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CYCLIC LOAD-INDUCED SETTLEMENT OF FOUNDATIONS ON CLAY

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ABSTRACT

Laboratory model test results for estimating the permanent settlement of a surface strip foundation supported by a saturated clay are presented. The tests were conducted with one model foundation and one clay soil. The model foundation was subjected to an initial static load, and then a cyclic load was superimposed on it. The magnitude of the static load intensity and the amplitude of the intensity of cyclic load were varied. Based on the model test results, relationships for the permanent foundation settlement and intensities of the static and cyclic load are presented.

KEYWORDS

Cyclic load, permanent settlement, saturated clay, static load, strip foundation

INTRODUCTION

Experimental studies relating to the settlement of shallow foundations under dynamic loading were initiated during the 1960's. The purpose of this paper is to summarize the results of some laboratory model tests conducted to determine the permanent settlement of a surface strip foundation supported by a near-saturated clay while being subjected to a static load superimposed by a cyclic load of low frequency (1 cps; Fig. 1). In Fig. 1, q_s is the intensity of static load and q_d is the intensity of the cyclic load with an amplitude of $q_{d(max)}$. The cyclic load was applied to the model foundation after a lapse time which was sufficient for the settlement of the foundation due to the initial static load to cease.

LABORATORY MODEL TESTS

The clay soil used for the model tests had about 98% passing U.S. No. 200 sieve. For conducting the model tests, the soil collected from the field was pulverized and mixed with water. The moist soil was placed in several bags and sealed. The bags were placed in a moist curing room for about a week before use.

Model tests were conducted in a box measuring 915 mm (length) \times 229 mm (width) \times 607 mm (height). The box was braced with angle irons to avoid yielding during soil compaction and actual testing. The model foundation was made of hard

wood and had dimensions of 76.2 mm (width, B) \times 229 mm (length) \times 38.1 mm (thickness).

The moist soil was compacted in 25.4-mm thick layers in the test box. The average properties of the clay soil in the compacted condition are given below.

Average moisture content	33.4%
Average moist unit weight	18.58 kN/m ³
Average degree of saturation	98%
Average undrained shear strength	11.9 kN/m ²

The model foundation was placed on the surface of the compacted clay. Two types of tests were conducted in the laboratory.

1. Static Ultimate Bearing Tests. These tests were conducted to determine the ultimate bearing capacity (q_u) and the corresponding settlement (s_u). Load to the foundation was applied by a hydraulic jack. A proving ring was used to measure the load, and a dial gauge were used to measure the corresponding settlement.

2. Cyclic Load Tests. These tests were conducted by first applying an allowable static load of intensity q_s on the foundation. Thus the factor of safety (FS) against ultimate bearing capacity failure is

