INFLUENCE OF ENCAPSULATED GEOGRID-SAND SYSTEM ON BEARING CAPACITY AND SETTLEMENT CHARACTERISTICS OF REINFORCED CLAY

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Abstract: *A study of bearing capacity and compressibility characteristics of cohesive soil, reinforced by geogrid and supporting square footing loads has been conducted. The lack of adequate frictional resistance between clay and reinforcing elements was compensated by using a thin sand layer (lens) encapsulating the geogrid sheet. In this way, tensile forces induced in the geogrid were transferred to the bulk clay medium through the sand particles and soil reinforcement was improved. Experiments were conduced on two sets of specimens, one set of 1 x 1 x 1 m dimension and the footing size of 19 x 19 cm (series A), and the other set of 0.15 x 0.15 x 0.15 m dimension and the footing size of 3.7 x 3.7 cm (series B). The loading systems for the above specimens were stress controlled and strain controlled respectively. All specimens were saturated and presumably loaded under an undrained condition. The results qualitatively confirmed the effectiveness of the sand lens in improving the bearing capacity and settlement characteristics of the model footing. In series A, the maximum increase in the bearing capacity due to the presence of the sand lens was 17%; whereas in series B, the amount of increase was 24%. The percentage reductions in the settlement for these results were 30% and 46% respectively.*

Keywords: *bearing capacity, settlement, footing, saturated clay, reinforcement, geogrid*

1. INTRODUCTION

With more advances in soil reinforcement techniques and applications, researchers became interested in examining the reinforced soil under footings and foundations. Binquet and Lee [1] reported an early study on the bearing capacity of shallow foundations placed on a reinforced ground. They presented design charts for strip footings on underlying sandy layer reinforced by metal strips. Although this technique appeared economical compared to other improvement methods, the corrosion of metal reinforcing elements convinced researchers to use other materials such as geosynthetics which perform more satisfactorily.

The use of geosynthetics for the reinforced soil under footings is not as extensive as for other applications like retaining walls, embankments, etc. More researches have been conducted on the bearing sand as by Guido et al., [2, 3, 4], Khing, et al, [5, 6], Takemura et al. [7], Omar et al. [8, 9], Yetimoglo et al. [10], and Adams and Collin [11]. Some studies are also reported on the bearing clay as by Ingold and Miller [12], Milligan and Love [13], Sakti and Das [14], Dawson and Lee [15], Das [16], Sah [17], Mandal and Sah [18] and Shin et al. [19]. The use of geogrids was favored in almost all of these studies due to its relatively high modulus and strength compared to geotextiles. According to these studies, the bearing capacity depends on the following parameters:

- Depth ratio of the first reinforcement layer (u/B)
- Vertical spacing ratio between reinforcement layers (h/B)
- Number of reinforcement layers (N)
- Footing dimension (B, L)
- Geogrid layer dimension ratio (b/B, l/B)
- Geogrid modulus
- Relative density of sand

The results of the above studies show that the bearing capacity for the case of reinforced soil is 1.8 to 4 times that for the unreinforced case.

Two studies are reported by Mandal and Sah [18], and Shin et al. [19] on square and strip footings on clay respectively. These results show that the ratio of bearing capacities for reinforced and unreinforced cases is about 1.5, which is much smaller than that obtained for sand. According to Shin's explanation for this difference, the bearing capacity increase is basically coming from two sources; the increase of soil modulus, and pullout resistance of reinforcement. The pullout resistance is composed of two phenomena; first, the frictional resistance between soil and element, and second, the passive resistance developed between transversal strips of geogrid and soil. Both mobilized resistances, particularly the passive resistance, depend on the friction angle of the soil. For saturated clay at undrained condition ($\phi = 0$ condition), the pullout resistance of geogrid is normally expected to be much smaller than that in sand.

