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SYNOPSIS: Laboratory model test results for the permanent settlement of a surface square foundation supported by a sand layer and subjected to a sustained static load superimposed by a cyclic load has been presented. Based on the model test results, the nature of variation of the permanent settlement of the foundation with the intensity of the static loading and the amplitude of the cyclic load intensity are presented.

INTRODUCTION

Settlement of foundations due to dynamic loading has been studied by several investigators in the past. Cunny and Sloan (1961), Shenkman and McKee (1961), Carroll (1963), and Jackson and Hadala (1964) made load-settlement observations of square foundations supported by sand and clayey soils while being subjected to transient loading. Raymond and Komos (1978) conducted laboratory model tests with strip surface foundations on sand in which the foundation was subjected to a cyclic load of rectangular wave form in order to measure the variation of permanent settlement with the number of applied load cycles. For those tests, no sustained static load was applied to the foundation. Brummund and Leonards (1972) studied the effects of the peak acceleration and transmitted energy on the permanent settlement of shallow square surface foundations on sand being subjected to cyclic loading. In that study the frequency of the cyclic load varied from 18 to about 60 Hz.

The present paper relates to a laboratory model study to evaluate the permanent settlement of a square surface foundation on dense sand when subjected to a combination of sustained static and cyclic loading. The cyclic load had a frequency which was well below the resonant frequency of the foundation.

LABORATORY MODEL TESTS

Only one type of sand was used for the present model tests. The sand had 100% passing U.S. No. 20 (0.85 mm opening) sieve, 26% passing U.S. No. 40 (0.425 mm opening) sieve, and 0% passing U.S. No. 60 (0.25 mm opening) sieve. The grain size distribution curve is shown in Fig. 1.

Laboratory tests were conducted by using a square model foundation measuring 76.2 mm x 76.2 mm (B x B). The base of the foundation was made rough by applying glue on it and rolling it over sand. The tests were conducted in a Plexiglas box having dimensions of 760 mm x 760 mm x 760 mm. To conduct a test, sand was poured into the box by raining in 25.4 mm thick layers. The accuracy of sand placement during raining was checked by placing small cans with known volumes at different locations in the box. The average unit weight of the compacted sand during the tests was 17.51 kN/m^3 at a relative density of 76%. The angle of friction at that average density of compaction was 39.5° (triaxial compression test).

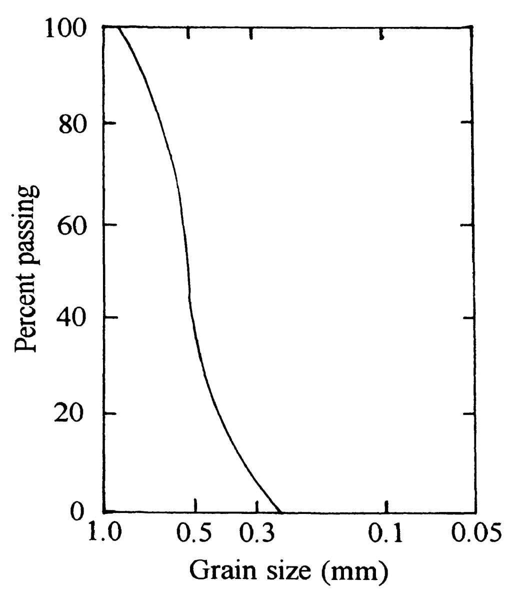

Fig. 1 Grain-size distribution of sand

In this test program, two series of tests were conducted. Series A was conducted to determine the ultimate static bearing capacity, and Series B was conducted to obtain the magnitude of foundation settlement under combined static and cyclic loading. All tests were conducted for surface foundation condition. For the static bearing capacity tests (Series A), load to the model foundation was applied by a hydraulic jack and the corresponding settlement was measured by a dial gauge. Tests in Series B were conducted using a Universal testing machine. Following are the steps for a cyclic load test:

Step 1. Application of an allowable static load of intensity q_s with known ultimate bearing capacity (q_u) from Series A (Note: $q_s = q_u/FS$, where FS = factor of safety)

Step 2. Superimposition of a cyclic load, the amplitude of which had an intensity of $q_{d(max)}$ and observation of the permanent settlement of the foundation by a data acquisition system. Figure 2 shows the sequence of loading. The time period of the cyclic load was kept at 1s for all tests. Table 1 gives the details of the laboratory test parameters (Series B).

