A bearing capacity characteristic of dredged and reclaimed ground reinforced by bamboo net

Une Caractéristique de Capacité de Rapport de Terre Draguée et Reconquise Renforcée par le Filet En bambou

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ABSTRACT

More practical surface strengthening methods are required in order to reinforce the soft ground of dredged or reclaimed ground with minimum troubles. To this end, bamboo which are cultivated or grow naturally in Korea are used as the reinforcement material due to their good physical properties and economical advantage. In this study, large scale plate loading test was conducted to investigate the characteristics of the load bearing capacity of very soft ground reinforced with bamboo net. From the test results for variables pertinent to bearing capacity, good relationships could be obtained between the bearing capacity ratio(BCR) and the ratio of embedded depth to bamboo spacing.

RÉSUMÉ

La surface plus pratique les methods fotifiantes est exigée pour renforcer la terre molle de terre draquée ou renconquise avec les problems minimaux. A cette fin, le bamboo qui sont culitvés ou grandissent naturellement en Corée est utilize comme la matière de renforcement en raison de leurs bonnes proprieties physiques et avantage économique. Dans cette etude, la grande plaque d'échelle chargeant l'épreuve a été accoplie pour enquêter sur les caractéristiques de la charge portant la capacité de terre très molle renforcée avec le filet en bamboo. Des resultants d'essai pour les variables appropriées envers le rapport de la capacité, de bons rapports pourraient être obtenus entre le rapport de capacité de rapport (BCR- Bearing capacity ratio) et le rapport de profondeur fixée à l'écartement en bambou.

Keywords : Large scale plate loading test, Bamboo net, Geotextile, Bearing capacity ratio

1. INTRODUCTION

It is required to develop an improved and practical ground strengthening method which can secure ground quality and economy by minimizing the problems which may occur in dredged or reclaimed ground. For this purpose, the ground strengthening method using bamboo which has good physical properties as a construction material, been used world wide, and grows across Korea has been developed and applied (K. S. Yang, M. C. Kang, 2004). In Japan and Southeast Asia, the availability of bamboo net in the soil covering work in ultra soft grounds reclaimed with marine clay, peat, or mine slime to enable heavy equipments travel on the ground has been verified and reported. In addition, the load bearing characteristics of bamboo net reinforcement was verified in laboratory tests, and limits related to the applicability of existing formula due to the change in the failure mechanism of rigidity reinforcement and the necessity of a new analysis model was identified (Yusuf, et al. 1989).

While the effect of the improvement of bearing capacity of the ground reinforced by bamboo net has been reported, the theory of bearing capacity evaluation based on the strengthening mechanism taking the material properties into consideration and related design technique have not been developed satisfactorily yet, and further studies are required because no quantitative in-situ measurement data is available yet. In this study, in order to investigate the load bearing characteristics of the ultra soft ground reinforced with bamboo net, large scale in-situ load test was conducted to evaluate the reinforcement effect and bearing characteristics of the bamboo reinforcement.

2. SITE LOADING TEST

2.1 Overview of the test

The bearing capacity of the reinforced ground can be evaluated on the basis of the failure mechanism of the ground. However, the loading tests with reinforcement materials in ultra soft grounds have mostly been conducted with laboratory model tests, and the reinforcement materials were geosynthetics or geogrid. In this study aimed at the analysis on the bearing capacity and reinforcement effect of bamboo net and soil covering depth, a large scale plate loading test apparatus which enables testing on ultra soft ground was developed. In addition, the testing method was improved to deliver load on the ultra-soft original ground. As it was the purpose of this study to evaluate the load bearing capacity of the reinforced ground by applying load, the undrained shear strength required for analysis was measured down to 3m deep in original dredged and reclaimed land using a field-vane shear test.

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2.2 Large scale plate loading test apparatus

For the application in reinforced ultra soft grounds, the weight of the covering soil becomes excessively heavy according to the depth, and even if heavy load can be born, and if the loading plate size is relatively smaller than the large soil covering depth, the influence of the load cannot be applied to the original ground.

If test weight is heavy, the possibility of safety accident is high due to the characteristics of the dredged and reclaimed ground which shows fluid behavior. To solve this problem, a loading device which enables loading on a loading plate of 1m x 1m size in order to secure safety of testing and appropriate results for analysis was developed. The loading test apparatus consisted of a base for weight, a loading plate, load, and a load box. The dimensions of the loading plate and the load were 100cm x 100cm x 2cm and 92cm x 92cm x 7.5cm, respectively. The weight of the load was 500 kgf for easy load calculation.

