Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Cyclic plate load test on geogrid-reinforced granular pad

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ABSTRACT: Results of field cyclic plate load tests on a granular pad with and without geogrid reinforcement are presented. The tests were conducted at the site of the Incheon International Airport in South Korea. The airport is constructed on land reclaimed from the ocean. The granular pads were constructed on the dredged soil. A circular plate was used for the load tests. The maximum depth of reinforcement was kept at 1.5 times the diameter of the test plate. The results of the plate load tests were used to estimate the shear modulus of the granular pad. The increase in the shear modulus due to the inclusion of geogrid reinforcement is also discussed. The shear modulus increase is a function of the stiffness of the geogrid, the spacing between the geogrid layers, the width of the geogrid layers compared to the diameter of the plate. Further investigation is necessary to determine the effect of these parameters.

1 INTRODUCTION

The elastic settlement at the center of flexible surface foundations supported by an unreinforced soil (Figure 1) is generally estimated from the relation,

$$S_e = \Delta\sigma B \frac{1-\mu_s^2}{E_s} I_\rho \qquad (1)$$

where S_e = elastic settlement, $\Delta\sigma$ = net pressure applied on the foundation; B = width of the foundation; μ_s = Poisson's ratio of the soil; E_s = modulus of elasticity of the soil; I_ρ = influence factor which is a function of the length and width of the foundation, or

$$I_\rho = \frac{1}{\pi}\left[\ln\left(\frac{\sqrt{1+m^2}+m}{\sqrt{1+m^2}-m}\right) + m\ln\left(\frac{\sqrt{1+m^2}+m}{\sqrt{1+m^2}-m}\right)\right] \qquad (2)$$

where $m = B/L$; L = length of foundation.

Cyclic load tests in the field can be performed to determine the modulus of elasticity of soil (E_s) supporting the foundation. In some instances, especially in the design of vibrating machine foundations, the shear modulus of the soil (G_s) is determined. Shear modulus is also not sensitive to the location of the ground water table. E_s and G_s are related by the relationship,

$$G_s = \frac{E_s}{2(1+\mu_s)} \qquad (3)$$

Combining Eqs. (1) and (3),

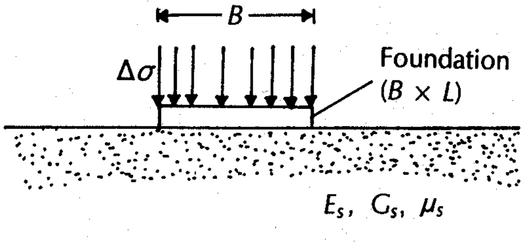

Figure 1. Surface foundation subjected to a load per unit area, $\Delta\sigma$.

$$S_e = \Delta\sigma B \frac{1-\mu_s}{2G_s} I_\rho \qquad (4)$$

During the past ten years or so, several laboratory test results relating to the ultimate and allowable bearing capacities of shallow foundations supported by geogrid-reinforced soils (Figure 2) have been published. They show that the inclusion of geogrid as reinforcement layers in the soil helps reduce the settlement of foundations (Gabr et al., 1998). Thus a reasonable estimate of the reduced elastic settlement of a foundation supported by a soil reinforced with layers of geogrid can be made using Eq. (4) if the increased value of G_s of the mechanically stabilized soil can be determined. Poisson's ratio, μ_s, is not a very sensitive parameter and can be assumed for reasonable results. It is important, however, to realize that the magnitude of G_s of the stabilized soil will be a function of several parameters (Figure 2) including: (a) stiffness of the geogrid; (b) number of geogrid layers in the zone of influence, N; (c) location of the first layer of geogrid below the bottom of the foundation, u/B; (d) width of geogrid layers, b/B; (e) distance between consecutive layers of geogrid, h/B; and (f) total depth of reinforcement, d/B.

This paper reports the results of four cyclic plate load tests conducted in the field on a granular soil pad both with and without geogrid reinforcement layers to observe the effects of various parameters on the shear modulus of soil.

