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The application of ground reinforcing materials for the pile foundation

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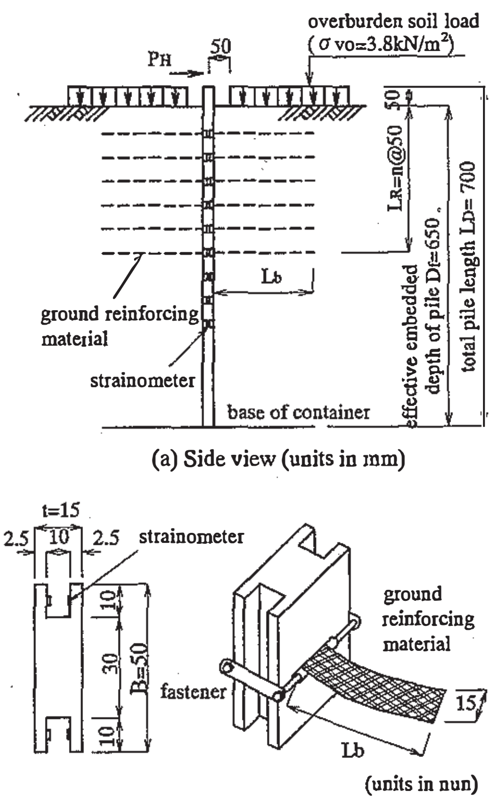
ABSTRACT: This study presents results of applying ground reinforcing materials to pile foundation for the purpose of improving the horizontal bearing capacity of the pile foundation, and the compound foundation consists of ground reinforcing material and pile. The objective of this study is to verify the effectiveness of ground reinforcing material, based on results of bearing capacity experiment using a physical model of a pile in sandy ground and numerical analysis. According to the results of the experiment and numerical analysis, it was confirmed that the horizontal bearing capacity increases in proportion to the length of ground reinforcing material and the improvement depth, which is the number of layers of ground reinforcing material. Therefore, the application of ground reinforcing material is an effective way of 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 are 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 ground reinforcing materials in improving horizontal bearing capacity of piles and the bearing capacity characteristics of hybrid foundation structure composed of ground reinforcing material and pile. This paper reveals the comparison of loading test and numerical analysis results. The loading test is performed to confirm the effectiveness of ground reinforcing material in improving horizontal bearing capacity of pile using model piles embedded in sand ground.



(a) Side view (units in mm)

(b) Top view (c) Ground reinforcing material installation

Figure 1. Pile model and ground reinforcing material.

2 TEST SUMMARY

2.1 *Pile model and ground reinforcing material*

A diagram of the model pile and ground reinforcing material is shown in Figure 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 ground reinforcing materials 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 ground reinforcing materials used.

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 ground reinforcing material 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 5cm × 40cm × 5cm and weight equivalent to σ_{v0}=3.8kN/m^2. These are set on both sides of the ground, i.e. active and passive.

2.3 *Loading apparatus and method*

A diagram of loading apparatus is shown in Figure 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 pile head would have hinged connection.

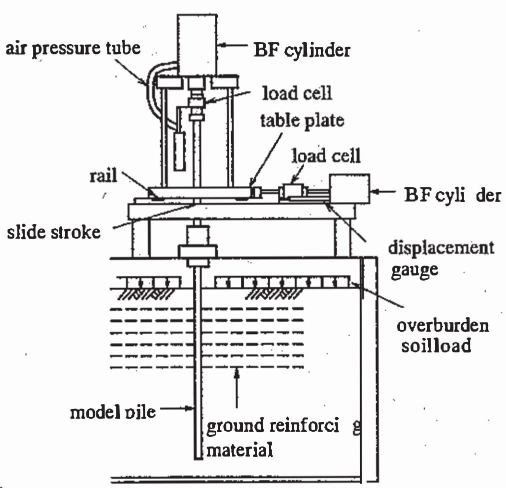


Figure 2. Loading apparatus.

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

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 bearing capacity of pile*

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

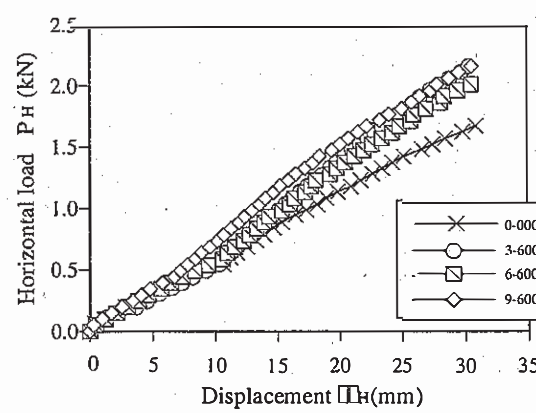


Figure 3. Effect of reinforced soil depth (L_b = 600mm).