It appears that if the lack of sufficient pullout resistance in clay could somehow be resolved, more improvement in the bearing capacity from the reinforcement should be accomplished. A study by Sridharan et al. [20] on the pullout resistances of metal bars which are confined by a thin cylindrical layer of sand placed in a cohesive medium shows that a 15 mm diameter sand layer would be sufficient to increase the pullout resistances of the bars to the amount as if the whole medium were composed of sand. It would therefore be expected if a reinforcing element is sandwiched between sand and used in clay soil beneath a footing, the bearing capacity should increase due to the improvement of the pullout resistance of the element. The study presented here experimentally examines this hypothesis.

2. TEST MATERIALS

The type of soil used in this study is clay with 70% passing the No. 200 sieve. The Unified Classification of the soil is CL, and other properties are LL=26%, PI=8%, G_s=2.67. For the soil surrounding the reinforcing element, a clean sand was used. The reinforcement was provided by a layer of geogrid made by Huesker Synthetic Company which is labeled Fortrac Geogrid 55/30-20. Its tensile strength was 55 kN/m at 12.5% strain, and with an aperture size of 20 x 20 mm.

3. EXPERIMENTAL PROGRAM

The experimental program was initially planned on testing prototype specimens. But, because of some deficiencies encountered with the loading and saturation systems of large scale models, some tests were also carried out on small specimens under improved testing conditions. These tests are explained and analyzed separately.

3.1. Large Scale Model (Series A)

3.1.1. Test Apparatus

The model footing was a steel square plate with 19 cm width and 3 cm thickness loaded under a stress controlled condition. The testing apparatus is schematically depicted in Fig. 1. This system is composed of a 1 x 1 x 1 m steel box, made sufficiently rigid to prevent any significant lateral deformation on its vertical sides under the footing loads. The loading system consists of a hydraulic hand-controlled jack which is held by a horizontal beam above the plate upside down, and a proving ring between the jack and the plate with capacity of 5 ton to precisely measure the applied load. The settlement of the plate was measured by two dial gages placed on two sides of the plate to provide an average settlement of the plate. A small semispherical indentation was made at the center of the plate in order to provide vertical load alignment.

3.1.2. Specimen Preparation

The dimension of the soil specimen bearing the footing load was 1m x 1m (box planar dimension) and 0.45m height. This height was selected such that the stress distribution ratio beneath the footing to be less than 0.1 at the depth of 0.45m. According to Westergaard Elastic solution, for a B x B square footing, the stress ratio at a depth of 2B beneath the footing becomes less than 0.1 (i.e. $q/q_o < 0.1$ where q and q_o are the applied pressure at surface and the induced vertical stress at depth respectively). Besides, the study by Adams and Collin [11] shows that the stress at depth of 2B beneath a square footing is negligible. Therefore, the above depth (45 cm) was selected that is slightly more than 2B. The remaining space at the bottom of the box was filled by coarse sand and gravel to provide a drain for saturating the soil specimen. The soil was compacted in 5 cm layers to a predetermined dry density of 0.9 x $\gamma_{d[max]}$ =1.68 g/cm^3 (16.48 kN/m^3). This density corresponds to 18% water content [the wet side of optimum] on the standard Proctor compaction curve.