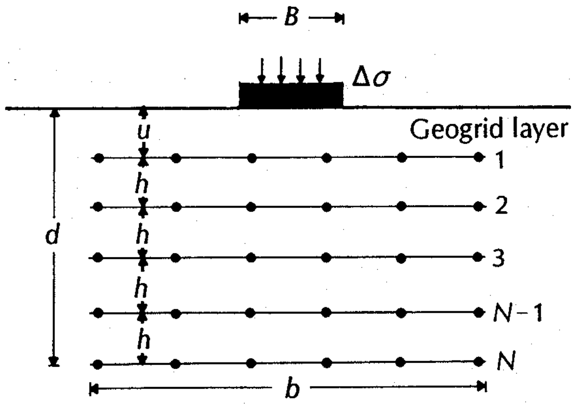

Figure 2. Surface foundation on geogrid-reinforced soil.

2 THEORETICAL BACKGROUND

Cyclic plate load tests in the field are conducted by applying step loads to a test plate, unloading them, and then reloading them. In this manner the elastic rebounds of the soil, s_e, at any stress level $\Delta\sigma$ can be determined (Figure 3a). The variation of $\Delta\sigma$ with s_e can be used to calculate the effect of elastic uniform compression, C_z, of the soil as (Figure 3b),

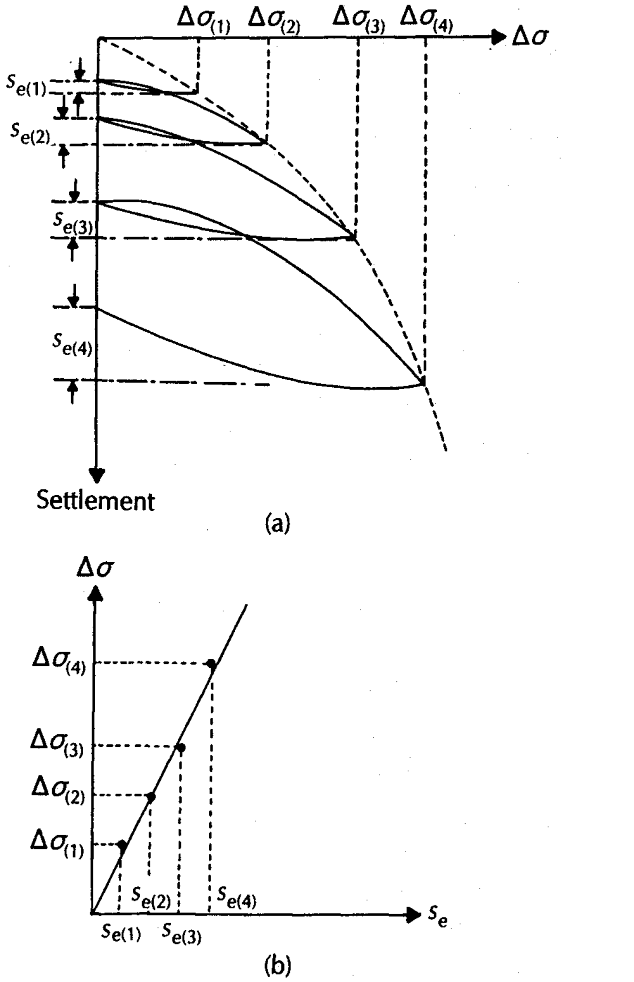

Figure 3. Cyclic plate load tests: (a) plot of $\Delta\sigma$ vs. settlement; (b) plot of $\Delta\sigma$ vs. s_e.

