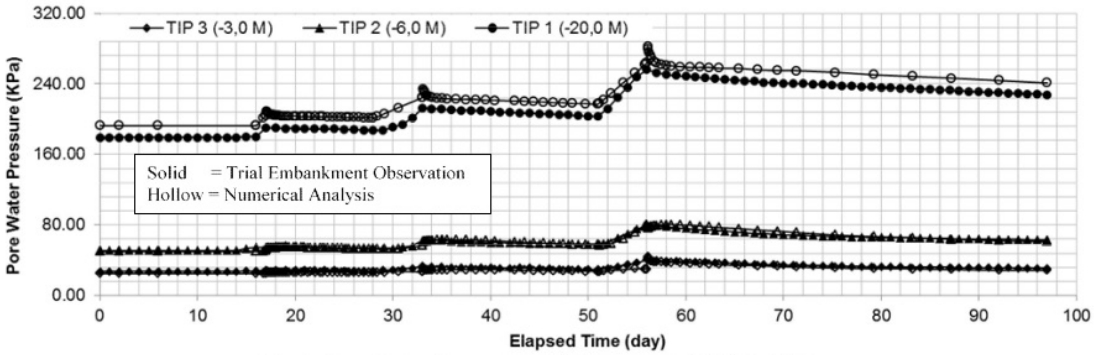

Fig. 6 Pore Water Pressure on Reinforcement with Hybrid Pile

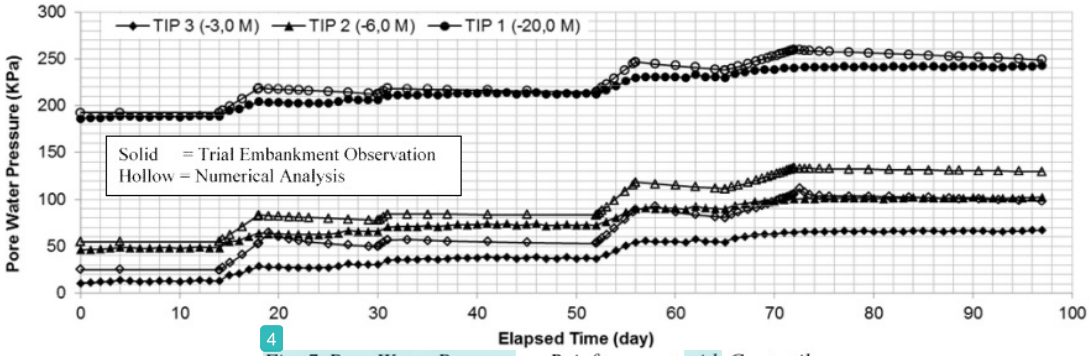

Fig. 7 Pore Water Pressure on Reinforcement with Geotextile

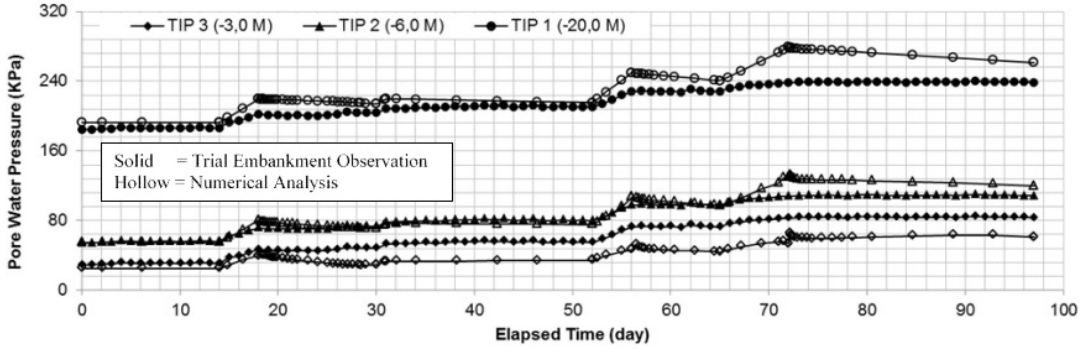

Fig. 8 Pore Water Pressure on Reinforcement with Conventional Micro Pile

V. CONCLUSIONS

The result of trial embankment observation and numerical analysis, it can be concluded as follows:

1. Combination of pile PVD as reinforcement type effectively used on 6-8 m length. Lateral displacement increased significantly at a depth 6-8 m and not occur by the deep layers. Heaving behaviour on toe embankment reinforced with hybrid pile only occur in the first month, be continued gradually decrease until the 3rd month.
2. Pile-PVD composite effectively to reduce settlement and simultaneosly accelerate rate of consolidation.

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