Case Study on Soft Soil Improvement using Innovative and Cost-Effective Reinforcing Techniques

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Abstract. This paper describes, discusses and compares three new innovations of reinforcement systems for soft soils: (a) a combination of gridded matrass and piles of bamboo, (b) a combination of matrass and piles of bamboo, and (c) a group of mini piles connected by small H-beams with a compacted top layer to hold the top mini piles. First, illustrations and applications of the three types of reinforcement are described from three full-scale field works. Technical bases for the three types are presented, while technical comparisons are discussed next. Finally, conclusions are developed. The case studies, analysis results, and full-scale fieldwork verifications show that the three reinforcement systems have worked properly. Each system has its own advantages and disadvantages in terms of construction duration and cost, capability/effectiveness and material availability, especially in rural areas.

Keywords: *soft soil; soil improvement; soil reinforcement; mini pile; gridded matrass; matress; simple technology.*

1 Introduction

In recent years, various geotechnical reinforcement systems in problematic soils, particularly soft soils, have been well developed. Through several experiences in embankments on soft soils, efforts have been made to establish new improved reinforcement systems. In this paper, three types of soft soil reinforcements are proposed, which offer the capability to overcome problems of embankments on soft soils. The three types of innovated reinforcements from three study cases–Gridded Matrass and Mini Piles, Matrass and Mini-Piles Irsyam, *et al.* [1], and Top Connected Mini Piles–will be presented and technically discussed respectively. We present three case studies, which show that all three proposed methods have succesfully been built. This paper also discusses and technically compares the three methods.

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2 Problem Definition–Soft Soil

On embankment constructions over soft clays, the height of the embankment that corresponds to the weight of the embankment fill directly induces an increase in soil stresses, as well as pore water pressures that continously accumulate. In this state, the loading is in undrained condition, where its behavior is similar to viscous fluid and leads to a critical condition of the corresponding structure, particularly bearing capacity problems.

As excess pore pressure starts dissipating, the volume reduces. Consequently, consolidation settlement begins to occur. Emphasis should be put on the stress transfer that sometimes requires considerable time, which influences the failure mechanism (progressive failure). During this process, additional strain often occurs when the soil has reached its failure state [2].

3 Case Studies

3.1 Gridded Matress and Mini-piles Application

In this first case, the discussion is focused on the embankment construction for a causeway in North Sumatra with an approximate length of 400 meters and an approximate height of 6.3 meters (Figure 1). In this case, the challenging part during the design phase was the geotechnical condition of the site, which was dominated by very soft to soft silty clays to depths of 22 to 30 meters below the existing ground surface (Figure 2), which led to a critical condition at the end of construction. At the beginning of construction, a prefabricated vertical drain (PVD) was installed for this solution system.

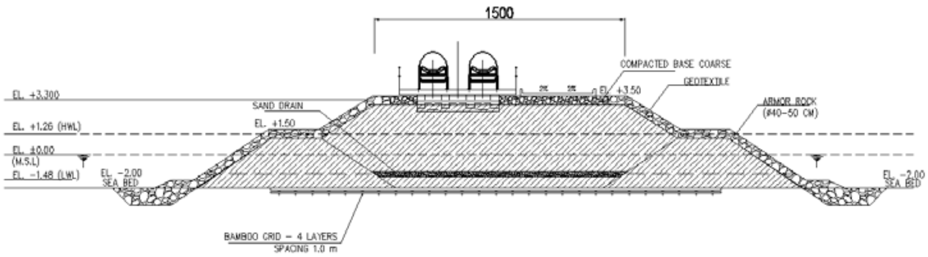


Figure 1 Cross Section of Planned Causeway Embankment.

For analysis, the undrained strength parameters for each layer were determined based on field vane shear test results, laboratory test results and N-SPT values (Figure 3). The groundwater level was approximately at +1.25 meters above ground surface. Additionally, the results of the laboratory tests are presented in (Figures 3 and 4).

