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INSTRUMENTED FULL SCALE TEST AND NUMERICAL ANALYSIS TO INVESTIGATE PERFORMANCE OF BAMBOO PILE-MATTRESS SYSTEM AS SOIL REINFORCEMENT FOR COASTAL EMBANKMENT ON SOFT CLAY

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Bamboo pile-mattress is a system that combines both bamboo piles and bamboo mattress for reinforcement embankment on soft clay. This system utilizes bamboo piles to act as friction piles and bamboo mattress to distribute embankment load uniformly, to alter critical failure surface, and to provide upward buoyancy pressure. The system has been utilized in several projects for coastal embankment on soft clay in Indonesia and has been proven reliable and durable.f. To investigate the performance of the system, instrumented full scale test was conducted at near shore area at Tambak Oso, Surabaya. At the area, very soft to medium clay layer was found until 30 m below ground surface. Stability analysis and settlement prediction was performed using analytical and numerical methods. The numerical method analysis was conducted using finite element method utilizing a commercial program package. Trial embankment was performed in several fill stages followed by observation of embankment stability and ground settlement. Field observation indicated that embankment using bamboo pile-mattress system showed adequate stability against slope failure and bearing capacity failure and actual settlement was also close to predicted settlement. Hence, bamboo pile-mattress system is proven to be reliable as ground reinforcement and to distribute settlement more uniformly and the calculation method was fit with actual condition.

INTRODUCTION

Several treatments have been used to reinforce coastal embankment on soft clay. Bamboo pile-mattress system was proposed as a reliable and cheap alternative of ground reinforcement for coastal embankment on soft clay for coastal area of Java. This system utilizes bamboo piles to act as friction piles and bamboo mattress to distribute embankment load uniformly, to alter critical failure surface, and to provide upward buoyancy pressure. This system was used in several projects of embankment on soft clay and has been proven reliable and durable. However the previous designs were based on an assumed calculation method. Full scale test program was performed to investigate the performance of the system and to check the calculation. The test was performed at near shore area at Tambak Oso, Surabaya.

SOIL CONDITION AT FIELD TEST LOCATION

First layer at field test location has characteristics of 25 to 45 m thickness of very soft soil layer having q_c = 0-15 kg/cm^2 and N-SPT value 1 to 2. Stiff to very stiff clay was found below the first layer (PT Citra Marga Nusaphala Persada Tbk., 1998). Soil properties used for analysis are presented in Table 1.

Table 1. Soil properties at test location (PT. Hutama Karya (Persero), PT. Citra Marga Nusaphala Persada Tbk, LPPM Institut Teknologi Bandung, 2005)

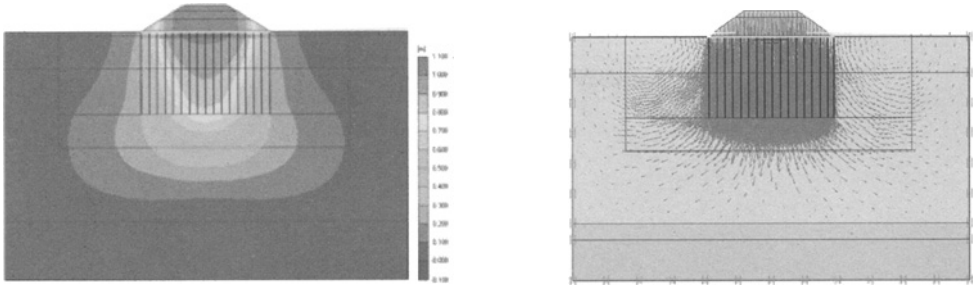
Depth (m)	Soil Type	c (kN/m^2)	ϕ(°)	γ(kN/m^3)	e_o	C_c
0-23	very soft clay	6-15	1	14	2	0,9
23-25	soft clay	15-35	1	15	1,8	0,8
25-30	médium clay	35-55	1	16	1	0,75
below 30	stiff to very stiff clay	55-150	1	16		

STABILITY AND SETTLEMENT ANALYSIS BEFORE TEST

Embankment stability and ground settlement analysis was performed before field test to ensure that ground soil has adequate bearing capacity, to ensure that the trial embankment stable against slope failure and to predict immediate and consolidation ground settlement. Stability and settlement analysis was performed using analytical and numerical methods. The numerical method analysis was conducted using finite element method utilizing a commercial program called PLAXIS (Brinkgreve & Vermeer, 1998). The analysis was performed for the first stage fill until an embankment height of 2.5 m and for the second stage fill until a final embankment height of 3.25 m.

