Dynamic Loading Induced Settlement of Strip Foundation on Geogrid-Reinforced Clay

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SYNOPSIS: Laboratory model tests to determine the supported by geogrid-reinforced saturated clay and presented. In conducting the test, the foundation was cyclic load was then super-imposed over the static settlement with the intensity of the static load and also presented. load. The variation of the maximum permanent subjected to a low-frequency cyclic load are initially subjected to an allowable static load. The permanent settlement of a surface strip foundation the intensity of the amplitude of the cyclic load are

INTRODUCTION

The study of the behavior of soils and foundations under various types of dynamic load applications was initiated during the 1960s and 1970s. During that period, a limited number of studies were conducted to determine the dynamic bearing capacity of shallow foundations and the resulting settlement (e.g. Triandafilidis, 1965; Vesic et al., 1965; Prakash and Chummar, 1967). Experimental observations to determine the load-settlement relationships of surface square foundations supported by sand & clay and subjected to transient loading were reported by Cunny and Sloan (1961), Shenkman and Mckee (1961), and Jackson and Hadala (1964). The results of most of these studies are summarized by Das (1992). Raymond and Komos (1978) presented experimental results for the settlement of a strip foundation on granualr soil under the effects of controlled cyclic vertical stress.

Recently, several attempts have been made to improve the ultimate and allowable bearing capacities of shallow foundations. Shin et al. (1993) conducted laboratory model tests on a surface strip foundation supported by geogrid-reinforced saturated clay (Fig. 1) to obtain the critical parameters required to derive the maximum ultimate bearing capacity for a given clay-geogrid combination. In Figure 1, B is the width, N is the number of geogrid layers each having a width b, u is the distance between the bottom of the foundation and the first geogrid layer, and h is the vertical distance between two consective geogrid layers. The total depth of geogrid reinforcement, d, can be expressed as

$$d = u + (N - 1)h \qquad (1)$$

The critical parameters derived from the study of Shin et al. (1993) were as follows:

$(u/B)_{cr} \approx 0.4$
$(b/B)_{cr} \approx 4.5$ to 5.0
$(u/B)_{cr} \approx 1.75$ to 1.8

In many instances, shallow foundations support vibrating machinery which may transmit cyclic load to the foundation. The purpose of this paper is to report the results of some laboratory model tests conducted to evaluate the nature of settlement of a surface strip foundation supported by a geogrid-reinforced saturated clay while being subjected to combination of static and cyclic loading of low frequency. To the knowledge of the author, results of such studies have not yet been reported in the literature.

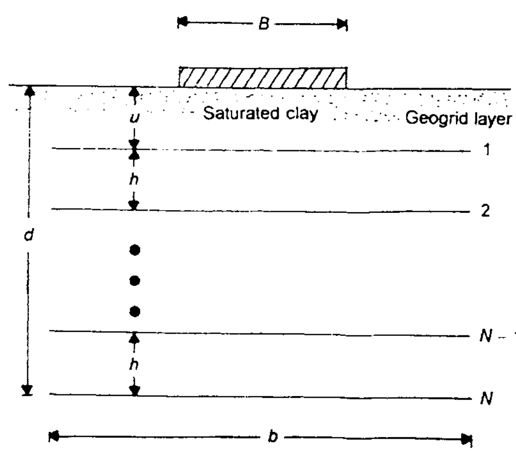

Fig.1 Strip foundation on geogrid-reinforced saturated clay

LABORATORY MODEL TESTS

Laboratory model tests were conducted in a clayey soil, the grain-size distribution of which is shown in Figure 2. About 98% of the soil could pass through a No. 200 US sieve (0.075-mm opening). The liquid and plastic limits of the soil were 44% and 24%, respectively. Tensar BX1100 geogrid was used as the reinforcing material. The physical properties of the geogrid are as follows:

(a) Structure: punctured sheet drawn
(b) Polymer: polypropylene/high-density polyethylene copolymer
(c) Junction method: unitized
(d) Aperture size:
- Machine direction: 25 mm
- Cross-machine direction: 33 mm