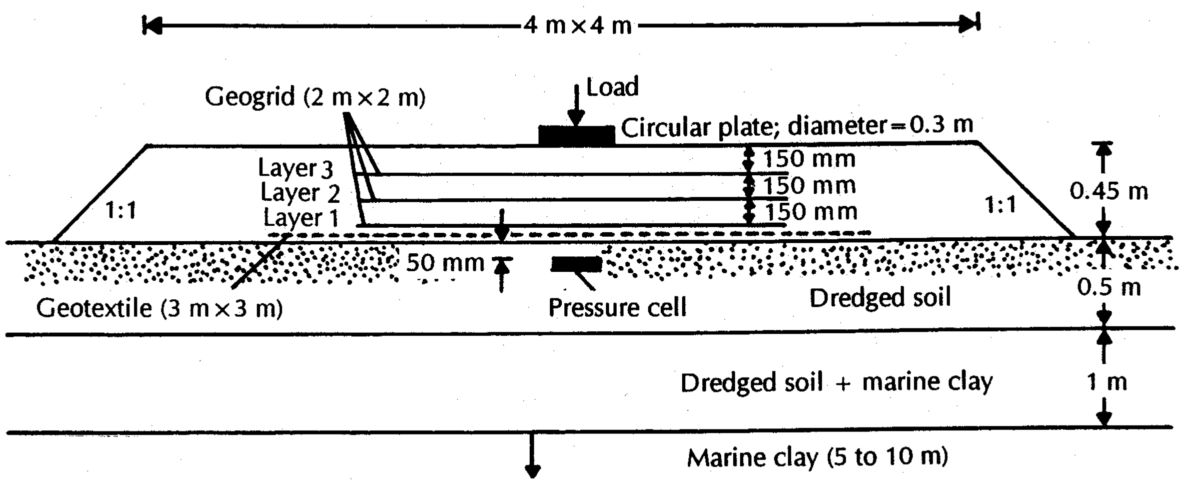

Figure 4. Schematic diagram of the field test arrangement.

$$C_z = \frac{\Delta\sigma}{s_e} \tag{5}$$

Barkan (1962) provided experimental verification to the fact that

$$C_z \propto \sqrt{A} \tag{6}$$

where A = area of the test plate.

The theoretical relationship provided by Barkan for C_z is of the form,

$$C_z = 1.13 \frac{E_s}{1-\mu_s^2} \frac{1}{\sqrt{A}} \tag{7}$$

Combining Eqs. (3) and (7), we obtain,

$$G_s = \frac{C_z (1-\mu_s)\sqrt{A}}{2.26} \tag{8}$$

In most cases, the magnitude of G_s determined by Eq. (8) will be for a strain level of about 10^{-4} to 10^{-3} (Prakash, 1981). This is the most likely strain level to calculate the elastic settlement of shallow foundations.

3 FIELD TEST ARRANGEMENT

A total of four cyclic plate load tests were conducted on four compacted granular soil pads at the site of the Incheon International Airport, South Korea. The airport was being constructed on land reclaimed from the ocean. Figure 4 shows the schematic diagram of the test arrangement, and Figure 5 gives the grain-size distribution of the soil layers shown in Figure 4. The loading plate used for the tests had a diameter of 0.3 m (B). The physical properties of the geotextile and geogrid used for soil reinforcement are given in Table 1, and details of the plate load tests are given in Table 2. The geotextile layer was used primarily for separation purposes. It can be seen from Table 2 that

-- In all cases, the d/B ratio was kept at 1.5. Laboratory studies by Omar et al. (1993) demonstrated that the magnitude of d/B for consideration of the stress influence as related to bearing capacity and settlement is about 1.5 for square foundations, and it increases to about 2 for strip foundations.

-- The magnitude of h/B for test Nos. 3 and 4 was kept at 0.5. Also, the magnitudes of u/B were 1.5, 1.0, and 0.5 for test Nos. 2, 3, and 4, respectively.

-- The magnitude of b/B was kept at about 6 for test Nos. 2, 3, and 4.