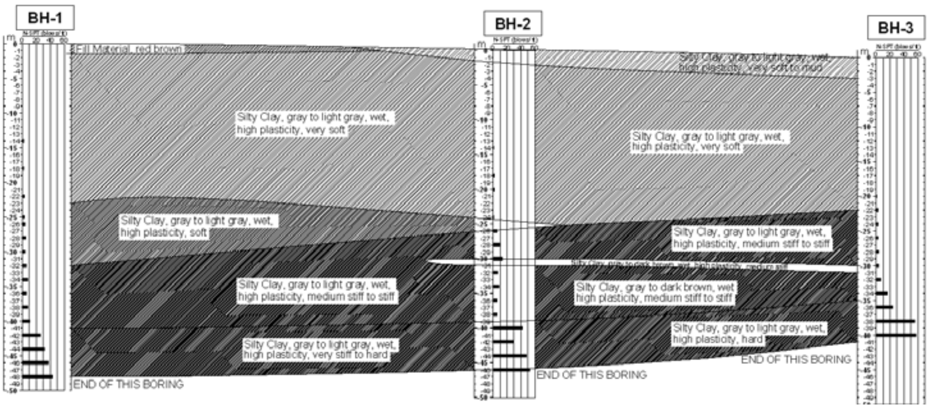


Figure 2 Soil Layering of Pangkalan Susu Case Study Site.

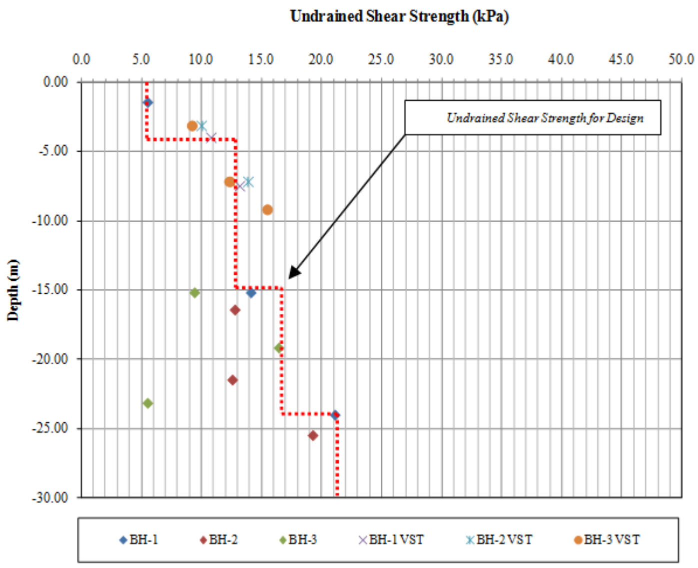
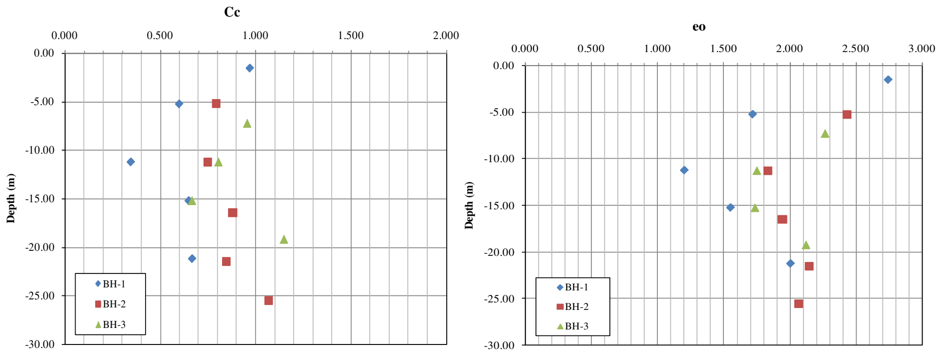


Figure 3 Relationship Between Undrained Shear Strength and Depth.

The gridded matrass to support the embankment is detailed in Figure 5. It consisted of 4 layers of bamboo pile that were set in a grid pattern with a space of 1 x 1 m^2 and placed and considered as an embankment foundation to increase the stability and stiffness of the subgrade. This type of reinforcement was proved to be effective.



(a) (b)

Figure 4 Laboratory Test Results for Various Depths: (a) Coefficient of Compressibility (b) Initial Void Ratio.

Figure 5 Gridded Matrass Bamboo for Soft Soil Reinforcement.

Table 1 Soil Parameters for Analysis of Case 1.