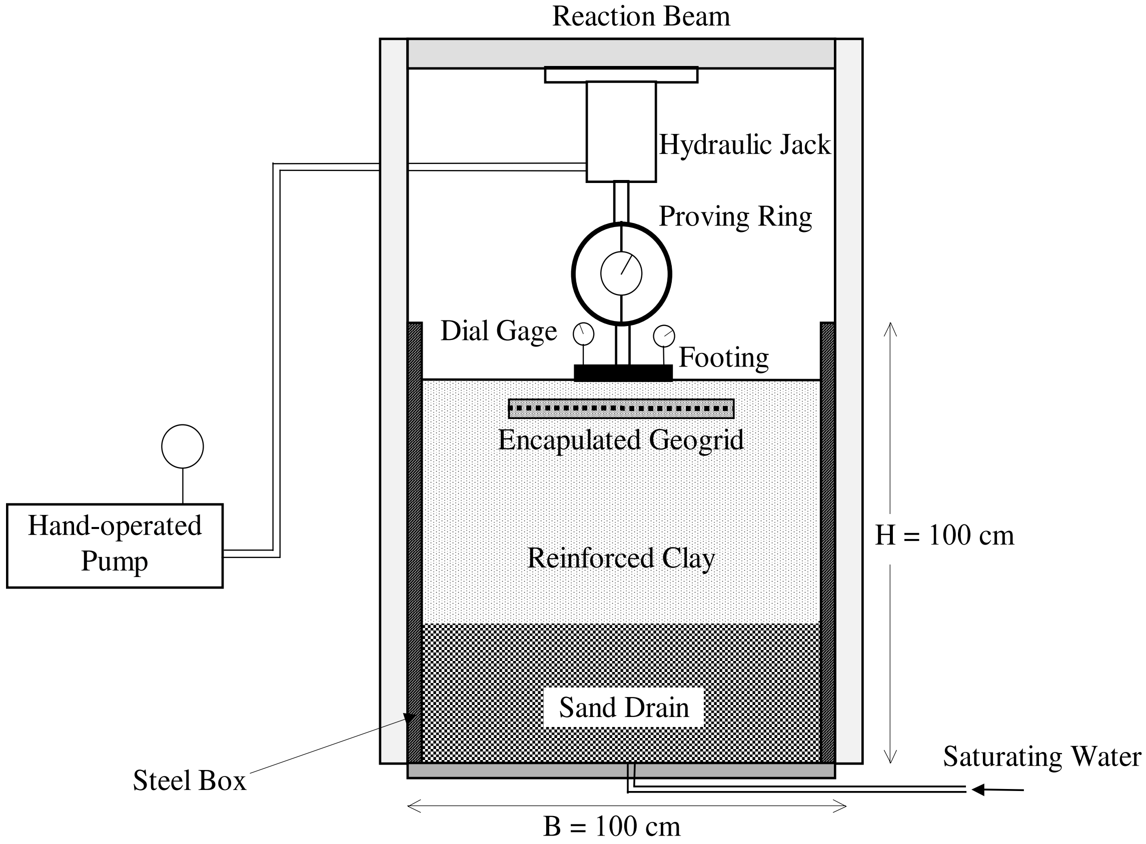

Fig. 1. Schematic representation of the testing apparatus in series A

All specimens were reinforced by one layer of geogrid with the dimension of 5B (95 x 95 cm). Shin and et al. [20] have reported the optimal dimension to be between 4.5B and 5B. The depth of geogrid from the bottom of the footing was 0.3B, which is between 0.2B and 0.4B proposed by Mandal and Sah [18], and Shin and et al. [19] respectively. Since the main objective in this study was to evaluate the effect of sand layer around geogrid on the bearing capacity and settlement of footing, the thickness of the sand lens was the only variable changing from 0 to 4 cm.

3.1.3. Saturation

The saturating system was made of a container placed at an elevation higher than the top of the box, and connected to the box bottom with a hose. Water could slowly flow through the drain layer to gradually saturate the clay layer. Because of small water gradient and low permeability of the clay, a complete saturation of each specimen could take five days. The degree of saturation (S) at the end of each test was determined by taking a soil sample and obtaining the unit weight (g), water content (w), and using the following expression, which varied between 93% and 97%.

$$\gamma = \frac{G_s(1+w)}{1+\frac{G_s w}{S}}\gamma_w$$

3.1.4. Loading

The load was applied incrementally with each step 20 kPa which is 1/5 of the estimated bearing capacity of the clay. Each load increment was held for 30 minutes and the settlement was recorded at elapsed times of 1, 2, 4, 8, 15, 30 min. The loading was continued until failure occurred in the clay or the total footing settlement reached 5 cm. At the end of each test, three soil samples were taken by 1.5 inch sampler (ELE International Ltd) from the section bellow the geogrid for determination of the unconfined compression strength, and the degree of saturation of the specimen.