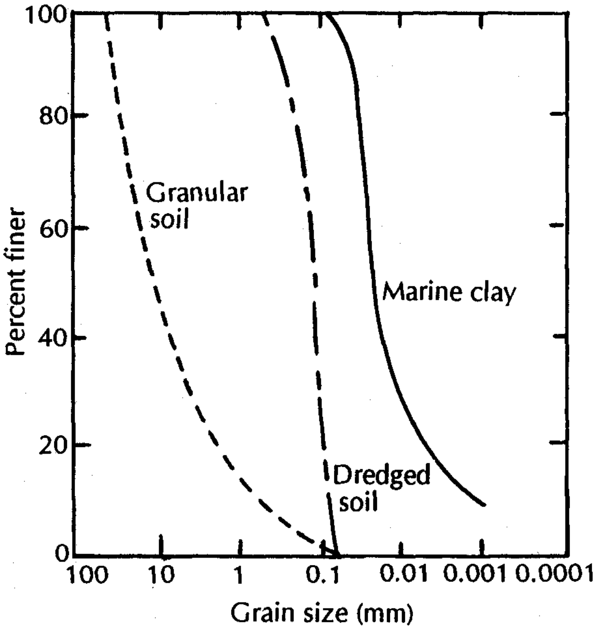

Figure 5. Grain-size distribution of the soil layers shown in Figure 3.

Table 1. Physical properties of geosynthetics used for soil reinforcement.

Property	Geogrid	Geotextile
Polymer type	Polypropylene	Polyester
Manufacturing type	Bi-axial	Non-woven
Product size	4m × 50m	8.5m × 50/100m
Mass per unit area (g/m^3)	650	700
Thickness (mm)	6.5 (junction)	4.5
Maximum tensile strength (kN/m)	MD-37.6; CD-40.8	1.745
Yield point elongation (%)	MD-10.1; CD-12.4	50 to 120
Tensile strength at 2% elongation (kN/m)	MD-20.2; CD-14.1	——
Tensile strength at 5% elongation (kN/m)	MD-32.3; CD-27.5	——
Aperture size (mm)	34 (MD) × 27 (CD)	——
Carbon black content (%)	2	——

Note: MD–machine direction; CD–cross-machine direction

Table 2. Details of plate load tests.

Test No.	Reinforcement details
1	No reinforcement
2	Reinforcement layer No. 1 (that is, one layer of geotextile and one layer of geogrid only)
3	Reinforcement layers No. 1 and No. 2
4	Reinforcement layers No. 1, No. 2, and No. 3

4 PLATE LOAD TEST RESULTS

Figures 6(a) and 7(a) show the results of plate load tests 1 and 3, respectively. The elastic rebounds at various stress levels for these tests were determined and are plotted in Figures 6(b) and 7(b). A similar procedure was also followed for tests 2 and 4. A summary of the coefficient of elastic uniform compression determined for all four field tests described in Table 2 is shown in Table 3. Assuming μ_s to be 0.3 and using Eq. (8), the experimental values of G_s for all tests were determined and are also shown in Table 3. From this table the following general observations may be made.

-- The inclusion of geogrid layers as reinforcement helps to increase the overall stiffness and, thus, the shear modulus of the soil.