Name	γ_{unsat} [kN/m^3]	γ_{sat} [kN/m^3]	$k_x = k_y$ [m/day]	ν [-]	E' [kN/m^2]	c [kN/m^2]	ϕ [°]	c' [kN/m^2]	ϕ' [°]
Very Soft Clay	9.5	14	0.0036	0.33	1500	5	0	2	12
Very Soft Clay	10	14	0.0036	0.33	2700	9	0	2	14
Very Soft Clay	10	15	0.0036	0.33	4350	14.5	0	4	16
Soft Clay	10.5	15.5	0.0036	0.33	6300	21	0	4	18
Soft Clay	10.5	15.5	0.0036	0.33	8400	28	0	5	19
Stiff Clay	11	16	0.0036	0.33	27000	90	0	7	26
Fill Material	14.8	16.5	0.0001	0.33	20000	70	0	10	28

A stability analysis was performed using Plaxis 2D v.8.2. soil parameters employing the Mohr-Coulomb model. The results are presented in (Table 1). In addition, Terzaghi 1-D consolidation theory was employed to predict the consolidation settlement of the embankment. The embankment with gridded matrass reinforcement and the construction sequences combined with the soil replacement from the existing surface were modeled. The embankment was constructed in three stages, with increments of 3 meters, 1.75 meters, and 1.5 meters in height (Figure 6). The analysis results show that the safety factor at the end of construction of the reinforced embankment was 1.29.

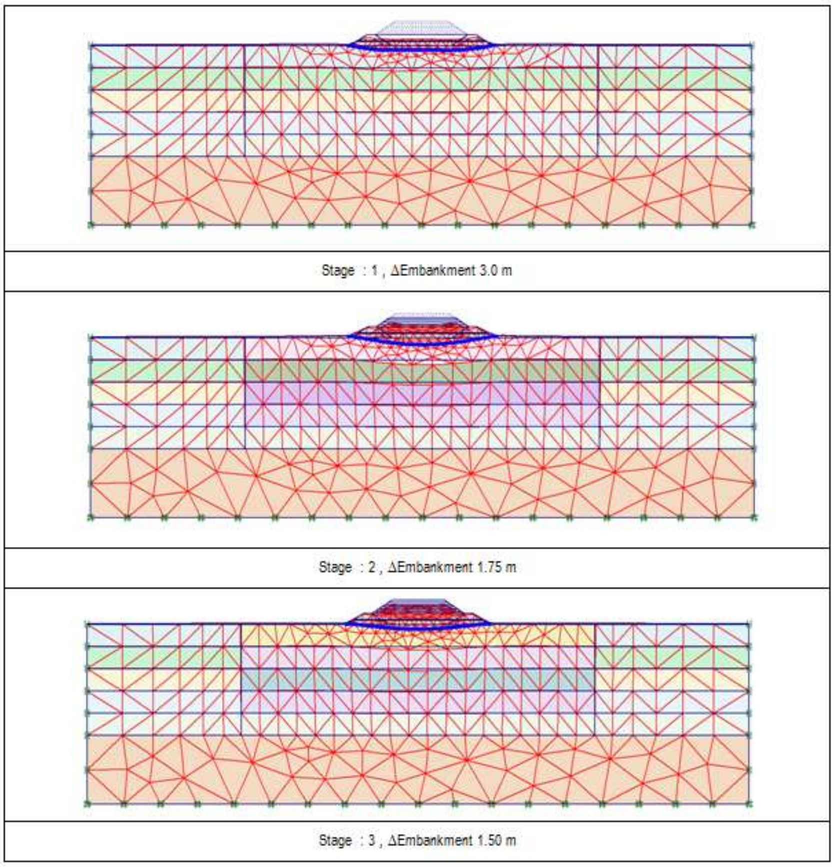


Figure 6 Construction Stages of The Embankment Analysis.

The results of the settlement analysis are summarized in Table 2. They show that the elastic settlement and the consolidation settlement with the finite element method were 157 cm and 172 cm, respectively. The analysis result of consolidation settlement by the 1D-Terzaghi theory was 182 cm, which is comparable to the finite element analysis result. Stability performance can significantly be increased by combining the gridded bamboo with matrass bamboo piles.

