Application of geosynthetics for the improvement of horizontal bearing capacity of piles

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ABSTRACT: This study, in consideration of the background shown above, has been made on the application of geosynthetics for the pile foundation on the purpose of improving the horizontal bearing capacity of a pile foundation, and property of compound foundations that are composed of geosynthetics and the piles. The objective of this thesis is, as one of the study results, to report the result of bearing capacity experiment conducted to verify the effectiveness of geosynthetics, using a pile model in sandy ground as a first step of an experiment. As a result of the experiment, we have confirmed that the horizontal bearing capacity increased in proportion to the length of geosynthetics and improvement depth (numbers of layers of geosynthetics). Therefore, the geosynthetics are effective measures in increasing the horizontal bearing capacity of piles.

1 INTRODUCTION

Pile foundation has a very small horizontal bearing capacity compared to its vertical because of its long and slender form. However, in most cases, the number and dimension of pile is determined by its horizontal bearing capacity since the new horizontal design load is about two to three times of the past seismic design load based on recent major earthquakes. Therefore, it implies the importance of evaluating the horizontal bearing capacity of pile and its methods of improvement.

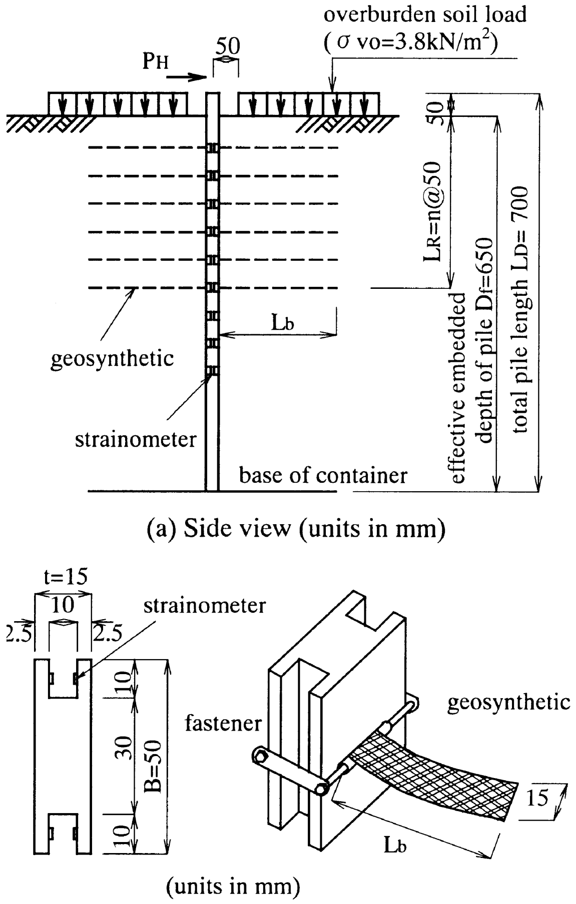
This study is about the application of geosynthetic materials in improving horizontal bearing capacity of piles and the bearing capacity characteristics of hybrid foundation structure composed of geosynthetic and pile. This paper reveals the comparison of loading test and numerical analysis results. The loading test is performed to confirm the effectiveness of geosynthetic in improving horizontal bearing capacity of pile using model piles embedded in sand ground.

2 TEST OUTLINE

2.1 *Pile model and geosynthetic*

A diagram of the model pile and geosynthetic is shown in Fig. 1. There are two types of model pile used that is made of brass. One has a dimension of 50mm wide, 15mm thick and 700mm long while the other has a 50mm-wide solid section, which has larger stiffness. Pile length is set from a value where its stiffness is about two to three times the ground to a length corresponding to long length pile. Also, the pile was shaped to have a pit on the sides for installation of strainometer and measuring device cords. The geosynthetics that were used are factory belts (0.6mm thick, 1mm mesh) made of Teflon glass fiber.

Tests were conducted according to the cases indicated in Table 1 in order to confirm the effect of length and number of layers of geosynthetics used.



(b) Top view (c) Geosynthetic installation

Figure 1. Pile model and geosynthetic

2.2 *Test ground preparation*

Test ground is formed using dried okagaki sand placed inside a large bucket that is 40cm wide, 236cm long, 65cm high. The sand was placed after setting the pile inside the bucket by passing three layers of sieve. During this process, the geosynthetic is clipped to the pile when the ground reached the installation position.