(e) Rib thickness: 0.76 mm
(f) Junction thickness: 2.29 mm

Laboratory model tests were conducted in a box measuring 915 mm (length) × 229 mm (width) × 607 mm (height). Three sides of the box were made of wooden planks and the remaining length side was made of Plexiglas. The model test box was braced with angle irons to avoid yielding during soil placement and actual testing. The inside of the model test box was made as smooth as possible to reduce friction with the edges of the model foundation during the application of load.
The model foundation was made of hard wood with dimensions of 76 mm (width) × 229 mm (length) × 38 mm (thickness). To ensure rigidity, an aluminum plate with the same width as the model foundation was mounted on its top. The base of model foundation was made rough by cementing a thin layer of sand to it with epoxy glue. On the top of the foundation, a hole was made to ensure that the applied centric load during model tests remained vertical.

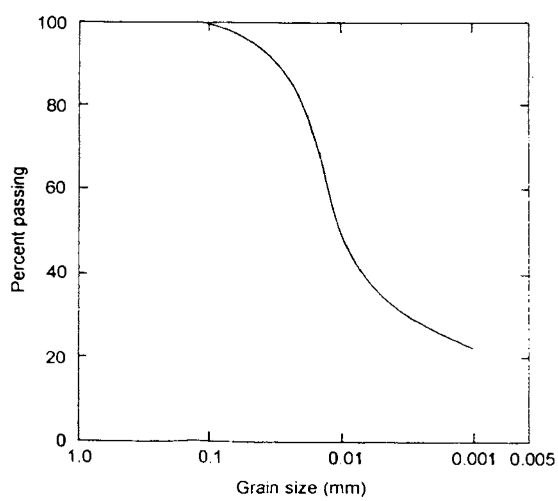

Fig. 2 Grain-size distribution of the clayey soil

The clayed soil obtained from the field was pulverized in the laboratory and mixed with predetermined amount of water. For uniform moisture distribution, the moist soil was put in several plastic bags which were then sealed and kept in a moist curing room for about a week before use. Table 1 shows the average physical properties of the compacted moist clay during the tests.

Table 1. Average Properties of Clay During Tests

Parameter	Quantity
Moisture content	34%
Moist unit weight	18 kN/m^3
Degree of saturation	96%
Undrained shear strength	12 kN/m^2

For actual model tests, the moist soil was placed in the test box and compacted in 25-mm thick layers by a flat-bottomed hammer. The geogrid layers were placed at desired values of u/B and h/B. The model foundation was placed on the surface of the compacted clay. Two types of test were conducted: (1) static loading tests to determine the ultimate bearing capacity, and (2) cyclic loading tests to determine the permanent settlement.

For the static loading tests, the load to the foundation was applied by a hydraulic jack. The load and corresponding settlement were measured by a proving ring and a dial gauge, respectively. The static tests were conducted on reinforced and unreinforced clay. The cyclic loading tests

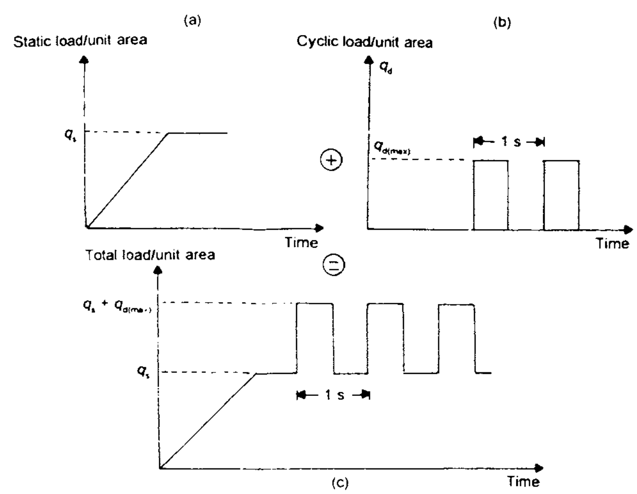

Fig. 3 Cyclic load test

were conducted by first applying a static load per unit area, q_s, of the type shown in Figure 3(b) was applied to the foundation. The frequency of the cyclic load was 1 cps. A Universal testing machine was used for the application of the static and cyclic loads on the foundation. Permanent settlement of the foundation due to the cyclic load only (s_d) was measured along with the number of load cycles. The load and corresponding settlement were measured by a loadcell and a LVDT. The number of load cycles and the corresponding foundation settlement were recorded by a data acquisition system.