3.1.5. Test Results and Discussion

In each test, the load-deformation characteristic and the type of instability were investigated. Also, the type of failure in geogrid layer was examined after removing the overlying soil layer; that appeared to be a pullout failure in all tests. As shown in Table 1, five tests were performed on large scale specimens. Two dimensionless parameters; BCR_u (Bearing Capacity Ratio at Ultimate Load), and *PRS* (Percentage Reduction in Settlement), as introduced in previous studies, are used here for analyzing the results:

$$BCR_u = \frac{q_{u(R)}}{q_u} \quad PRS = \frac{S_u - S_r}{S_u}(\%)$$ where:

q_u = ultimate bearing capacity of footing on unreinforced soil

$q_{u(R)}$ = ultimate bearing capacity of footing on reinforced soil

S_u = settlement of footing on unreinforced soil at bearing pressure of q_u

S_r = settlement of footing on reinforced soil at bearing pressure of q_u

Fig. 2 presents the load-settlement curves for five tests. The ultimate bearing capacity for each test was obtained based on the method proposed by Brand et al. [4], which defines the ultimate load at a point where the plot of bearing load against settlement becomes practically linear. According to these curves, the type of failure is expected to be local shear or punching because there is no distinct break on the curves. Observations also confirmed this failure mode as there was very slight soil swell around the footing, and the plate just penetrated into the underlying soil.

Table 1. Summary of test results in series A [B = 19 cm, u/B = 0.3, b/B = 5]

Test No.	Sand Lens Thickness, (cm)	Reinforced [R] Unreinforced [U]	$q_{u[R]}$ (kPa)	BCR_u	S_u/B (%)	S_r/B (%)	*PRS* (%)
A-1	0	U	q_u=78	-	-	-	-
A-2	0	R	116	1.49	17	9.5	44
A-3	1	R	120	1.54	20	10.9	36
A-4	2	R	128	1.64	24	11.4	33
A-5	4	R	130	1.66	26	12.0	30

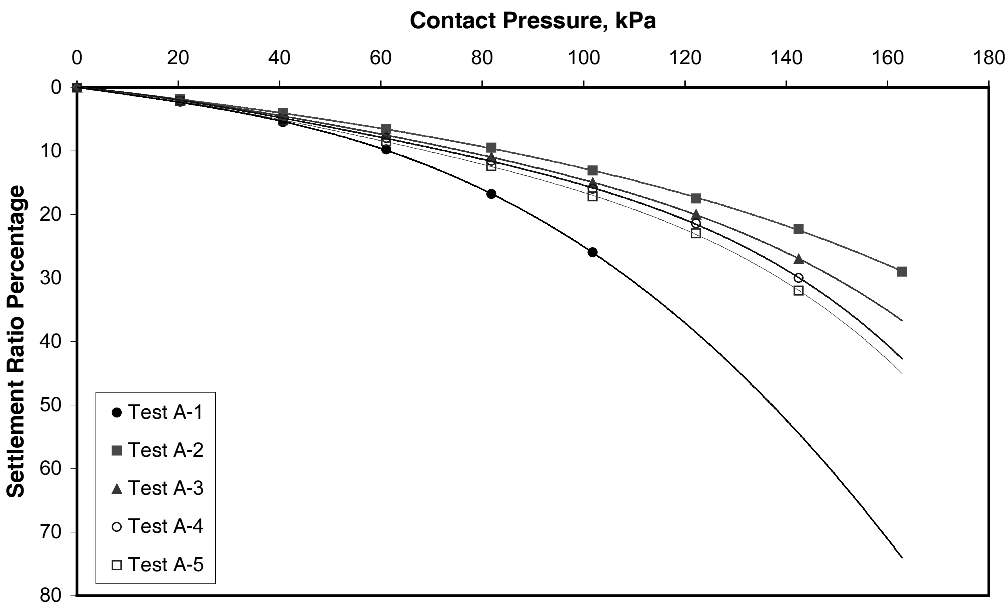

Fig. 2. Load-settlement results in test series A

The influence of lens thickness on BCR_u coefficient is seen in Table 1. It appears that the presence of lens, on one hand, increases the bearing capacity of the clay (increase of BCR_u), and on the other hand, decreases its modulus (decrease of *PRS*).