3.2 *Ground reinforcing material length and horizontal bearing capacity of pile*

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

3.3 *Effect of ground reinforcing material 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 ground reinforcing material 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 ground reinforcing materials. 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 ground reinforcing materials.

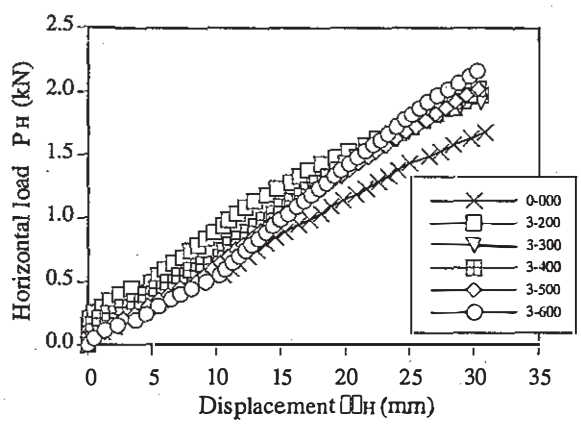


Figure 4. Effect of ground reinforcing material length L_b (3 layers, L_R = 150mm).

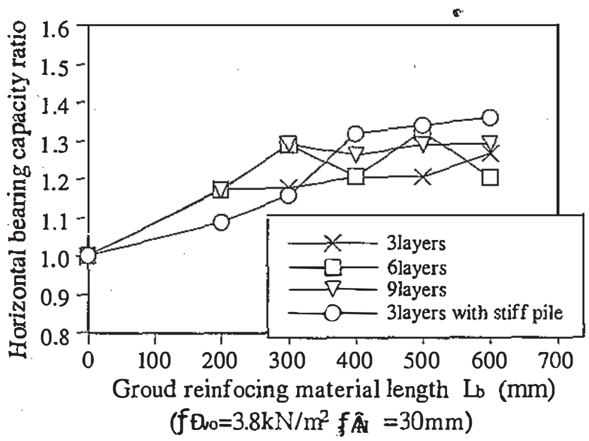


Figure 5. Relationship of ground reinforcing material length and horizontal bearing capacity ratio.

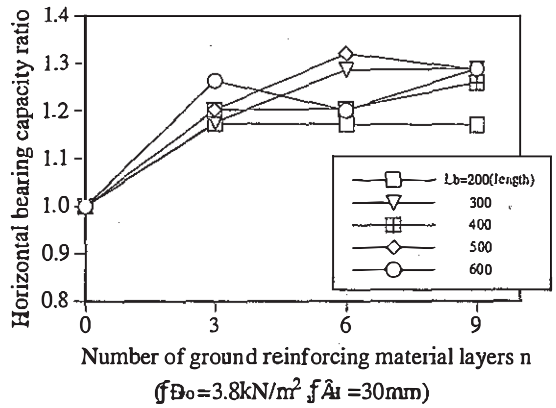


Figure 6. Relationship of reinforced soil depth and horizontal bearing capacity ratio.

Figure 6 shows the relationship between 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 about three layers of ground reinforcing materials, 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 of calculation and analytic model*

In this calculation, elastic beam model is used where the ground and ground reinforcing materials are assumed as spring elements. Here, the spring constant $\overline{K}$ of ground that considers the effect of ground reinforcing materials can be express as follows.

$$\overline{K} = \frac{(K_{H1} \cdot B \cdot \delta_H + \sum \alpha_i \cdot T_i)}{B \cdot \delta_H} \quad (1)$$

Where, δ_H is the displacement, B is the pile width, k_{HI} is the ground spring constant, T_i is axial force of ground reinforcing material, α_i is the parameter with respect to axial force (α_i=0 when δ_{ti}=0 and α_i=1 when δ_{ti} >0), and δ_{ti} is the displacement at the location of ground reinforcing material. Moreover, the spring element, which represents the ground and ground reinforcing material, is assumed to be elastic since the load-displacement relationship at pile head shows elastic behavior based on the load test result as illustrated in Figure 7. The applied values was k_{HI}=9400 kN/m^2, where test value is equal to analytic value for ordinary ground as shown in Figure 10.

On the other hand, ground reinforcing material is only effective at its axial direction and modeled as rigid-plastic since tension reaches its maximum value for minute changes. The tension of ground reinforcing material can be computed according to the following equation, as illustrated in Figure 8.

$$T_i = 2\times L_b \times W_b \times (\sigma_{v0} + \gamma_d \times Z_i)\tan\delta \qquad (2)$$

Where, Lb is the length of ground reinforcing material, Wb is its width, σ_{v0} is the overburden soil load, γ_d is the weight per unit volume of dry soil (γ_d=16kN/m^3), δ is the friction angle between the ground and ground reinforcing material. Here, δ is 29 degrees based on the direct shear test result.

