Application of reinforcing techniques on soft ground using geosynthetics and bamboo-net in Korea

Yang, Kee-Sok: *Director-General PE, Korea Port Engineering CORP.*
Ham, Tae-Gew: *Senior Researcher*, Geotechnical Engineering Research Division, Korea Institute of Construction Technology
Cho, Sam-Deok: *Research Fellow*, Geotechnical Engineering Research Division, Korea Institute of Construction Technology
You, Seung-Kyong: *Associate Professor*, Dept. of Civil Engineering, Myongji College

Key words: bamboo net, geosynthetics, on-site loading test, bearing capacity ratio (BCR)

ABSTRACT: The reinforcing technique of soft ground by geotextiles, geogrids, and bamboo-net is a common practice to obtain a trafficability of construction vehicles on soft ground in Korea. Nevertheless, design method and codes for surface remediation have not been well researched. In order to understand the behavioral characteristics of geosynthetics-reinforced ground, application examples for surface remediation were investigated and large scale plate loading tests were performed on soft ground using bamboo-net and geosynthetics as a surface reinforcements. Also on-site loading test for the bamboo-net reinforced system produced by a variety of binding methods was conducted to evaluate the engineering characteristics and optimal binding method of bamboo-net. And bearing capacity ratio(BCR) distribute from 7.26 to 7.77 for bamboo-net and from 2.51 to 2.75 for geotextile. From on-site loading test results, it was recognized that the maximum strength of bamboo-net system was measured in the range of 2.10kN-11.02kN depending on its interval and the binding force of bamboo joint using steel wire was very excellent compare with tie cable and PP band.

1. Introduction

Thanks to the rapid industrialization and economic d evelopment since the 1960's, Korea has quickly gro wn into the high-ranked trading country in the world. As most of its trading volume uses seaports and airports, the port infrastructure of Korea has been constructed at a fast pace. In general, one of the most widely used surface treatment methods for very-soft ground is to reinforce the surface layer with non-stiff materials, such as geo-textiles, geo-grids and with stiff reinforcements, such as bamboo-nets, and use the conveyor belt or the forced dry sand installation system to subbase soil the ground. Due to the absence of a reasonable surface treatment design technique taking the behavior characteristics of the ground and the material characteristics of the reinforcement into consideration during construction, however, experiential bearing capacity review based on track records in construction is applied to design.

2. Scope of research

This study determined the load-deformation behavior of fasteners through field membrane testing of bamboo-nets and the load-deformation behavior in cyclic loading. Also, in a surface treatment field where the reinforcement and subbase soil were installed, the bearing capacity characteristics of the dredged fill ground, which was reinforced with bamboo-nets and geo-textiles and subbase soiled, was evaluated in a large plate loading test, and the possibility of equipment operations was predicted in case the soft ground improvement method was applied, and the Bearing Capacity Ratio(BCR) was analyzed to evaluate the bearing capacity characteristics before and after surface reinforcement.

3. Field member force test of the bamboo-net

3.1 Test outline and test procedure

The member force test is a basic member force evaluation test for characterizing the behavior of the bamboo-net in relation to its strength at a site where very-soft surface treatment is being done when loads are applied. In this loading test the ground strength is "0," in other word, only the member force of the bamboo-net is applied. The member force of the bamboo-net was measured in the on-site loading test for the bamboo-net. The actual-size fasteners used were PP bands, Tie

-Cables, and wires, and the intervals of the bamboo-net were 0.4m×0.4m, 0.5m×0.5m, and 0.7m×0.7m. To determine the dynamic characteristics of the bamboo-net, the test was conducted with the double joint located at the center and on the outside in consideration of the site conditions as shown in Table 1. The conceptual map of the loading test device used for the test is illustrated in Figure 1. The test procedure can be summarized as follows:

① Arrange the bamboos so that they crisscross each other perpendicularly, and make the bamboo-net so that the vertical and horizontal intervals are uniform.

② Place the bamboo-net horizontally on the table.

③ Install the loading plate, the load cell and the lower plate, adjust the zero point, and set up the load transfer device.

④ Use the drive motor and the reduction gear to apply the load while making sure that the load transfer rate is 2cm/min, and measure the applied load and displacement at a certain interval.