Table 2. gives the details of the various test parameters. It is important to point out that Tests 2 through 11 were conducted with the geogrid reinforcement in place. For all of these tests the critical values of u/B, b/B, and d/B determined by Shin et al. (1993) were used. Also, h/B for all tests was kept at 1/3.

MODEL TESTS RESULTS

Figure 4 shows the experimental variation of the load per unit area versus s/B (s=foundation settlement) obtained from the bearing capacity Tests 1 and 2. The magnitude of s/B at ultimate load for reinforced and unreinforced cases was approximately the same. The magnitude of q_u and $q_{u(R)}$ obtained from Tests 1 and 2 was, respectively, 61 kN/m^2 and 86 kN/m^3, thus giving a bearing capacity ratio, BCR = $q_{u(R)}/q_u$ = 1.41.

Table 2. Details of Test Parameters

Test Series	Test No.	$q_s/q_{u(R)}$ (%)	$q_{s(max)}/q_{u(R)}$ (%)	Comments
I	1	-	-	Static test for q_u without reinforcement
	2	-	-	Static test for $q_{u(R)}$ with reinforcement u/B=0.4, h/B=1/3, b/B=5, d/B=1.73
II	3	31.7	3.4	Cyclic test with reinforcement
	4	31.7	7.4	u/B=0.4, h/B=1/3, b/B=5, d/B=1.73
	5	31.7	14.6	(See Fig.1 for u, b, h, and d)
III	6	23.4	3.4	
	7	23.4	7.4	
	8	23.4	14.6	
IV	9	14.6	3.4	
	10	14.6	7.4	
	11	14.6	14.6	
V	12 .	23.4	3.4	Cyclic test without reinforcement
	13	23.4	7.4	
	14	23.4	14.6	

Note: q_u = ultimate static bearing capacity without geogrid reinforcement; $q_{u(R)}$ = ultimate static bearing capacity with geogrid reinforcement.

Figures 5, 6, 7 and 8 show plots for the foundation settlement results from the application of cyclic load only (s_d) conducted in Series II, III, IV and V, respectively. Based on the plots shown in these figures it appears that, for a given $q_s/q_{u(R)}$ and $q_{d(max)}/q_{u(R)}$ combination, the general nature of the variation of s_d/B with logarithm of the number of load cycle applications (log n) is as shown in Figure 9.

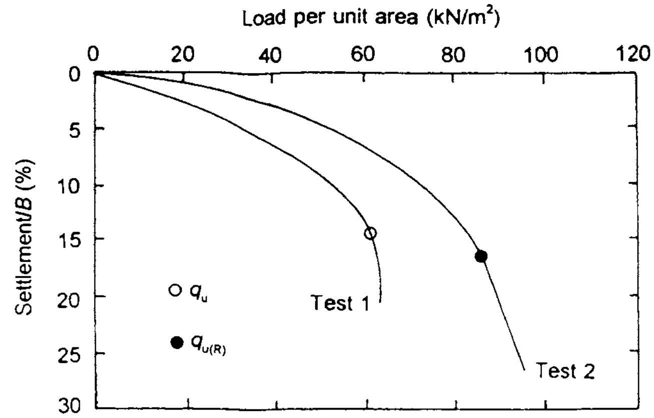

Fig. 4 Plot of load per unit area versus settlement (Tests 1 and 2)

The plot of s_d/B versus log n can be divided into three zones. Zone I is a rapid settlement zone ($n \le n_r$) during which a major portion of the ultimate permanent settlement takes place.
The permanent settlement due to cyclic load application at n = n_{cr} is equal to $s_{d(r)}$. The magnitude of n_r is about 10. Following the rapid settlement zone, there is a zone (Zone II) of slowly retarding rate of settlement between n = n_r and n = n_{cr}. Zone III is a zone in which practically no additional permanent settlement takes place due to cyclic load application.