Moreover, in order to approximate the actual in-situ condition, overburden soil pressure (σ_{v0}) is applied on top of ground since the effect of soil weight is very small in small-scale model test. The overburden soil load is composed of ten steel weights; each has a dimension of 5cmx40cmx5cm and weight equivalent to σ_{v0}=3.8kN/m^2. These are set on both sides f the ground, i.e. active and passive.

2.3 *Loading apparatus and method*

A diagram of loading apparatus is shown in Fig. 2. It applies load to the pile head by moving the table plate horizontally using BF cylinder. Although this apparatus is capable of applying both horizontal and vertical loads simultaneously, only horizontal loads were applied in the test. Furthermore, specially made joints were installed at connection of rod and pile so that the

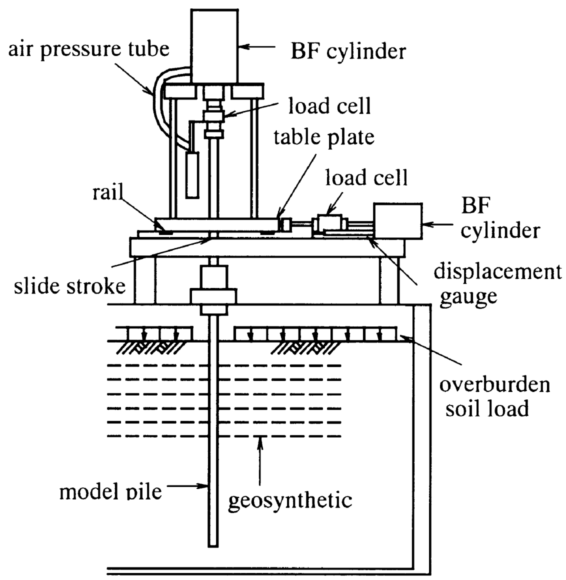


Figure 2. Loading apparatus

pile head would have hinged connection.

Monotonous loading process is considered where the magnitude of load is gradually increased by ΔP_H=49N every 30 seconds. In between load steps, the load is held for 30 seconds in order to check if the displacement settles. Moreover, the magnitude of load is set to a certain range so that the stress of model pile is within its allowable range; thus, large displacements and ultimate state of pile are beyond the scope of this study.

3 STUDY OF TEST RESULTS

3.1 *Reinforced soil depth and horizontal bearing capacity of pile*

Figure 3 shows the effect of number of geosynthetic layers in improving horizontal bearing capacity of pile using L_b=600mm geosynthetic. The graph implies that horizontal bearing capacity of improved grounds is larger than unimproved ground in all cases.

3.2 *Geosynthetic length and horizontal bearing capacity of pile*

Figure 4 shows the effect of geosynthetic length Lb when reinforced soil depth is 150mm, i.e. using three layers of geosynthetic. Based on this, horizontal bearing capacity is greater using longer geosynthetics.

3.3 *Effect of geosynthetic to horizontal bearing capacity of pile*

Figure 5 reveals the relationship of horizontal bearing capacity ratio (i.e. ratio of improved ground with respect to unimproved ground) and geosynthetic length when displacement of pile head is set to δ_H=30mm. Based on this result, horizontal bearing capacity ratio increases with length and number of layers of geosynthetics. Also, horizontal bearing capacity is much more improved when using stiffer pile, where in this case the dimension of pile is 50mmx50mm with three layers of geosynthetics.