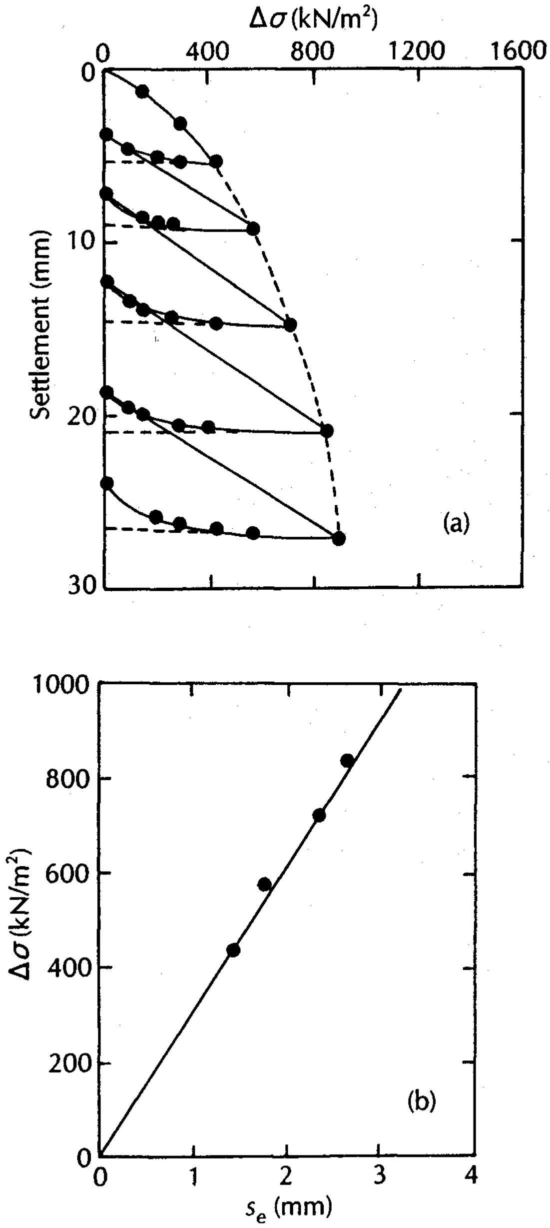

Figure 6. Results of plate load test No. 1.

Table 3. Summary of test results.

Test No.	C_z (kN/m^3)	Poisson's ratio, μ_s[a]	G_s[b] (kN/m^3)
1	30.25×10^4	0.3	24,910
2	33.1×10^4	0.3	27,240
3	39.1×10^4	0.3	32,180
4	46.7×10^4	0.3	38,430

[a] assumed; [b] Eq. (8)

-- Keeping the total depth of reinforcement constant, the shear modulus gradually increases with the increase in the number of layers of reinforcement.

-- For this study, with three layers of reinforcement in place, G_s increased by about 54%. With only one layer of reinforcement at $d = 1.5B$, the magnitude of G_s increased by only

9%. This was expected since the zone of stress influence for a circular plate is about 1.5B below the plate.

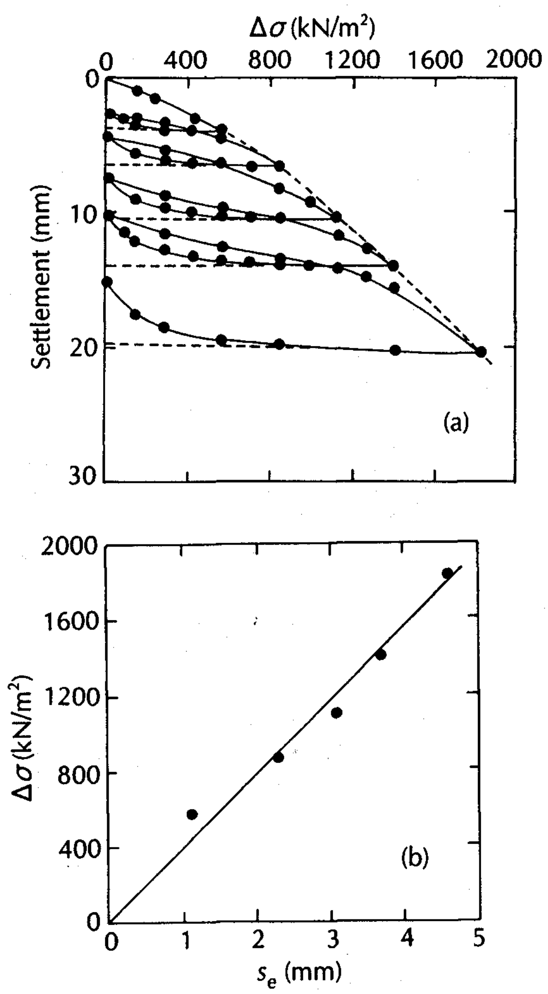

Figure 7. Results of plate load test No. 3.

5 CONCLUSIONS

A limited number of cyclic plate load test results on granular pads both with and without reinforcement using layers of geogrid were presented. Based on the results of the plate load tests, the variation of the shear modulus of the mechanically stabilized earth was determined. For the present study, the maximum depth of reinforcement was kept at 1.5 times the diameter of the test plate; however, the number of reinforcement layers was varied. Results show that, for the same maximum depth of reinforcement, the shear modulus increases with the number of layers in place (that is, with the decrease in the spacing between reinforcing layers). The shear modulus of the mechanically stabilized material can be used to estimate the elastic settlement of the foundation.

Further study is recommended to determine the optimum values of u/B, b/B, and h/B for deriving the maximum benefit for improving the shear modulus of the mechanically stabilized soil mass below the foundation.

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