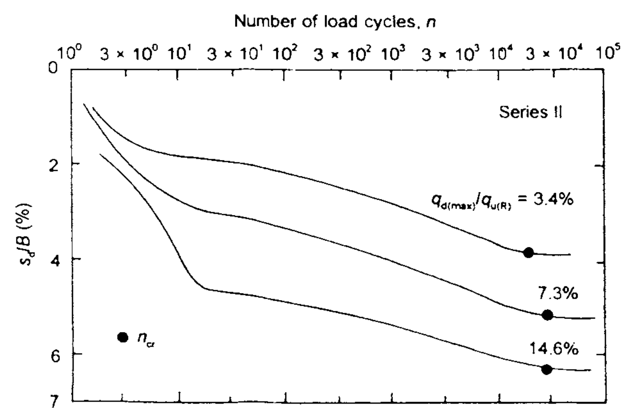

Fig. 5 Variation of s_d/B with n, $q_s/q_{u(R)}$ = 31.7%

Hence, for allpractical purposes, the ultimate permanent settlement due to cyclic load application may be taken as $s_{d(u)}$ which corresponds to n = n_{cr}.

Using the concept described above, the variations of $s_{d(u)}/B$ for different combinations of $q_{d(max)}/q_{u(R)}$ and $q_s/q_{u(R)}$ were determined and are plotted in Figure 10. Based on the plots, the following general conclusions can be drawn:

(1) For a given value of $q_{d(max)}$, the magnitude of the permanent settlement increases with the increase in q_s.

(2) For a given value of q_s, the magnitude of the permanent settlement increases with the increase of $q_{d(max)}$.

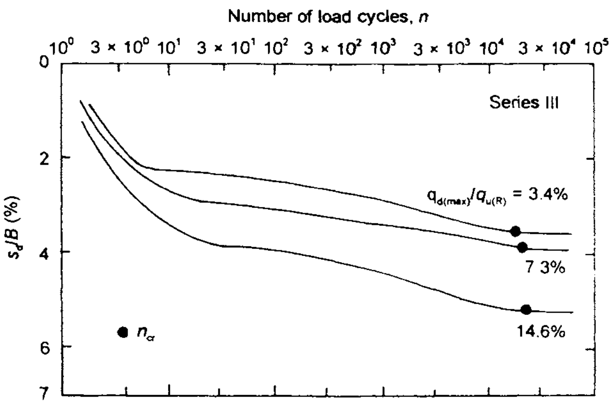

Fig. 6 Variation of s_d/B with n, $q_s/q_{u(R)}$ = 23.4%

For the present tests, with minor deviations, the permanent settlement due to cyclic loading can be expressed as (for 4% ≤ $q_{d(max)}/q_{u(R)}$ ≤ 15%)

$$\frac{s_{d(u)}}{B}(\%) = 0.16\left[\frac{q_{d(max)}}{q_{u(R)}}(\%)\right] + 8.33\log\left[\frac{q_s}{q_{u(R)}}(\%)\right] - 8.6 \quad (2)$$

It can also be seen from Figures 5, 6, and 7 that the magnitude of n_{cr} for series II, III, and IV was 2×10^4 - 2.5×10^4, 1.8×10^4 - 2.3×10^4, and 1.5×10^4 - 1.7×10^4, respectively.

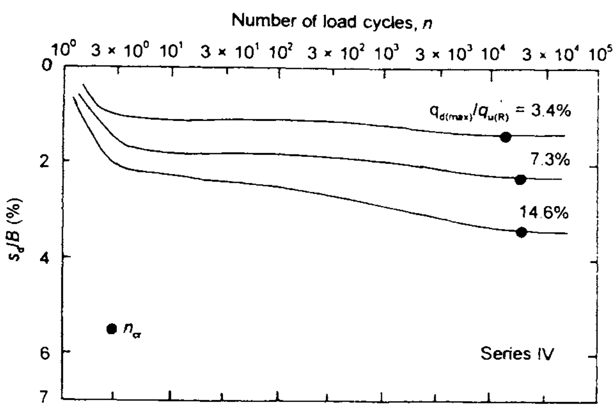

Fig. 7 Variation of s_d/B with n, $q_s/q_{u(R)}$ = 14.6%

Hence it appears that the magnitude of n_{cr} increases with the increase in q_s and $q_{d(max)}$. A comparison of the permanent settlements shows that full depth geogrid reinforcement can decrease the permanent settlement of the foundation by 20% to 30% due to cyclic loading.