Figure 6 shows the relationship of horizontal bearing capacity ratio and number of layers used. This indicates that horizontal bearing capacity ratio increases with number of layers. However, it also reveals that the rate of increase is largest when using

Table 1. Test outline

(units in mm)

No.	Range of reinforced soil		abbreviated designation
	LR	Lb	
1	3 layers (LR=3@50=150)	200	3-200
2		300	3-300
3		400	3-00
4		500	3-500
5		600	3-600
6	6 layers (LR=6@50=300)	200	6-200
7		300	6-300
8		400	6-400
9		500	6-500
10		600	6-600
11	9 layers (LR=9@50=450)	200	9-200
12		300	9-300
13		400	9-400
14		500	9-500
15		600	9-600
16	0	-	0-000

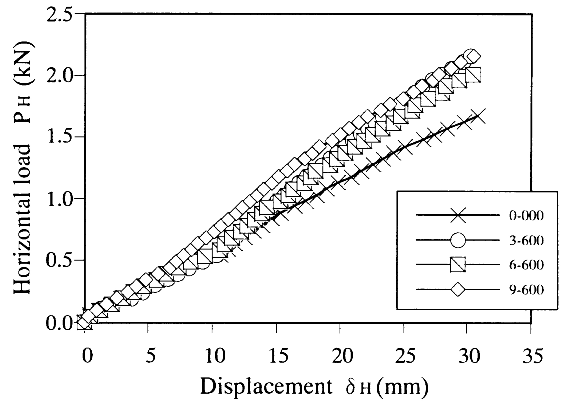


Figure 3. Effect of reinforced soil depth (L_b = 600mm)

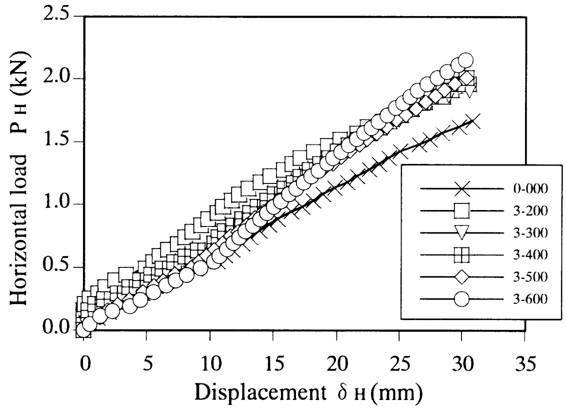


Figure 4. Effect of geosynthetic length L_b (3 layers, L_R = 150mm)

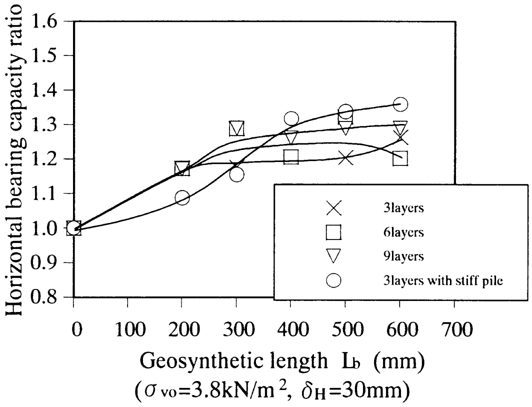


Figure 5. Relationship of geosynthetic length and horizontal bearing capacity ratio

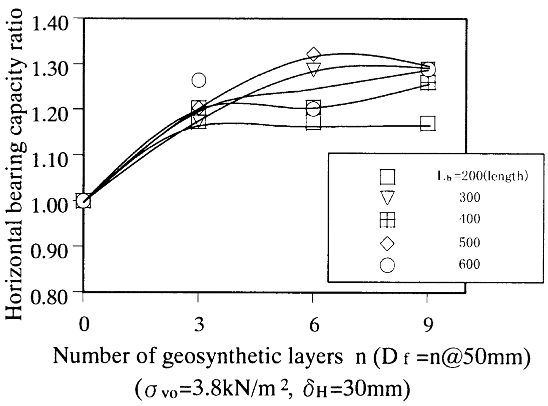


Figure 6. Relationship of reinforced soil depth and horizontal bearing capacity ratio