Table 2 Analysis Results of Settlement Prediction.

No.	Analysis Type	Settlement			Total
		Stage 1	**Stage 2**	**Stage 3**	
1	Elastic settlement – FEM	105 cm	34 cm	18 cm	157 cm
2	Consolidation settlement – FEM	85 cm	49 cm	37 cm	172 cm
3	Consolidation settlement – Terzaghi 1D	107 cm	42 cm	33 cm	182 cm

Field observations during construction showed that the values were comparable to field conditions. Unfortunately, field settlement records are still not available. However, the field conditions after construction showed satisfactory performance of the embankment. Figure 7 illustrates the embankment after the end of construction.

Figure 7 Causeway embankment after construction in Pangkalan Susu.

3.2 Matrass and Piles of Bamboo Combination (Taken from publication of Irsyam, *et al.* [1])

A highway road embankment was constructed on a high deposit of soft soil in Tambak Oso, Surabaya, East Java. According to the soil investigation report (Irsyam, *et al*. [1]), very soft to soft soil was discovered with an approximate thickness of 30 meters. Within this soft layer, tip cone resistance (q_c) ranged from 1-4 kg/cm^2. The groundwater level was approximately at the existing ground surface (elev. 0.0 meter).

A reinforcement system which consisted of matrasses and piles of bamboo was constructed. Prior to the construction and application of the embankment with reinforcement, trial embankment experiments had been conducted. Its performance was observed by placing instrumentation to monitor ground settlement and pore water pressure. After settlement records for 3 months had been obtained, they were compared with finite element analysis and with the analytical results.

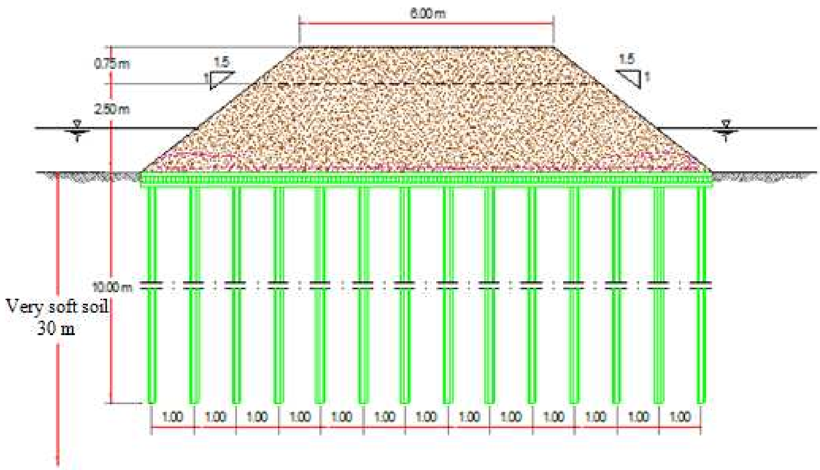


Figure 8 The Full Scale Trial Embankment Model Using a Combination of Matrasses and Piles of Bamboo [1].

Table 3 Soil Parameters for Analysis in Case 2 [1].

Name	c_{ref} [kN/m^2]	ϕ [°]	γ [kN/m^3]	e_o [-]	c_c [-]
Very soft clay	5	0	14	2	0.9
Soft clay	9	0	15	1.8	0.8
Medium clay	14.5	0	16	1	0.75
Stiff to very stiff clay	21	0	16		

As shown in Figure 8, the full scale trial embankment was reinforced by matrasses and piles of bamboo. The matrass systems were assembled from four layers of bamboo and intersected with each another to form an embankment foundation. They were combined with piles consisting of three vertical bamboo poles with a length of 10 meters and placed at a distance of 1 meter from each other. The total trial embankment height was 3.25 meters, which was constructed in two consecutive stages. The first stage was carried out to achieve a height of 2.5 meters, while the second stage was started after 75 days by adding embankment height until reaching a height of 3.25 meters (Figure 9). During construction, instrumentation reading was also conducted.

Figure 9 Trial Embankment Construction [1].