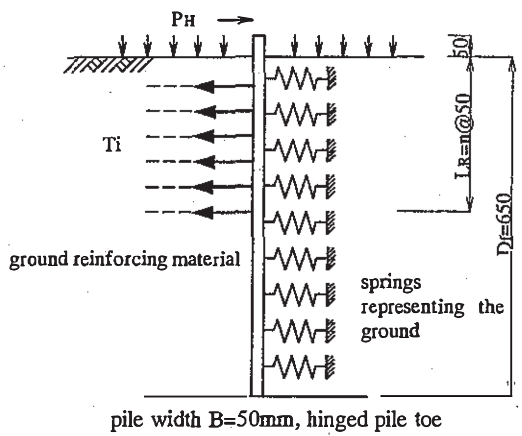


Figure 7. Analytic model.

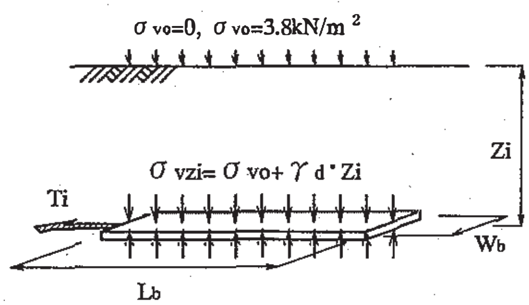


Figure 8. Tension resistance of ground reinforcing material.

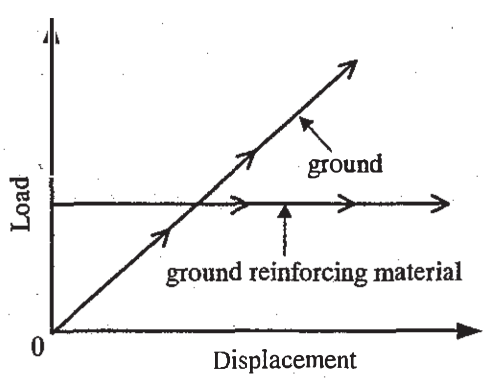


Figure 9. Spring model for ground and reinforcing material.

4.2 *Summary of analytic results*

4.2.1 *Load-displacement relationship*

Figure 10 shows the load-displacement relationship of ordinary ground without overburden soil load (σ_{v0}=0kN/m^2). It shows that the load test and numerical analysis reveal similar results when k_{HI}= 9400 kN/m^2. Also, the load-displacement relationship of load test and numerical analysis for reinforced ground (3 layers-600mm) is compared in Figure 11. The correlation is best when Ti is five times the value computed using equation 2. This is because the ground strength increases due to the component of force acting downward which occurs when ground reinforcing material moves in response to pile deformation. Thus, it can be considered that the actual tension is approximately few times the tension based on equation 2 because of the compound effect of the ground and ground reinforcing material. Also, in Figure 12 calculated bending moments of pile show good correlation with values determined from readings in strainometer.

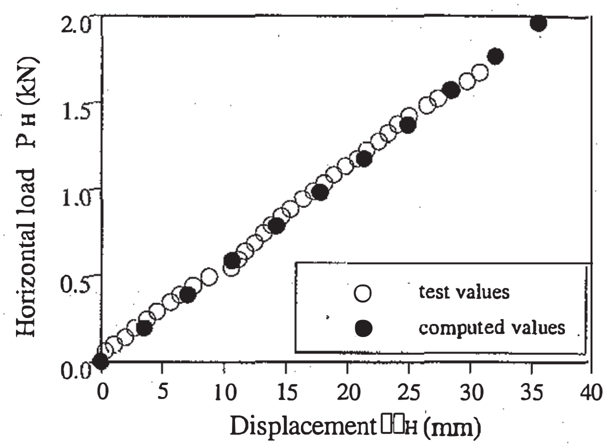


Figure 10. Comparison of computed values and test values for ordinary pile.

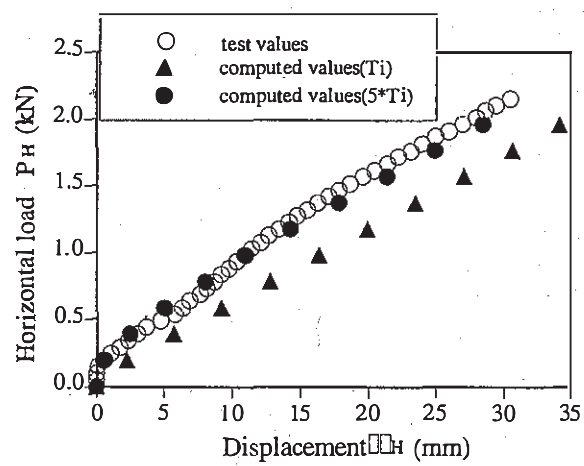


Figure 11. Comparison of computed values and test values for case 3-600.