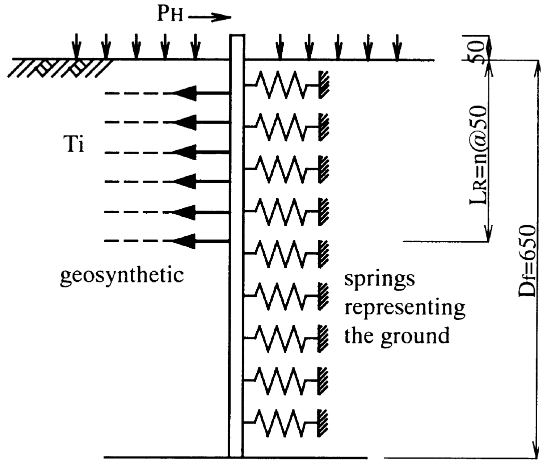
about three layers of geosynthetics, which is the case where reinforced ground depth is relatively shallow. Therefore, this means that, for flexible structures like pile foundations, horizontal bearing capacity can be effectively improved by reinforcing the shallow part near the surface of ground. This is due to the large effect of passive resistance of ground near the surface with respect to horizontal resistance of pile.

4 NUMERICAL ANALYSIS

4.1 *method and model of analysis*

As shown in Fig. 7, the model is composed of series of elastic springs representing the ground and elastic beam element for the pile. The coefficient of ground reaction is set to K_H=4900 kN/m^2 where computed value agrees with test result for non-reinforced ground. Moreover, the relationship of load and displacement near pile head is considered elastic based on the loading test results, although the ground can be modeled to have bilinear characteristics and have varying spring constants with depth.

Geosynthetics are only valid when tension is acting. As illustrated in Fig. 8, the resistance of geosynthetic can be found according to the following equation.



pile width B=50mm, hinged pile toe
Figure 7. Analytic model

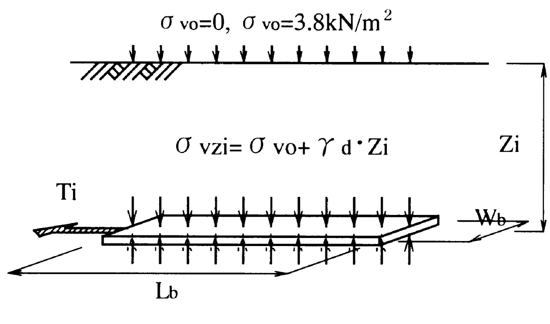


Figure 8. Tension resistance of geosynthetic

$$Ti = 2 \times L_b \times W_b \times (\sigma_{v0} + \gamma_d \times Zi) \tan\delta \quad (1)$$

where L_b = geosynthetic length; W_b = geosynthetic width; σ_{v0} = overburden soil load; γ_d = soil's dry weight per unit volume (=16 kN/m^3); and δ = friction angle between geosynthetic and soil. Herein, the friction angle is considered to be 29 degrees based on single shear test result. The pull-out resistance is assumed to be constant irrespective to displacement since it reaches maximum values with minute change in displacement. Furthermore, the analysis model can not consider the mutual interaction between geosynthetics and ground since spring constant and geosynthetic resistance were found to be independent factors; although it was expected that confine pressure of soil and resistance of geosynthetic should increase due to their mutual interaction.

5 STUDY OF COMPUTED RESULTS

5.1 *Load and displacement relationship*

The relationship of load and displacement without geosynthetic and overburden soil load (σ_{v0}=0) is shown in Fig. 9. It reveals that computed values (K_H=4900 kN/m^2) agree with loading test results. Also, in Fig. 10, calculated bending moments of pile show good correlation with values determined from readings in strainometer.

5.2 *Geosynthetic effect*

Figures 11 and 12 show the computed horizontal bearing capacity of pile with geosynthetics. The former corresponds to the case without overburden soil load and the latter to the case with overburden soil load of σ_{v0}=3.8 kN/m^2. The vertical axis indicates the effect of geosynthetic similar to Fig. 6. It can be estimated that the effect of geosynthetic is approximately 0.5 to 5.0% in Fig. 11 and about 3 to 11% in Fig. 12. The effect is proportional to the length and number of layers of geosynthetics provided that it only demonstrates advantageous effect within three to six layers of geosynthetics; the rate of increase of effect gradually declines using more layers. This