Table 1 Dynamic characteristics evaluation test conditions of bamboo-nets

Classification	bamboo-net interval	fastener	Remarks
Case 1	0.4m×0.4m	Steel wire	double joint at the center
Case 2	0.5m×0.5m	Steel wire	
Case 3	0.7m×0.7m	Steel wire	
Case 4	1.0m×1.0m	Steel wire	
Case 5	0.5m×0.5m	Tie Cable	
Case 6	1.0m×1.0m	Tie Cable	
Case 7	1.0m×1.0m	PP band	
Case 8	0.4m×0.4m	Steel wire	double joint outside
Case 9	0.5m×0.5m	Steel wire	
Case 10	0.7m×0.7m	Steel wire	
Case 11	1.0m×1.0m	Steel wire	

As the result of the loading test may vary depending on the location of the double joint of the bamboo-net, the loading test was conducted by having two locations of the double joint: i.e. center and outside.

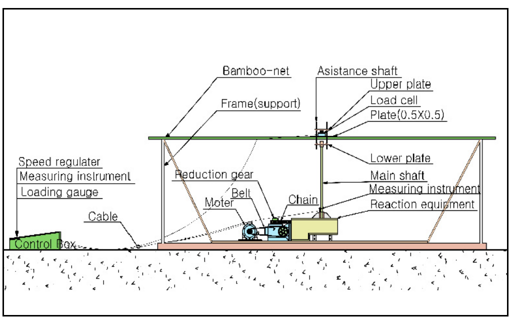


Figure 1 Conceptual map of the loading test device

3.2 Test results and behavior analysis

For the field member force test for the stiff reinforcement, loading tests were conducted for a total of 11 cases with the intervals from the fastener varying. The resulting load-displacement characteristics are shown in Table 2. The maximum load of the bamboo-net varied between 2.10kN and 11.02kN depending on the interval, and the narrower the interval of the bamboo-net, the greater the maximum load. As the interval grew, the maximum load declined. It is believed to be because the bearing capacity is manifested in proportion to the strength of the reinforcement. Also, the displacement at this time ranged between 181mm and 604mm.

After the measurement of the maximum load, secondary compression was done, and the typical results are illustrated in Figure 1. According to the test results, the maximum load during the secondary compression ranged between 4.60kN and 10.46kN depending on the interval, and it is 73% ~ 95% of the maximum load during the initial compression. When the maximum load of the bamboo-net is reached, part of the bamboos near the load will split along the length of the bamboos, not just cut. Therefore, it is thought to be attributed to the residual resistance of the members destroyed during the secondary compression and the resistance of the members other than the destroyed members.

Table 2 Maximum load-displacement by test condition

Classification	fastener	maximum load(KN)		displacement(mm)		Remarks
		compression	recompression	compression	recompression	
0.4×0.4	Steel wire	11.02	10.46	599	595	center
0.4×0.4		5.94	5.06	500	358	outside
0.5×0.5		7.47	6.79	604	424	center
0.5×0.5		5.67	4.15	430	464	outside
0.7×0.7		4.48	4.60	453	409	center
0.7×0.7		3.32		342		outside
1.0×1.0		3.66		498		center
1.0×1.0		3.32		477		outside
0.5×0.5	tie cable	4.21		346		center
1.0×1.0		2.68		481		center
1.0×1.0	PP band	2.10		181		center

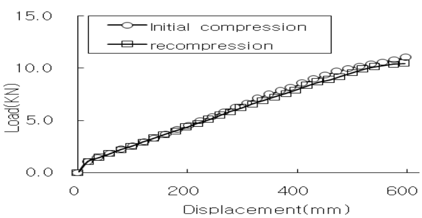
3.3 Trafficability of construction vehicles

In the surface treatment method utilizing the bamboo-net, the bamboo-net resists the load of construction vehicles installed on top along with the clay layer, thereby ensuring the trafficability of construction vehicles. The trafficability of construction vehicles is evaluated by comparing the ground contact pressure of the vehicles transferred through the subbase soil layer with the resistance of the bamboo-net and the ground.

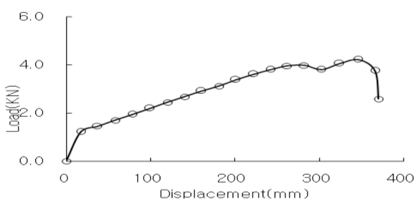
Accordingly, to evaluate the resistance of the bamboo-net alone excluding the resistance of the ground, the above load-displacement characteristics must be evaluated as stress-displacement characteristics.