TABLE I. Laboratory Test Parameters - Series B

Series	FS	q_s/q_u (%)	$q_{d(max)}/q_u$
B-1	3	33.3	4.3, 7.5, 10.3, 14.5, 22.5
B-2	4	25.0	4.3, 7.5, 10.3, 14.5, 22.5
B-3	8	12.5	4.3, 7.5, 10.3, 14.5, 22.5

MODEL TEST RESULTS

The plot of the load per unit area versus s/B (s = foundation settlement) obtained from test series A is shown in Fig. 3. It can be seen from the plot that the ultimate bearing capacity is about 64 kN/m^2 at s/B ≈ 3%.

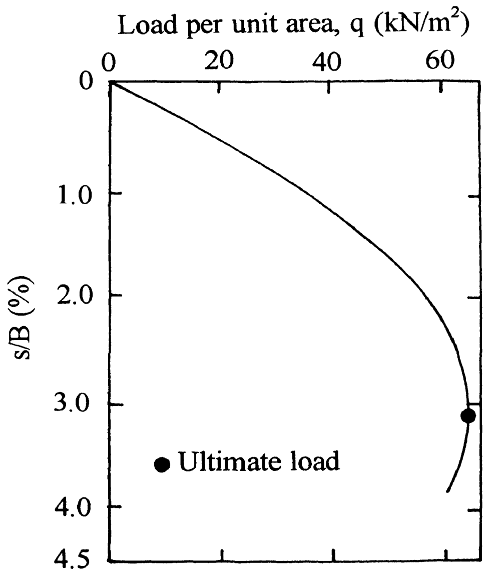

Fig. 2 Nature of load application–Series B

For the tests conducted in Series B, the general nature of the variation of foundation settlement was of the type shown in Fig. 4. In this figure, s_s is the settlement due to the application of static load of intensity q_s, and n is the number of cyclic load applied. The net settlement due to the application of cyclic load can be given as

$$s_d = s = s_s \quad (1)$$

where s_d = settlement of the model foundation due to cyclic load only, and s = total settlement.

The magnitude of s_d generally increases with the number of load cycles (n) up to an approximate maximum value of $s_d = s_{d(u)}$ at $n = n_{cr}$. For $n > n_{cr}$, the slope of $\Delta s/\Delta n$ is practically zero or negligible. Hence for all practical purposes $s_{d(u)}$ may be taken as the ultimate permanent settlement.

Figures 5, 6, and 7 show the plots of s_d versus n for various values of $q_{d(max)}/q_u$ and q_s/q_u as conducted in Test Series B-1, B-2, and B-3. For each plot, the location of n_{cr} has been identified. Based on the experimental results shown, the following general conclusions can be drawn.

1. For a given value of q_s/q_u = FS and number of cycles of load application the magnitude of s_d/B increases with increase of $q_{d(max)}/q_u$.

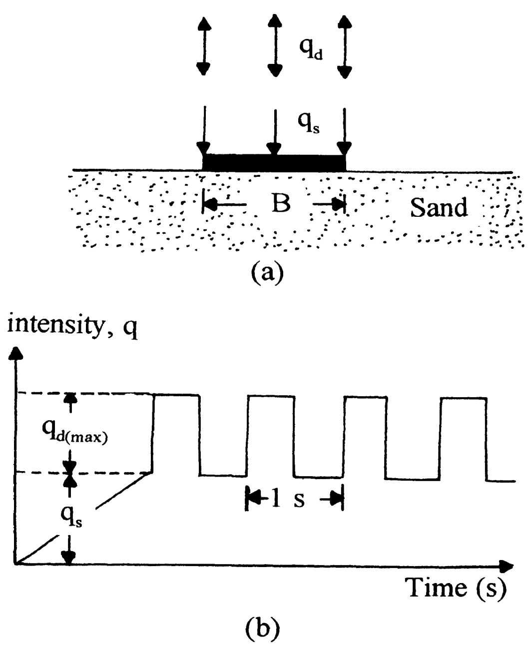

Fig. 3 Plot of load per unit area versus s/B

2. The magnitude of n_{cr} varies between 2.5 × 10^5 to 3.5 × 10^5 cycles irrespective of the combination of q_s/q_u and $q_{d(max)}/q_u$.