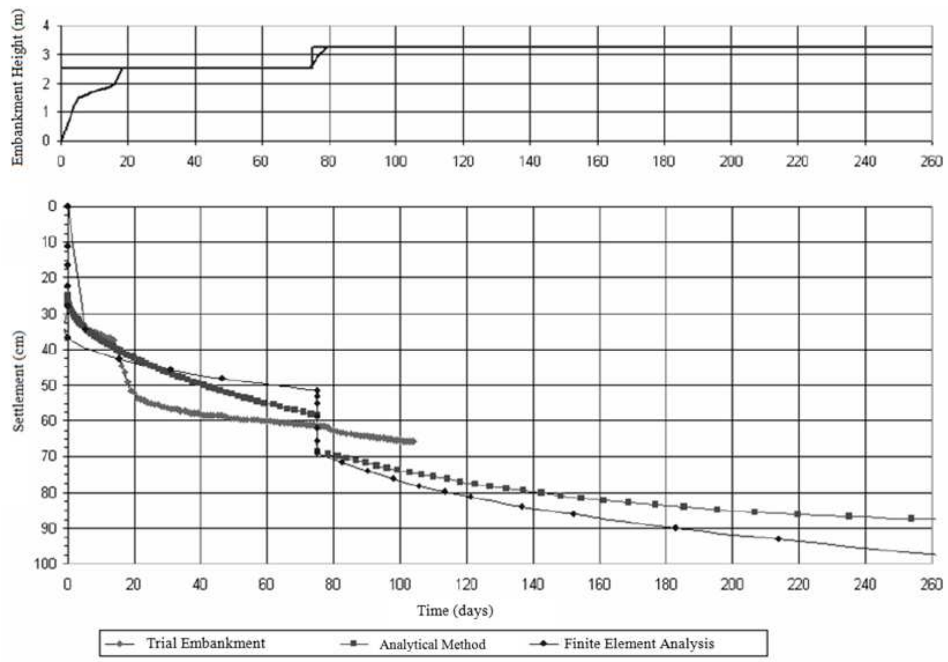


Figure 10 Settlement Comparison of Field Monitoring and Analytical Results [1].

The results of this experiment to determine whether the reinforcement was reliable or not, are presented in Figure 10. To verify the settlement readings from the field, two analytical results are included. The soil parameters that were used in the analysis are summarized in Table 3. Based on this experiment, it can be concluded that the embankment with 3.25 meters height was stable in the large deposit of soft soil with application of matrasses and piles of bamboo.

3.3 A Group of Mini-Piles of Woods and/or Mini Spun Piles Connected by H-beam Application

From the beginning to the middle of 2013, a jetty embankment with an approximate height of 1 meter was built on soft clay in Riau. The ground water table was approximately at the ground water surface level (0.0 meter). Special care was taken because several expensive generators for a power plant would pass over the embankment. Similar to the previous cases (Figure 11), the embankment would be put on a large deposit of soft clay. To avoid bearing capacity failure during both construction and service life, several reinforcements had been tried but unfortunately none increased the stability to a satisfactory degree.

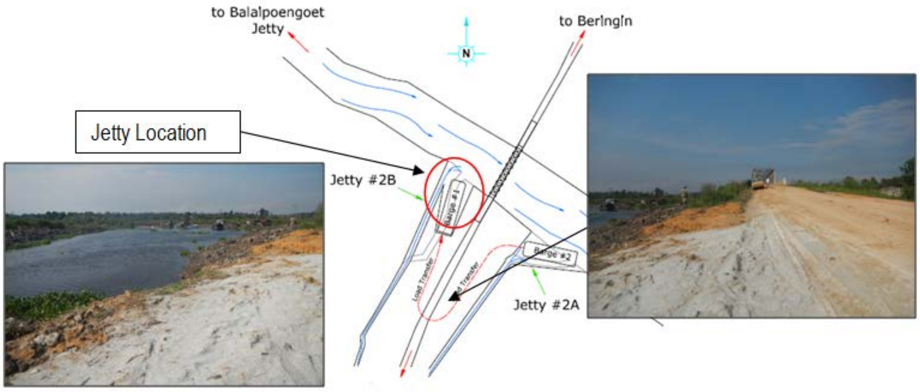


Figure 11 Illustration of Site Location and Conditions.