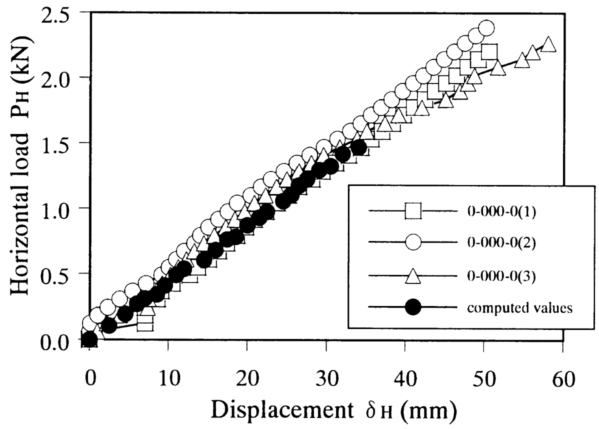


Figure 9. Relationship between load and Displacement (without using geosynthetic)

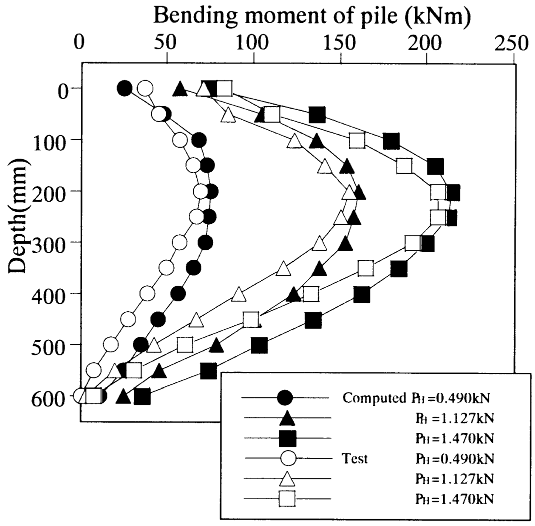


Figure 10. Comparison of bending moments of pile (without using geosynthetic)

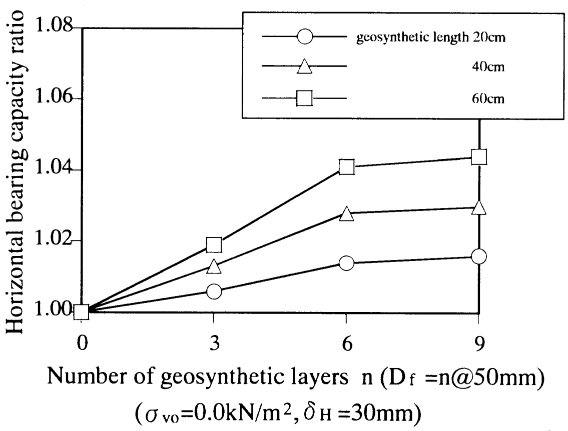


Figure 11. Effect of geosynthetic (σ_{v0}=0.0 kN/m^2)

trend is almost similar to test results of model pile. Moreover, it is found that the rate of reinforcement is greater determined from test results than computed values. Therefore, the computed results herein are rather low estimate of effect of improved ground.

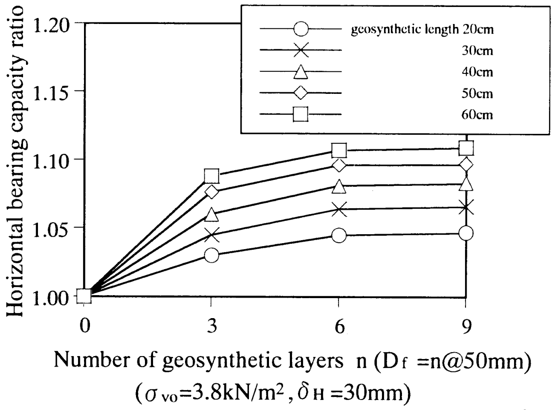


Figure 12. Effect of geosynthetic (σ_{v0}=3.8 kN/m^2)

6 CONCLUSIONS

The following can be concluded from the results above.

1. It is confirmed that horizontal bearing capacity of pile can be improved using geosynthetics.
2. Improving shallow part of ground near the surface increases horizontal bearing capacity. Also, applying overburden soil load alters its effect. Furthermore, horizontal bearing capacity tends to increase when using stiffer pile but results due to mutual interaction effect of ground's forced displacement and geosynthetic is expected.
3. Using the analysis model proposed in this study, calculated results are well consistent with test values for non-improved ground but show lower effect than test values for improved grounds.

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