The maximum increase in the bearing capacity due to the sand lens corresponds to 4 cm sand lens (BCR_u=1.66), indicating 17% increase in the bearing capacity compared to the result of reinforced clay without the lens (BCR_u=1.49).

The contribution of the sand lens on the bearing capacity and settlement can be attributed to three factors as explained below:

1) The pullout resistance of the geogrid embedded in the sand layer is higher than that laid in clay, which in turn should influence the bearing capacity positively.

2) The presence of a sand layer itself in a clay medium can increase the bearing capacity as theoretical expressions for footings placed on layered systems indicate. For the test model dimension used in this study, a very thin sand layer could still influence the results, and the effect should enhance with increasing the sand thickness.

3) The saturation technique employed here appeared to adversely affect the bearing capacity. The presence of free water at the soil surface could facilitate the swelling process in the clay particularly the portion near the surface. Consequently, the strength and stiffness of the clay could decrease due to the swelling. This phenomena was observed to be more pronounced in the specimens with sand lens.

In the results presented in Fig. 2 and Table 1, the above three influences of the sand lens might have acted simultaneously. The first and second factors causing BCR_u and *PRS* coefficients to increase while the third factor causing BCR_u and *PRS* coefficients to decrease. A quantitative distinction between these factors and the contribution of each may not be feasible from the results of this study. Nevertheless, the overall effect of the lens on the bearing capacity improvement is positive as the results show. Besides, the test series *B* of this study (explained in the next section) showed that the effect of the sand itself on the bearing capacity is negligible; therefore, indicating an important contribution of the lens on the increased pullout resistance of the geogrid, and consequently on the bearing capacity.

As can be realized in Table 1, the variation of *PRS* parameter with the lens thickness decreases with increasing the thickness, meaning that the sand layer has had adverse effects on the settlement. For the specimen without the lens, the *PRS* value is 44% that reduces to 30% for the specimen with a 4 cm sand lens. This result may be explained in regard to more softening of the clay layer and the reduction of its modulus resulting from the improper saturation technique. Besides, the sand lens, acting as a drain, could speed the consolidation with increasing its thickness during 3 hours loading.

3.2. Small Scale Model (Series B)

Having realized some deficiencies of the loading system, sample preparation, and particularly the saturation process in large specimens, some experiments were conducted on small scale specimens under strain controlled loading in the unconfined compression apparatus. The load was applied at the rate of 1.5 mm/min on a square plate with the dimension of 3.7 cm and thickness of 1 cm. The soil specimen was prepared in a cubic metal box with the dimension of 15 cm. The total thickness (height) of the clay layer was 12 cm, a little more than 3B, therefore minimizing the boundary condition effects. All tests were performed on saturated clay specimens prepared, however, differently from the method employed in the series A tests.

A new procedure was undertaken to prepare a saturated clay specimen. The dry clay was first mixed with 22% of water (a percentage between the plastic and liquid limits). Then, the moist soil was allowed to cure in a plastic bag for a week so that water could thoroughly be distributed in the clay, and a homogenous sample to be made. The soil was then compacted in 2 cm thickness layers to a predetermined dry unit weight of 1.68 g/cm^3 (16.48 kN/m^3). Similar to the large scale tests, one geogrid layer was used with the dimension of 4B x 4B (B=3.7 cm) and the coefficient of u/B equal to 0.4. Table 2 shows the information about the small scale tests. Each test was proceeded until a clear drop in axial load occurred or the total settlement of the plate reached to 1.5 cm.

3.2.1. Test Results and Discussion

Fig. 3 has depicted the results of small scale specimens. The bearing capacity for each test was obtained from the procedure explained before. Correspondingly, the calculated BCR_u and *PRS* parameters for each test are presented in Table 2.