2.3 Performing lage sale pate lading test

As the preliminary step for the loading test, the test site was selected, and expected allowable load bearing capacity was estimated by evaluating the physical properties of the ground and the strength characteristics of the ground by field vane shear test. The loading steps were adjusted according to the expected allowable bearing capacity. The test area was selected to be 10m x 10m where soil covering depth across the area was measured to be the same.

A settlement meter was installed at the center of the test area to measure the displacement of the center by loading, followed by the installation of the loading plate. The load base was installed in the manner to prevent overturn or failure in foundation. The crane for moving the load was located where the influence on the test can be minimized.

The loading method was Kentledge load method where the test loads representing the weight of heavy equipments for the soil covering depth were placed on the loading plate. The maximum test load was 2.5 times of the ground pressure of the heavy equipment, within the limit of the planned maximum load which did not exceed the ultimate bearing capacity of the ground in the soil covering steps. The loading was carried out by adding unit loads which did not exceed 1/5 of the planned maximum load in each loading step. Each load was measured accurately and loaded so that static load is applied to the ground. The intervals of the accumulative loading cycles 15 minutes or longer, maintaining load until the settlement is stopped or become constant.

The vertical displacement of the ground was measured with dial gauges which can measure 150mm of displacement at two points. In order to observe the vertical displacement according to loading, two levels were installed at two points where no settlement or displacement would occur during the test, and the entire vertical displacements were measured and averaged to obtain the displacement of the pertinent loading step. The testing of each loading step was continued until the ratio between the settlement and load became constant, or the settlement became negligible, approaching the completion of settlement. The testing of each step was completed when the total accumulative settlement became 10% of the size of the plate, or yield load could be identified. The measurement continued after the completion of the observation of the final load increase, for 24 hours maximum. Fig. 1 shows the loading and displacement measuring procedures.

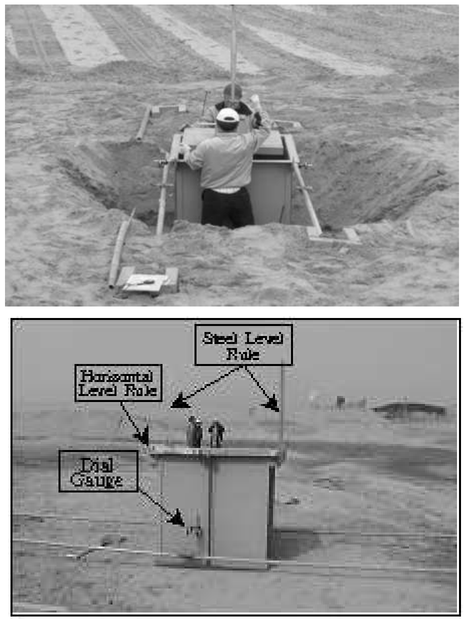

Figure 1. Loading and displacement measurement

3. ANALYSIS ON THE RESULTS OF THE LOADING TEST

3.1 Calculation of allowable bearing capacity

With the results of the large scale plate loading test, the allowable bearing capacities for each test were determined by plotting load-displacement curve with Log P-Log S, Log P-S, P-S curve method and calculating the yield strength as the average of the yield strength obtained from the curves. Because the allowable bearing capacities evaluated from the tests conducted with the reinforcements were obtained from different soil covering depths and ground strength conditions, it is important to consider the effect of reinforcement on the basis of the equivalent original ground conditions for objective evaluation of the effect of each reinforcement material. To this end, the bearing capacity ratio (BCR) used by Saleme et al., (2000) was applied. The BCR is defined by the ratio of the allowable bearing capacity of the original ground (q_o) and that after reinforcement (q_a) obtained from loading test.

$$BCR = \frac{q_a}{q_0} \tag{1}$$

As it is not possible to conduct large scale plate loading test due to the characteristics of the dredged and reclaimed ground, the bearing capacity theory of Terzaghi was applied to calculate the of clay ground, for non-reinforced ground. As shown in the Table 1, the BCR of bamboo net was 2.92~7.72 and that of geosynthetics was 2.78~4.73. Fig. 2 shows that, the BCR tends to increase according to the increase of soil depth and the decrease of bamboo spacing at the same soil depth. It is clear that the BCR of the bamboo net is superior to that of the geosynthetics by a factor of about 1.5.