To this end, this analysis of characteristics took advantage of the area of the loading plate used when loads are applied to the bamboo-net system to evaluate the maximum stress for each test condition, and the results are shown in Table 2, and the results of the double wire fastening are illustrated in Figure 2 (a).

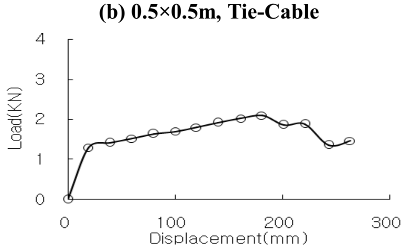
In case of wire fastening, if the bamboos are fastened at the center for each interval, the maximum compression stress was 14.6~44.1(KN/m^2), and in consideration of the fact that the ground contact pressures of the Dozers (40 KN,90KN), mostly used during the primary molding were 20.0(KN/m^2) and 27.8(KN/m^2) respectively, if the interval of the bamboos was less than 0.5×0.5m, they were able to be loaded without any subbase soil, and in case of other intervals (0.7×0.7m, 1.0×1.0m), the loadability must be evaluated in consideration of the stress distribution due to the subbase soil and the strength of the original soft ground.



(a) 0.4×0.4m, Steel wire



(b) 0.5×0.5m, Tie-Cable



(c) 1.0×1.0m, PP Band

Figure 3 Load-displacement curve of the bamboo-net

4. On-site large plate loading test

4.1 Outline of the test

To characterize the bearing capacity of the dredged fill ground whose surface layer was reinforced by the bamboo-net and geo-textiles and for which molding was done, the method of testing the bearing capacity of the dirt with appropriate loads applied was used to conduct the large plate loading test (loading plate area=1.0m×1.0m, laminated) by subbase soul thickness of the reinforcement as shown in Table 3.

Table 3 Test conditions by loading test section

Section	A	B	C	D	E	F	G	H	I
Reinforcement	geotextiles(150 KN/m^2) 2 layers			geotextiles(150KN/m) 3 layers			bamboo-net (0.4×0.4)		
Subbase soil height	0.5m	1.0m	1.5m	0.5m	1.0m	1.5m	0.5m	0.75m	1.0m

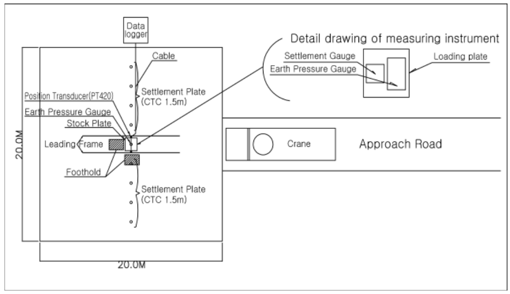


Figure 3 Detail drawing of the measuring instrument during the on-site large plate loading test

4.2 Bearing Capacity Ratio by Reinforcement

To understand the reinforcement effect of the reinforcement and the thickness of the subbase soil, the Bearing Capacity Ratio (BCR) was evaluated. The Bearing Capacity Ratio is the ratio of the allowable bearing capacity of the original ground before reinforcement to that of the reinforced ground. The greater the Bearing Capacity Ratio, the greater the reinforcement effect of the reinforcement and the subbase soil.

$$BCR = q_a / q_0 \qquad (1)$$

Where, BCR: Bearing Capacity Ratio, q_a: Allowable bearing capacity of the reinforced ground (assessed through the loading test), q_0: Allowable bearing capacity of the original ground before reinforcement

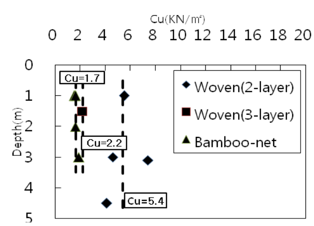


Figure 4. Undrained shear strength by depth

Table 4 Results of the BCR (Bearing Capacity Ratio) assessment by subbase soil thickness and by reinforcement