In analytical method, immediate settlement was calculated by modeling soil as elastic material whereas consolidation settlement was calculated using Terzaghi's one dimensional consolidation theory (Terzaghi, 1967). Modulus elasticity for immediate settlement calculation was obtained from correlation of modulus elasticity with overconsolidation ratio and plasticity index from Jamiolkowski (1979). In consolidation analysis, bamboo piles were modeled as group of piles and stress increase due to embankment load was assumed to follow load transfer of friction pile proposed by Tomlinson (1977). In finite element analysis, subsurface soil and embankment were modeled as elastic-plastic solid material using Mohr-Coulomb failure criteria whereas bamboo piles and mattress were modeled as elastic-plastic springs and elastic plastic beams respectively. Stability analysis was performed using c-ϕ reduction method provided in the program and settlement analysis was performed using modulus elasticity of soil in undrained and drained condition and by modeled pore water pressure dissipation.

Stability analysis showed that safety factor of the embankment at end of construction was 1.6 (for embankment height 2.5 m) and 1.3 (after additional fill to 3.25 m). Using analytical method, immediate settlement was predicted to be approximately 35 cm and consolidation settlement was predicted to be approximately 54.5 cm, whereas using finite element method, immediate settlement was predicted to be approximately 40 cm and consolidation settlement was predicted to be approximately 58 cm. Output of settlement analysis using finite element method is presented in Figure.

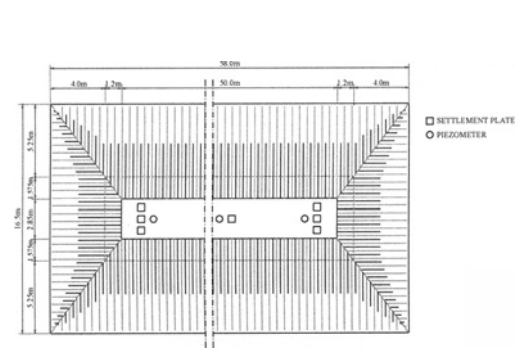


(a) Deformation Pattern (Shading) (b) Deformation Pattern (Vector)

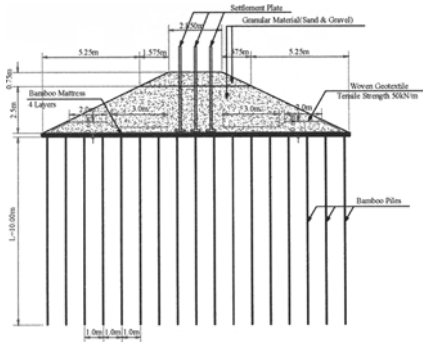
Figure 1. Settlement prediction using finite element method

Construction of trial embankment

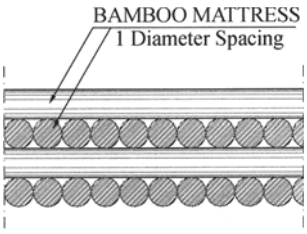
The trial embankment was 58 m long, 16.5 wide and 3.25 m high as shown in Figure 2. Ground soil was reinforced by 10 m depth bamboo piles and 4 layers bamboo mattress. Bamboo used for the trial embankment had 5 to 10 cm diameter. Woven geotextile having tensile strength 50 kN/m was used as separator between fill material and bamboo mattress. There was no special treatment on bamboos before used since after construction bamboos were always in soaked condition and therefore were preserved (Frick, 2004). As shown in Figure 2 (a) and Figure 2 (b) seven settlement plates and three piezometers were installed to monitor ground settlement and pore pressure dissipation below embankment respectively.



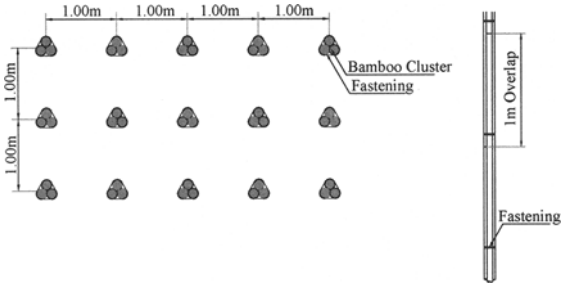
(a) Plan view of the trial embankment



(b) Cross section of the trial embankment



(c) Detail of bamboo mattress



(d) Detail of bamboo pile

Figure 2. Detail of the trial embankment

Construction of trial embankment was performed by installing bamboo piles and then placing bamboo mattress above the piles. After geotextile was laid above bamboo mattress, granular material as fill material was placed and compacted layer by layer. Embankment fill was performed in two stages, first stage until embankment height of 2.5 m and second stage was to add fill until final height of embankment was 3.25 m. Construction of the trial embankment is presented in Figure 3.