Table 1. BCR of materials

	Size	H (m)	C_u (tonf/m^2)	Nc	q_a (tonf/m^2)	q_o (tonf/m^2)	BCR
G/T	15t/m	0.60	0.54	5.3	5.17	1.40	2.78
		0.95	0.53	5.3	3.90	1.40	3.81
		1.30	0.53	5.3	5.65	1.40	4.73
		1.94	0.53	5.3	6.64	1.43	3.61
B/N	0.5×0.5	1.00	0.23	5.3	3.61	0.61	5.92
	0.7×0.7	0.40	0.27	5.3	2.09	0.87	4.15
	1.0×1.0	0.60	0.46	5.3	3.97	0.87	7.72
		0.60	0.31	5.3	3.89	0.98	4.00
		0.95	0.33	5.3	3.63	0.98	5.10
		1.45	0.33	5.3	5.35	1.22	3.25
		1.95	0.33	5.3	6.75	0.82	4.74
	1.25×1.25	0.95	0.37	5.3	3.92	0.72	2.92
		1.25	0.37	5.3	5.00	0.72	4.81

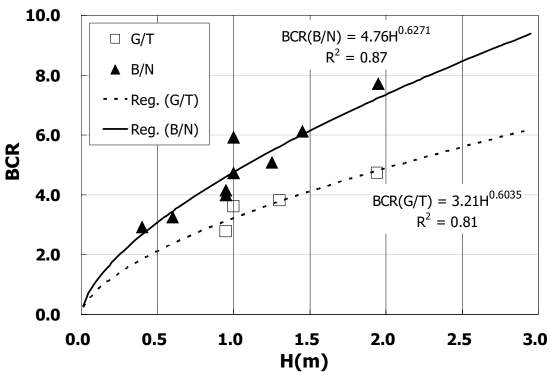

Figure 2. BCR with reinforcement materials

3.2 Correlation analysis of BCR

According to the large scale plate loading test, the allowable bearing capacity of bamboo net calculated with traditional theoretical equation is significantly less than that was actually measured. This was thought to be; as the theoretical equation is based on geo-net whose tensile strength precedes strength rather, the equation is not suitable for reflecting the physical properties of bamboo which has very good bending stiffness. This is thought to be the reason that Yusuf et al. (1989) calculated the bearing capacity of soft grounds reinforced with geosynthetics using the existing theoretical equation, in the testing of bearing capacities of soft ground reinforced with bamboo and geosynthetics.

In order to evaluate the bearing capacity of dredged and reclaimed ground reinforced with bamboo net, the correlation between the undrained shear strength of the ground, spacing of the bamboo net, and soil depth and the BCR measured in the large scale plate loading test was analyzed. The correlation was good as shown in Fig. 3 where the vertical and horizontal axes present BCR and soil depth and bamboo spacing, respectively. The BCR increased according to the increase of the soil depth and the decrease of bamboo spacing. Such characteristics of correlation show the similar results to the study of Yusuf et al. (1989) that the effect on the bearing capacity of bamboo is superior to that of geosynthetics.

The Equation (2) below is the correlation equation of bearing capacity proposed in this study, which is believed to be useful in the evaluation of the bearing capacity of bamboo reinforced ground.

$$BCR = 4.56\ Y^{0.644} \tag{2}$$

where Y is the ratio of soil depth to bamboo spacing (H/S).

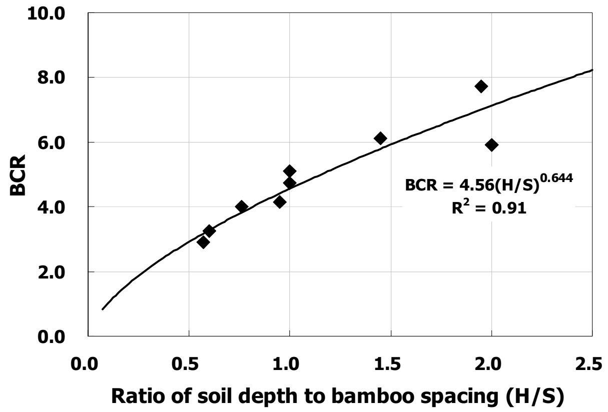

Figure 3. Relationship between BCR and H/S

3.3 Applicability of the theoretical equation

In order to evaluate the applicability of the traditional theoretical equation on the bearing capacity of reinforced ground, the bearing capacities of the ground reinforced with the reinforcement materials were calculated with the theoretical equation of Yamanouch (1985). In the calculation, the 20 degrees of deformation angle of reinforcements was applied considering the relation between ground strength and deformation angle presented by Nishiyabasi (1994), the undrained shear strength of the ground and the design samples.