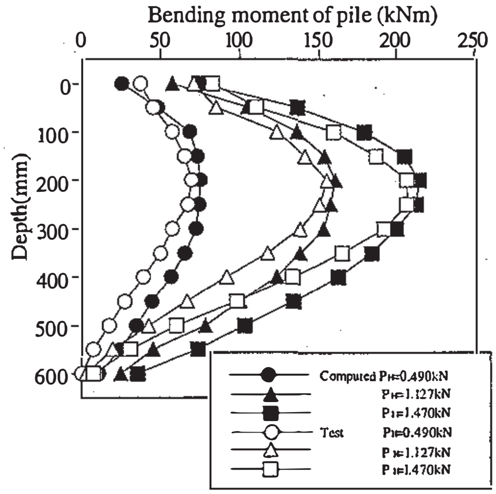


Figure 12. Comparison of bending moments of pile (without using ground reinforcing material).

4.2.2 *Effect of ground reinforcing material*

Figures 13 and 14 show the effect of ground reinforcing material to horizontal bearing capacity of pile. Figure 13 shows the effect of ground reinforcing material length to horizontal bearing capacity that is the same with Figure 5. It illustrates that reinforcement effect is better when ground reinforcing material length is longer. Figure 13 presents the effect of reinforcement depth (i.e. number of ground reinforcing material layers) to horizontal bearing capacity that is similar to the result shown in Figure 6. It reveals that horizontal bearing capacity increases by approximately 10 to 60 percent due to the effect of ground reinforcing material. Furthermore, although the reinforcement effect is proportional to ground reinforcing material length and number of layers, it was found that reinforcement effect occurs significantly when using 3 to 6 layers and gradually increases when using more number of layers. This result is almost similar to the test result of the pile.

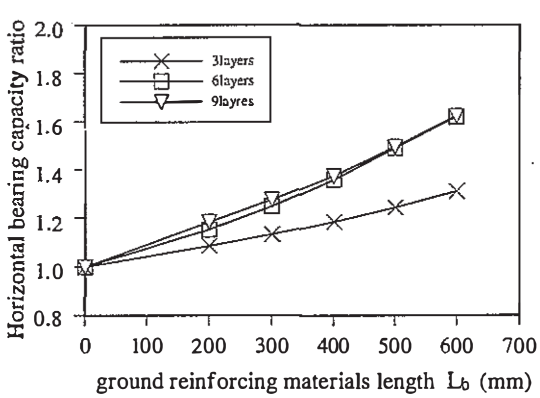


Figure 13. Calculated ground reinforcement effect (ground reinforcing material length).

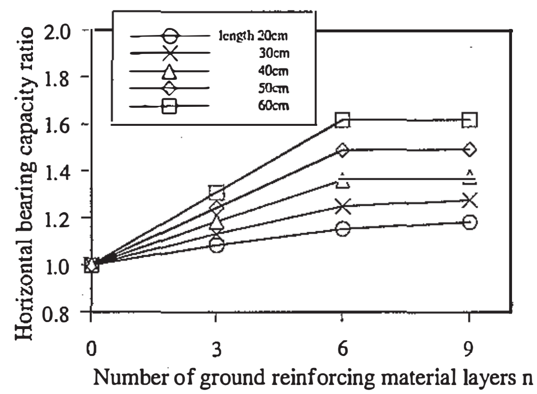


Figure 14. Calculated ground reinforcement effect (number of ground reinforcing material layers).

model. Moreover, the degree of increase in horizontal bearing capacity is little higher compared to the test result in the case with longer ground reinforcing material, i.e. length is 50cm and 60cm. This is because the increase in ground strength is evaluated a little higher when assuming the spring constant for ground reinforcing material, as explained in section 4.1.

5 SUMMARY

The results obtained in this study can be summarized as follows.

1. The horizontal bearing capacity of pile can be increased by using ground reinforcing material.
2. Reinforcement is attainable only within shallow ground near the surface, that is, the horizontal bearing capacity of pile increases within $1/\beta$ range of reinforcement. In the test, number of layers should be approximately six. The horizontal bearing capacity of pile increases with pile stiffness. Moreover, horizontal bearing capacity of pile is expected to increase due to its mutual relationship with ground reinforcing material acted by forced displacements of ground.
3. The results of numerical analysis and load test are almost similar for both ordinary and reinforced ground. Here, an analytic model is proposed for stability analysis. Computed tension for reinforced ground is less than its actual value but it coincides with test result when multiplied by few times. This is because of the effect of the component force acting downward developed due to the displacement of ground reinforcing material acted by pile movements, as mentioned in section 4.1. Therefore, it can be concluded that the magnitude of tension is few times larger than computed value due to compound effect of ground and ground reinforcing material.

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