3. For given values of $q_{d(max)}/q_u$ and n, the magnitude of s_d/B increases with an increase in q_s/q_u.

Based on the definition of ultimate permanent settlement [$s_{d(u)}$] at n = n_{cr} as shown in Fig. 4, the experimental values of $s_{d(u)}$ were determined from Figs. 5, 6, and 7 and are plotted in Fig. 8. Within the limits of the test results it appears that, for a given value of q_s/q_u and $q_{d(max)}/q_u$ > about 7.5%, the plot of $q_{d(max)}/q_u$ vs $s_{d(u)}/B$ is linear. Also, the slopes of the lines for the plots $q_{d(max)}/q_u$ vs. $s_{d(u)}/B$ are approximately the same. Figure 8 clearly demonstrates that

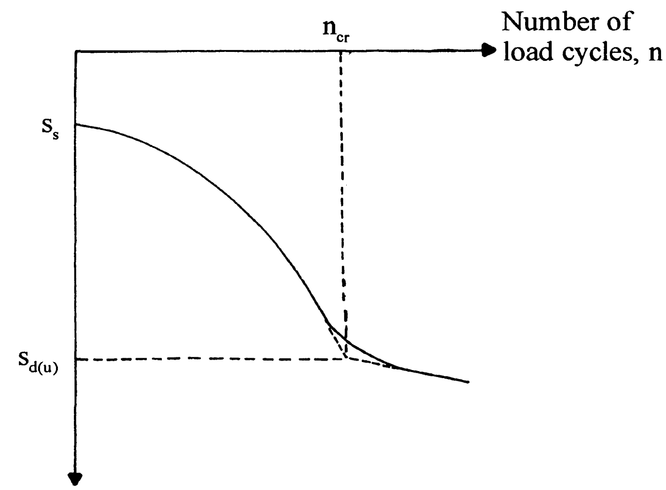

Fig. 4 Nature of variation of settlement–Series B

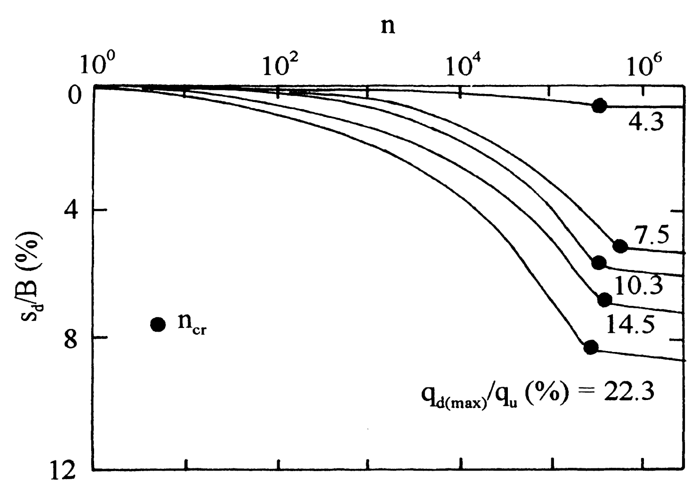

Fig. 5 Variation of s_d/B with n (q_s/q_u = 33.5%)

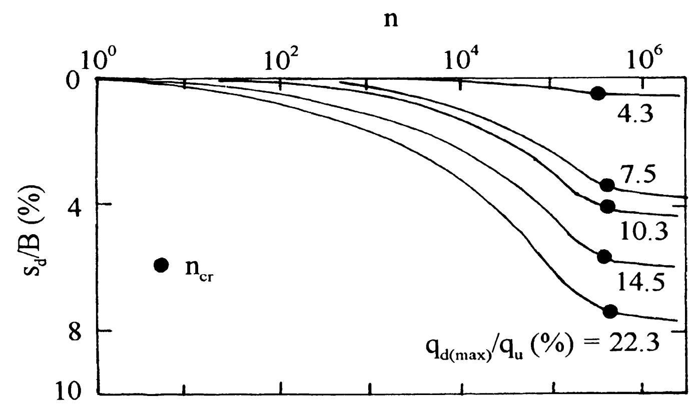

Fig. 6 Variation of s_d/B with n (q_s/q_u = 25%)

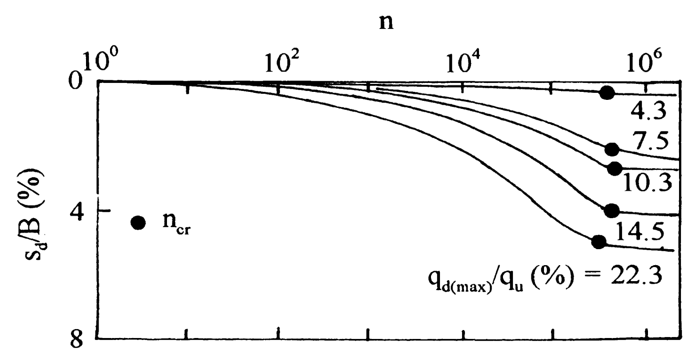

Fig. 7 Variation of s_d/B with n (q_s/q_u = 12.5%)