As shown in the Fig. 4 and Fig. 5, the average ratio of the allowable bearing capacity of the geosynthetics measured in the test to that calculated with theoretical equation is 105%. It can be judged that 20 degrees of deformation angle can be applied in design. It needs, however, careful consideration in the construction work. On the other hand, the ratio of the bamboo was about 65%, showing that larger value is estimated theoretically than the real value. This is thought to be; because the theoretical equation is for geo-net method, it is not suitable for the material properties of bamboo whose stiffness precedes tensile strength.

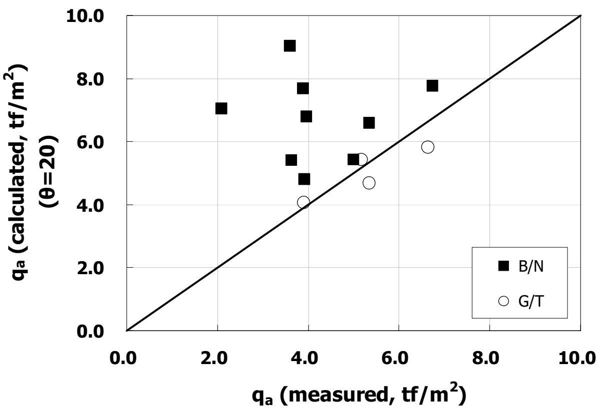

Figure 4. Comparison between the measured and calculated allowable bearing capacities

In order to verify the design variable of the traditional theoretical equation, deformation angles were calculated from the allowable bearing capacities obtained from the large scale plate loading test. The results are presented in the Fig. 5. From the test results, it is suggested that, in the design based on the traditional theoretical equation, the deformation angles of 7 and 20 degrees for bamboo and geosynthetics, respectively, will minimize the difference between the calculated and the real values, and reflect the characteristics of the reinforcements to a certain extent, though not satisfactorily.

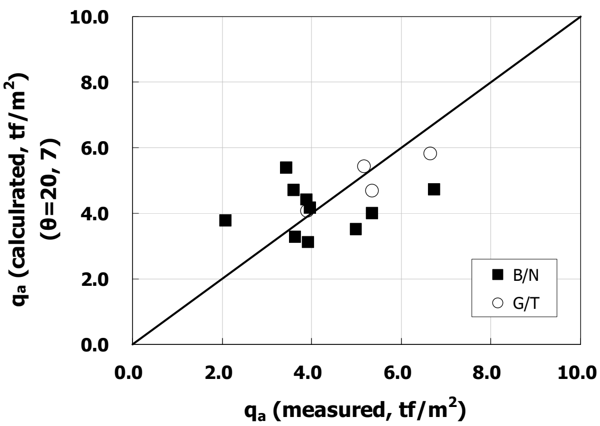

Figure 5. Comparison between the measured and calculated allowable bearing capacities by θ-transformed

4. CONCLUSIONS

In this study, in-site large scale plate loading tests was conducted with a test apparatus developed to evaluate the engineering features of soft ground reinforced with the bamboo net. The bearing capacity of an ultra soft ground, dredged and reclaimed, reinforced with bamboo was measured and evaluated. The results from the research are as follows;

1) The BCR, which represent the effectiveness of reinforcement, of bamboo net and geosynthetics were 2.9-7.7 and 2.8-4.7, respectively. The BCR of bamboo net, whose bending strength is higher, was superior to that of geosynthetics by a factor of 1.5.

2) From the analysis on the variables in the same ground conditions conducted for the objective evaluation of the bamboo reinforced ground, the correlation was;

$$BCR = 4.56\ (H/S)^{0.644}$$

It is suggested that further studies should be conducted, including in-site loading test and numerical analyses, on the basis of this study, in order to verify the applicability of bamboo net, both economically and practically, as a ground reinforcement material

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