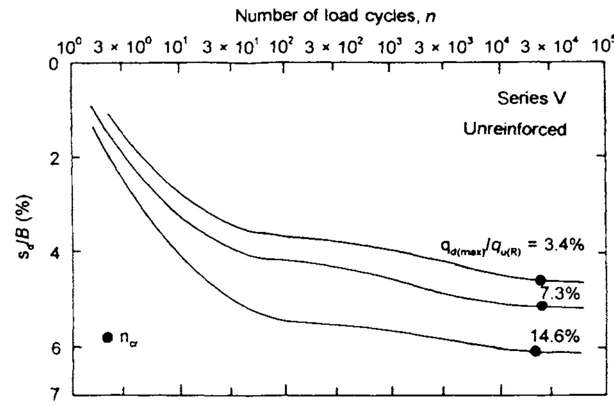

Fig. 8 Variation of s_d/B with n, $q_s/q_{u(R)}$ = 23.4%

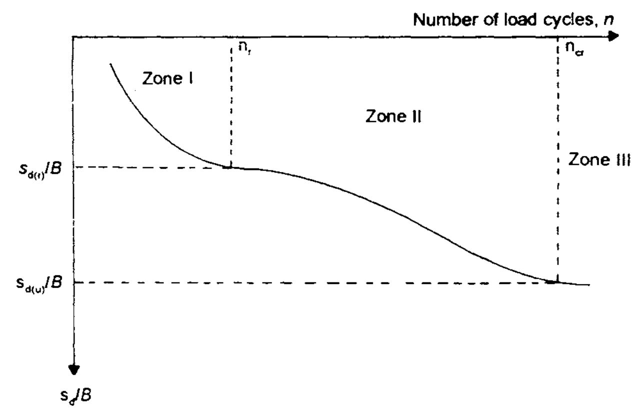

Fig. 9 General nature of variation of s_d/B with n

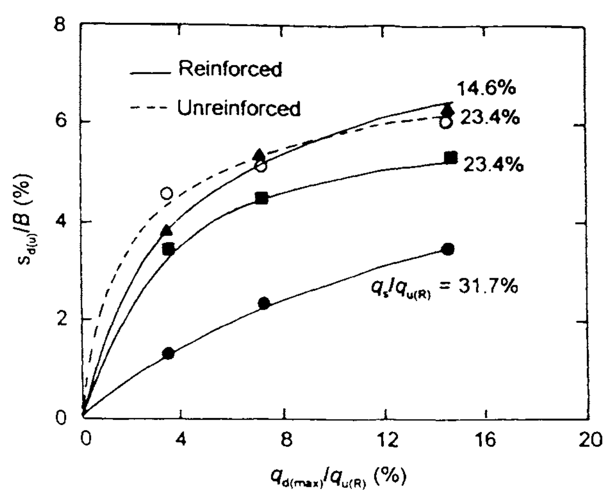

Fig. 10 Plot of s_d/B versus $q_{d(max)}/q_{u(R)}$ for various values of $q_s/q_{u(R)}$

CONCLUSIONS

Laboratory model tests to estimate the permanent settlement of a surface strip foundation supported by geogrid-reinforced saturated clay and subjected to low-frequency cyclic loading have been presented. Based on the model test results, the following conclusions can be drawn:

1. For a given amplitude of the cyclic load intensity, the maximum permanent settlement increases with the increase in the intensity of the static load.

2. For a given intensity of static loading, the maximum permanent settlement increases with the increase in the amplitude of the cyclic load intensity.

3. Full depth geogrid reinforcement may reduce thepermanent settlement of a foundation by about 20% to 30% compared to one without reinforcement.

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