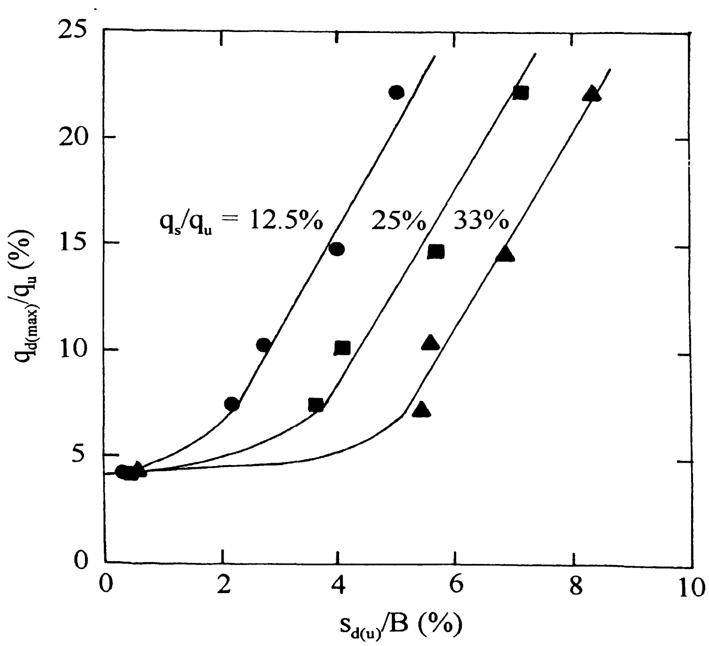

Fig. 8 Variation of $q_{d(max)}/q_u$ with $s_{d(u)}/B$

the magnitude of the intensity of static load has a large influence on $s_{d(u)}$.

Figure 9 shows the plot of $s_{d(u)}/s_s$ (for definition of s_s see Fig. 4) vs. $q_{d(max)}/q_u$ for various values of q_s/q_u. From the plot it can be seen that, in spite of some scatter, the variation can be expressed by a single curve. Also, for $q_{d(max)}/q_u < 4\%$ the permanent settlement due to dynamic loading is practically negligible.

CONCLUSIONS

Laboratory model test results to determine the cyclic load– induced settlement of a surface square foundation supported by a layer of sand have been reported. Based on test results the following conclusions can be drawn.

1. The ultimate settlement, $s_{d(u)}$, due to cyclic load is a function of $q_{d(max)}/q_u$, q_s/q_u, and degree of compaction of the soil.

2. For a given sustained load intensity (q_s) and number of load cycles, the magnitude of s_d increases with $q_{d(max)}$.

3. For similar values of $q_{d(max)}$ and number of load cycles, the magnitude of s_d increases with q_s.

4. For a soil with a given degree of compaction, the ratio of $s_{d(u)}/s_s$ bears a unique relationship with $q_{d(max)}/q_u$ irrespective of the combination of $q_{d(max)}/q_u$ and q_s/q_u.

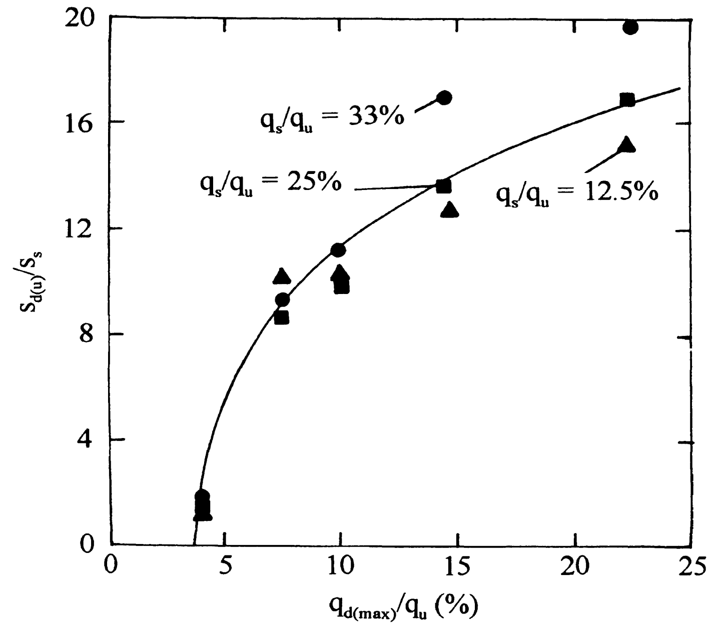

Fig. 9 Variation of $s_{d(u)}/s_s$ with $q_{d(max)}/q_u$

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