As can be realized from the comparison between the results of tests B-2 and B-1, the 0.5 cm sand layer without the geogrid has a negligible effect on the bearing capacity as BCR_u = 1.06. Therefore, the main contribution of the sand lens on the bearing capacity can be the improvement of the pullout resistance of the geogrid. This is seen from the comparison between the results of tests B-3 and B-4. In test B-3 in which only the geogrid is used, the bearing capacity has increased 25% and the settlement has decreased 33.3% (i.e., BCR_u = 1.25, PRS = 33.3%). But, in test B-4, with a thin layer of sand (thickness = 0.5 cm) placed around the geogrid, the results have improved to 49% increase in the bearing capacity and 46.3% decrease in the settlement (BCR_u = 1.49, PRS = 46.3%). Consequently, the presence of the sand layer around the reinforcing element appears to have important effects on both the bearing capacity and settlement characteristics of the reinforced saturated clay.

The results in Table 2 also show that the ratios of the ultimate settlement (S_u/B) in the reinforced and unreinforced cases are almost identical varying between 24% and 27%. This result is similar to those reported by Shin et al. [19].

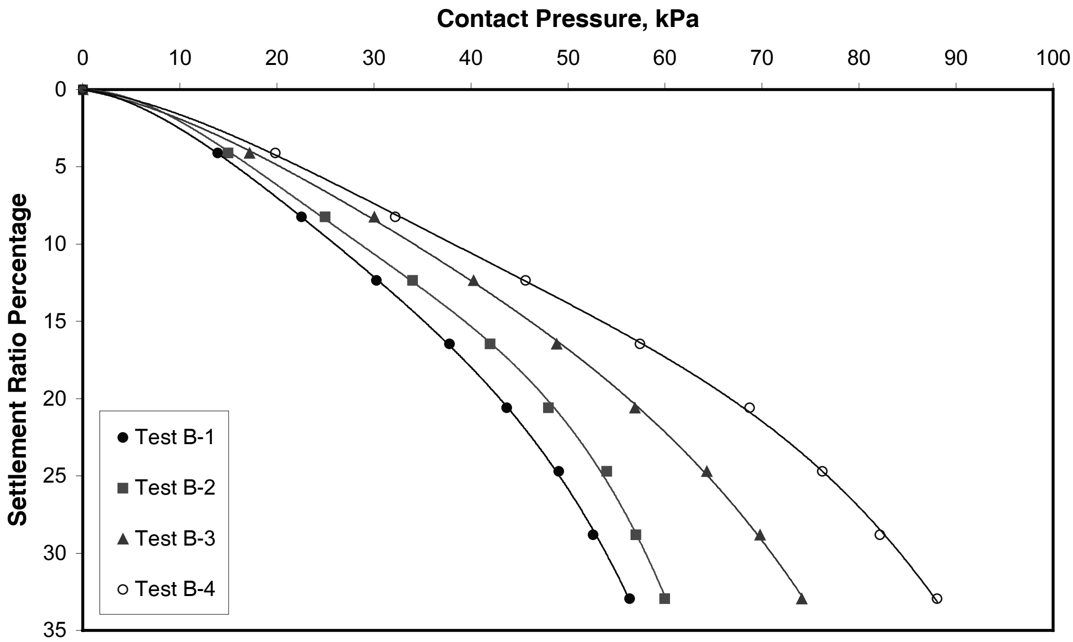

Fig. 3. Load-settlement results in test series B

Table 2. Summary of test results in series B [B = 19 cm, u/B = 0.3, b/B = 5]

Test No.	Sand Lens Thickness, (cm)	Reinforced [R] Unreinforced [U]	$q_{u[R]}$ (kPa)	BCR_u	S_u/B (%)	S_r/B (%)	*PRS* (%)
B-1	0	U	q_u=51	-	27	-	-
B-2	0.5	U	54	1.06	26	23	14.8
B-3	0	R	63.5	1.25	24.5	18	33.3
B-4	0.5	R	76	1.49	25	14.5	46.3

4. COMPARATIVE ANALYSIS

The results of test series A should generally be considered more reliable than those of series B due to the much larger specimens used in series A that could minimize the scale effects on the results. However, because of the adverse effects of the saturation process and the loading method in series A as explained before, a sound and comprehensive comparison between the results of two series may not be attainable. But, one important conclusion can be made from all results that the presence of sand around the geogrid does increase the bearing capacity of the footing due to the increased pullout resistance of the geogrid. This contribution of the sand layer appears to be slightly more pronounced in tests B with 24% increase of BCR_u (see Table 2) whereas in tests A, the maximum increase of BCR_u is 17% corresponding to the test A-5 in Table 1.