Later on, a new idea came up, to apply a combination of mini-piles of logs and mini spun piles, wooden blocks, H-beams, and sand bags. Systematically, the consideration of using these as reinforcement elements took into account the performance and mechanism of load carrying caused by the turbine/generators in order to avoid any factor leading to failure. The axial load would be retained by mini-piles which were set to a depth of 6 meters and placed in a grid pattern of 1 x 1 meter^2. To increase the mechanism of group responses and to increase the rigidity of the pile tops, wooden blocks were added, deeming that the composition of mini-piles with such a pattern plays an important role in assuring stability. The group of mini-piles was next connected by H-beams on the heads of the piles (Figure 12) in order to sustain any lateral load induced by the embankment and passing turbine/generator load.

Figure 12 Embankment Construction.

Table 4 Soil Parameters for Analysis of Case 3 (Total Parameter).

Name	Type	γ_{unsat} [kN/m^3]	γ_{sat} [kN/m^3]	$k_x = k_y$ [m/day]	ν [-]	E_{ref} [kN/m^2]	c_{ref} [kN/m^2]	ϕ [°]
Embankment-Sand	Drained	16	18	1	0.33	40000	1	32
Embankment-Clay	Undrained	16	18	0.0001	0.33	25000	56	0
Very Soft Clay	Undrained	12.1	14	0.0001	0.33	2000	10	0
Soft Clay	Undrained	13.6	15.5	0.0001	0.33	5000	25	0
Soft Clay	Undrained	14	16	0.0001	0.33	10000	50	0
Stiff Clay	Undrained	16.5	18	0.0001	0.33	29733	148.67	0
Firm Clay	Undrained	18.4	20.2	0.0001	0.33	60000	250	0

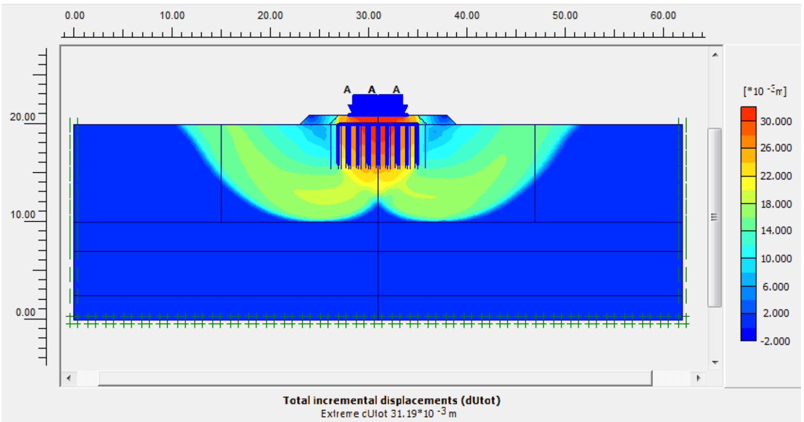


Figure 13 Failure Mode of Finite Element Analysis Model.

To investigate the effectiveness and mechanism of the reinforced embankment, a finite element analysis was carried out. CPT data were taken; they are presented in Table 4. The results of the analysis show that the embankment was stable, represented by a safety factor of 1.28 and predicted failure mechanism as shown by Figure 13. Field construction and the successful passage of the turbine/generators has proven the results of the analysis and the effectiveness of the reinforcement system.

4 Conclusion

Three different embankment cases on soft soil have been elucidated in the previous section. Moreover, reinforcement with a combination of bamboo piles has been proven to provide a potential solution to solve the low bearing capacity of soft soils in embankment construction. The numerical analysis and full-scale field test discussed in this paper show how the three reinforcement systems can technically improve the stability and safety of an embankment.

References

[1] Irsyam, M & Krisnanto, S., *Full Scale Test and Analysis of Bamboo Pile-Mattres Reinforcement System for Road Embankment on Soft Soils in Tambak Oso Surabaya (Text in Indonesian)*, Forum Teknik Sipil, **XVIII**, 2008.

[2] Weech, C.N. & Lister, D.R., *Highway Embankment Construction Over Soft Soils in The Lower Mainland of British Columbia*, Annual Conference of the Transportation Association of Canada, Vancouver, British Columbia, 2009.