Section	Subbase soil thickness (m)	Cu (KN/m^2)	Nc	q_0 (KN/m^2)	q_a (KN/m^2)	BCR
geotextiles 2- layers	0.50	5.40	5.300	14.31	38.34	2.679
	1.00	5.40	5.300	14.31	35.88	2.507
	1.50	5.40	5.300	1.431	39.33	2.748
geotextiles 3- layers	0.50	2.20	5.300	5.83	29.90	5.129
	1.00	2.20	5.300	5.83	30.64	5.255
	1.50	2.20	5.300	5.83	38.52	6.608
Bamboo-net (0.4X0.4)	0.50	1.70	5.300	4.51	32.71	7.262
	0.75	1.70	5.300	4.51	33.03	7.332
	1.00	1.70	5.300	4.51	35.02	7.773

The Bearing Capacity Ratio (BCR) by reinforcement and by subbase soil thickness ranged between 2.51 and 7.77. Also, the 3-layer section, the bamboo-net section and the two-layer section were compared. The results showed that the BCR of the 3-layer section was 2.1 on the average, while that of the bamboo-net section was 2.9. Accordingly, as the stiffness or tensile strength of the reinforcement increased, the bearing capacity increased as well.

The bearing capacity ratio according to the thickness of the subbase soil was reviewed, and the results showed that there was variation by reinforcement type, but in proportion to the thickness of the subbase soil. Also, the correct tensile strength applied during design cannot be determined in consideration of the 3-layer geotextiles (Ta=113 KN/m), and the bamboo-net (Ta=120.6 KN/m), but the Bearing Capacity Ratio (BCR) of the bamboo-net section increased somewhat due to the stiffness effect of the bamboo-net.

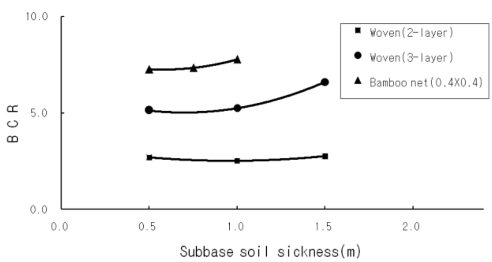


Figure 5 BCR by subbase soil thickness

5. Conclusions

As part of the research to systematically establish the surface treatment design techniques fit for domestic sites, this study analyzed cases of surface treatment, compared the results of the on-site stiff reinforcement member force test and the on-site large plate loading test, and reached the following conclusions:

1. The results of the field member force test of stiff reinforcements showed that the maximum load during secondary compression when loads are applied to the stiff reinforcement ranged between 4.60kN and 10.46kN depending on intervals, which is 73% ~ 95% of the maximum load during the initial compression. It clearly tells us that the bamboo-net can be used as reinforcement for the surface layer.
2. Despite the different types of surface layer reinforcements, the ground bearing capacities were similar. This is believed to be attributed to the use of stiff reinforcements with great reinforcement on very-soft ground, and the use of non-stiff reinforcements on very-soft ground with a relatively good ground strength to secure the trafficability of construction vehicles.
3. The results of the on-site large plate loading tests showed that the allowable bearing capacity by reinforcement and by subbase soil thickness ranged between 29.9 and 39.3 KN/m^2. Also, the Bearing Capacity Ratio (BCR) of the ground after reinforcement of the original ground strength ranged between 2.50 and 7.77. The greater the stiffness of the reinforcement, the greater the improvement of the bearing capacity.
4. As the result of the large plate loading test in sites reinforced with stiff reinforcement, the effect of the original ground, the tensile strength effect, the subbase soil effect, and the stiffness effect are working at the same time, a design method taking relevant design parameters into consideration is in order.

Acknowledgment

This study is part of the construction technology innovation project called the “Research on the Optimum Design Technique for soft Ground Surface reinforcement.”

References

1. G.G. Meyerhof, 1981, "The Bearing Capacity and Settlement of Foundation," Technical University of Nova Scotia, pp223-229
2. K.H. Khing et al., 1994, "Foundation on Strong Sand Underlain by Weak Clay with Geogrid at the Interface", Geotextile and Geomembranes 13, pp199-206
3. J.N. Mandal & H.S. Sah, 1992, "Bearing Capacity Tests on Geogrid-Reinforced Caly", Geotextile and Geomembranes 11, pp327-333
4. Yamanouchi (1985), "Recent developements in the used synthetic geofabrics and geogrids”, Symposium on Recent Developements in Ground improvement techniques. Bankok, pp.205-224.