Some discrepancy is seen between the results of two test series regarding the settlement behavior and the PRS values. These differences could be attributed to some or all of the following causes:

1. Sample preparation and saturation process were different in two series. The saturation method employed in series A could create a nonuniform density inside the soil with very soft and highly swelled portion near the surface whereas the specimens in series B had a uniform density throughout the soil medium.
2. The applied load in series A, was stress controlled while in series B it was strained controlled, causing the test duration to be 3 hours, and 10 minutes respectively.
3. Consolidation could occur in series A due to the much longer test duration. The presence of the sand layer could act as a drain to speed up the process.

Observations of all specimens after failure revealed that the instability in the geogrid was a pullout failure. This means that the tensile strength of the geogrid was never mobilized in any test because of its high magnitude compared to the frictional resistance of the geogrid. Therefore, in order to more efficiently reinforce a bearing clay soil, elements with smaller modulus and tensile strength like flexible geotextiles may be more appropriate for the reinforcement application in soft soils like a saturated clay, provided the required settlement of the footing for the mobilization of the tensile strength of the geotextile will not proceed the allowable settlement of the footing.

5. CONCLUSIONS

In order to increase the pullout resistance of geogrid used in a reinforced bearing saturated clay layer, an idea of placing sand around the reinforcing element (geogrid) was experimentally examined. Two test series; large scale, and small scale tests were conducted. The following conclusions can be made from this study:

- The use of sand lens around the geogrid appears to increase the bearing capacity with respect to the case when geogrid is only used. This improvement in bearing capacity enhances as the lens thickness increases. This contribution of the sand layer is more pronounced in tests B with 24% increase of BCRu whereas in tests A, the maximum increase of BCRu is 17%.
- The settlement results are not quite comparable. While in test series A the presence of the sand lens caused more settlement to occur, the series B results indicate some decrease in the settlement. Different saturation techniques and loading systems in the series A and B have most likely been the main reasons for this discrepancy. Hence, the saturation method employed in series B is recommended for making saturated clay specimens.
- For the long term behavior of a footing, the presence of a sand lens could speed up the consolidation, causing more settlement to occur in a shorter time period. The lens itself, on the other hand, does not influence the bearing capacity considerably.
- Flexible fabrics with low tensile strengths and modulus like some of geotextiles should be more appropriate than geogrids for reinforced clay applications. This could, however, require more settlement of the footing, which may not be tolerable by the overlying structure.
- Although the results of this study can not quantitatively be applicable for field applications, they qualitatively confirm the

effectiveness of the sand lens in improving the bearing capacity and settlement characteristics of reinforced cohesive soils.

REFERENCES

[1] Binquet, J., and Lee, K. L. (1975a). "Bearing capacity tests on reinforced earth mass.", Jour. of Geotech. Engrg., ASCE, Vol. 101, No. GT12, PP. 1257-1276.

[2] Guido, V. A., Biesiadecki, G. L., and Sullivan, M. J. (1985). "Bearing capacity of a geotextile reinforced foundation.", *Proc. 11th Int. Conf. Soil Mech. and Found. Engrg.,* San Francisco, Vol. 3, PP. 1777-1780.

[3] Guido, V. A., Dong, K. G., and Sweeny, A. (1986). "Comparison of geogrid and geotextile reinforced earth slabs.", *Can. Jour. of Geotech. Engrg*., Vol. 23, No. 1, PP. 435-440.

[4] Guido, V. A., Knueppel, J. d., and Sweeny, M. A. (1987). "Plate loading tests on geogrid-reinforced earth slabs.", *Proc. Geosynthetics'87 Conf*., New Orleans, PP. 216-225.