(a) Installation of bamboo piles

(b) Installation of bamboo mattress

(c) Embankment fill

(d) Trial embankment at final condition

Figure 3. Construction of trial embankment

Monitoring

Monitoring of embankment stability and ground settlement was performed from May 26, 2005 to September 6, 2005. Stability monitoring showed that trial embankment did not exhibit slope failure as well as bearing capacity failure that was conformed to prediction analysis. Ground settlement monitoring showed that consolidation settlement until the end of observation was relatively uniform and close to calculated settlement. Average rate of consolidation for the settlement plates decreased from 9 mm/day at the beginning of consolidation process to 0.9 mm/day at the end of observation. Based on timerate consolidation settlement calculation, after 3 months (at the end of observation) the amount of consolidation settlement reached 30 % of total consolidation settlement. Summary of settlement observation for all settlement plates and predicted timerate consolidation is presented in Figure 4. From the observation it is proven that pile-mattress system reliable to

act as ground reinforcement and to distribute settlement more uniformly and the calculation method was also fit with actual condition.

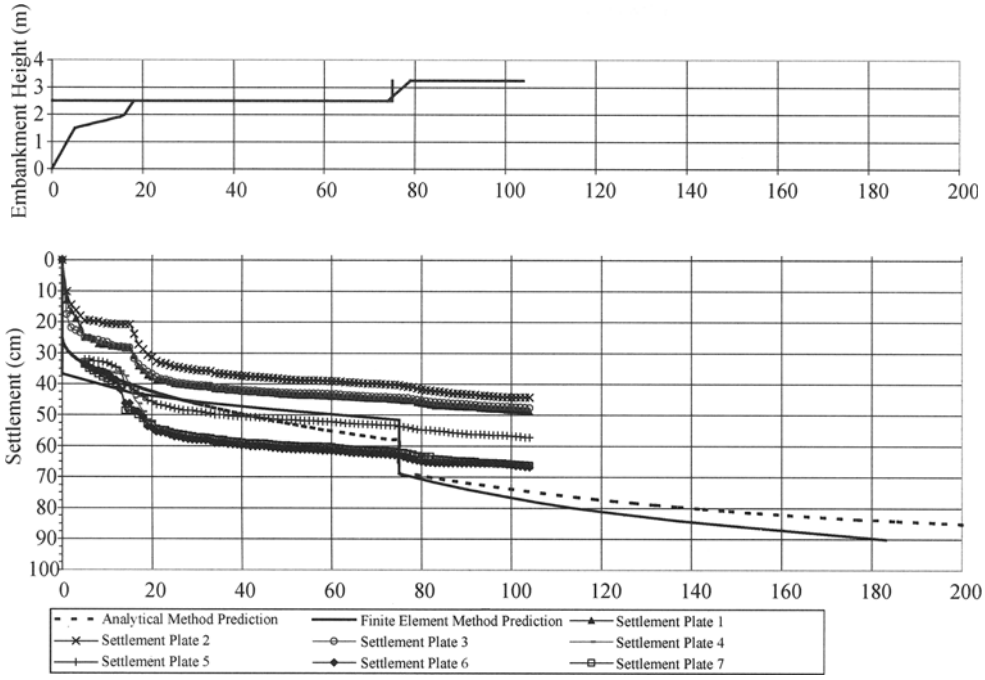


Figure 4. Monitoring and prediction settlement result

CONCLUSION

1. From the observation, it is concluded that using bamboo pile-mattress system:
   - Reinforced soil has adequate bearing capacity to sustain embankment load
   - Embankment has adequate slope stability
   - Consolidation settlement is relatively uniform (14.9 cm to 17.5 cm after 3 months observation)
   - After 3 month, average rate of consolidation is decreased from 9 mm/day to 0.9 mm/day and when compared to settlement prediction, at 3 month, timerate consolidation has reached 30%.
2. Bamboo pile-mattress system is proven to be reliable and hence can be used as ground reinforcement for coastal embankment having height 3.25 m on a thick soft soil layer.

ACKNOWLEDGEMENT

The full scale test was performed by PT. Hutama Karya (Persero), PT Citra Marga Nusaphala Persada Tbk., and Lembaga Penelitian dan Pengabdian Masyarakat (LPPM) of Bandung Institute of Technology as a collaborative research in 2005. Construction of trial embankment was performed by PT. Hutama Karya (Persero).

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