[5] Khing, K. H., Das, B. M., Puri, V. K., Cook, E. E., and Yen, S. C. (1992). "Bearing capacity of two closely-spaced strip foundations on geogrid-reinforced sand.", *Proc. Earth Reinforced Pract*., Balkema, Fukuoka, Kyushu, Japan, PP. 619-624.

[6] Khing, K. H., Das, B. M., Puri, V. K., Cook, E. E., and Yen, S. C. (1993). "The bearing capacity of a strip foundation on geogrid-reinforced sand.", *Jour. of Geotextiles and Geomembranes*, Vol. 12, No. 4, PP. 351-361.

[7] Takemura, J., Okamura, M., Suesmasa, N., and Kimura, T. (1992). "Bearing capacity and deformations of sand reinforced with geogrids.", *Proc. Earth Reinforced Pract*., Balkema Fukuoka, Kyushu, Japan, PP. 695-700.

[8] [8] Omar, M. T., Das, B. M., Puri V. K., and Yen, S. C. (1993b). "Ultimate bearing capacity of shallow foundations on sand with geogrid reinforcement.", *Can. Jour. of Geotech. Engrg*., Vol. 30, No. 3, PP. 545-549.

[9] Omar, M. T., Das, B. M., Puri, V. K., Cook, E. E., and Yen, S. C. (1993a). "Ultimate bearing capacity of rectangular foundations on geogrid-reinforced sand.", *Geotech. Testing Journal*, ASTM, Vol. 16, No. 2, PP. 246-252.

[10] Yetimoglo, T., Wu, J. T. H., and Saglamar, A. (1994). "Bearing capacity of rectangular footings on geogrid-reinforced sand.", *Jour. of Geotech. Engrg*., ASCE, Vol. 120, No. 12, PP. 2083-2099.

[11] Adams, M. T., and Collin, J. G. (1997). "Large model spread footing load tests on geosynthetic reinforced soil foundations.", *Jour. of Geotech. and Geoenvir. Engrg*., ASCE, Vol. 123, No. 1, PP. 66-72.

[12] Ingold, T. S., and Miler, K. S. (1982). "Analytical and laboratory investigations of reinforced clay.", *Proc. of the 2nd Int. Conf. on Geotextiles*, Vol. 3, Las Vegas, PP. 587-592.

[13] Milligan, G. W. E., and Love, J. P. (1984). "Model testing of geogrids under an aggregate layer on soft ground.", Proc. Sym. on Polymer Grid Reinforcement in Civil Eng., Netlon, London, No. 4.2.

[14] Sakti, J., and Das, B. M. (1987). "Model tests for strip foundation on clay reinforced with geotextile layers.", Transportation Research Record No. 1153, National Academy of Sciences, Washington, D. C., PP. 40-45.

[15] Dawson, A., and lee, R. (1988). "Full scale foundation trials on grid reinforced clay." *Geotech. Special Publication*, No. 18, ASCE, New York, PP. 127-147.

[16] Das, B. M., (1989). "Foundation on sand underlain by soft clay with geotextile at sand-clay interface.", *Geosynthetic'89 Conf*., Vol. 1, San Diego, PP. 203-213.

[17] Sah, S. H. (1990). "Experimental studies on bearing capacity of geosynthetics reinforced saturated clay.", M. Technology Dissertation, UT, Bombay.

[18] Mandal, J. N., and Sah, H. S. (1992). "Bearing capacity tests on geogrid-reinforced clay.", *Jour. of Geotextiles and Geomembranes*, Vol. 11, PP. 327-333.

[19] Shin E. C, Das, B. M., Puri, V. K. Cook, E. E., and Yen, S. C. (1993). "Bearing capacity of a strip foundation on geogrid-

reinforced clay.", *Geotech. Testing Jour.*, ASTM, Vol. 16, No. 4, PP. 534-541.

[20] Sridharan, A., Srinivasa Murthy, B. B., Bindumadhava, and Revanasiddappa, K. (1991). "Technique for using fine-grained soil in reinforced earth.", *Jour. of Geotech. Engrg.*, ASCE, Vol. 117, No. 8, PP. 1147-1190.