$$FS = q_u/q_s \quad (1)$$

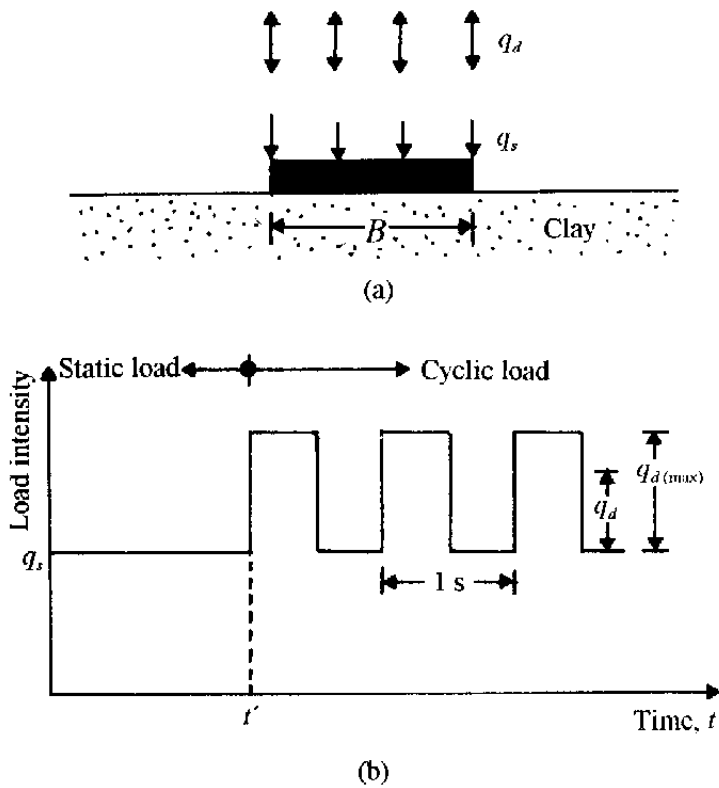


Fig. 1 Nature of static and cyclic load application on the model foundation

Some time was allowed to elapse after the application of the static load so that the elastic settlement of the foundation would be completed. Following that, a cyclic load of intensity q_d was applied to the foundation. The nature of the cyclic load is shown in Fig. 1. It had a period of 1 s with an amplitude of $q_{d(max)}$. A Universal testing machine was used to apply the static and cyclic load on the model foundation. The load and corresponding settlement were measured by a load cell and an LVDT. Permanent settlement of the foundation due to the cyclic load application only (s_d) was measured along with the number of load cycles using a data acquisition system.

LABORATORY TEST RESULTS

Based on the load-settlement plots obtained from the static bearing capacity tests, the average ultimate bearing capacity (q_u) was determined to be 58 kN/m² at a settlement s_u of about 18% of the width (B) of the foundation.

Figures 2, 3, and 4 show the results of the cyclic load tests. The figures show plots of s_d/B (s_d = permanent settlement due to cyclic load) versus number of load cycles n for various combinations of FS and $q_{d(max)}/q_u$. The actual variation of s_d/B with n is shown by solid lines. From these figures, it appears that each plot can be approximated by three straight lines. These are shown by the dotted lines in the figures. Figure 5 shows the general nature of the straight-line approximations of the plots of s_d/B versus n . It can generally be divided into three zones:

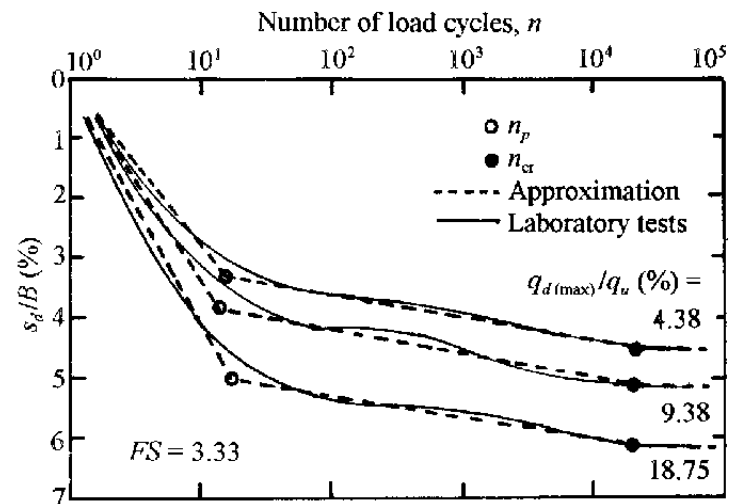


Fig. 2 Variation of s_d/B with n — $FS=3.33$

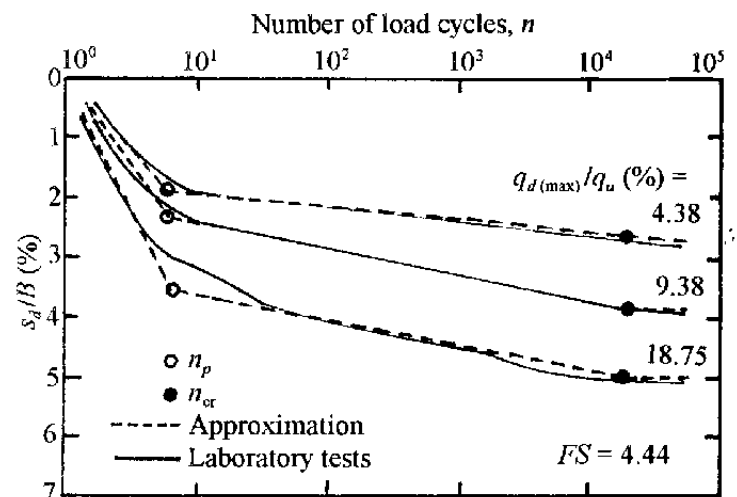


Fig. 3 Variation of s_d/B with n — $FS=4.44$

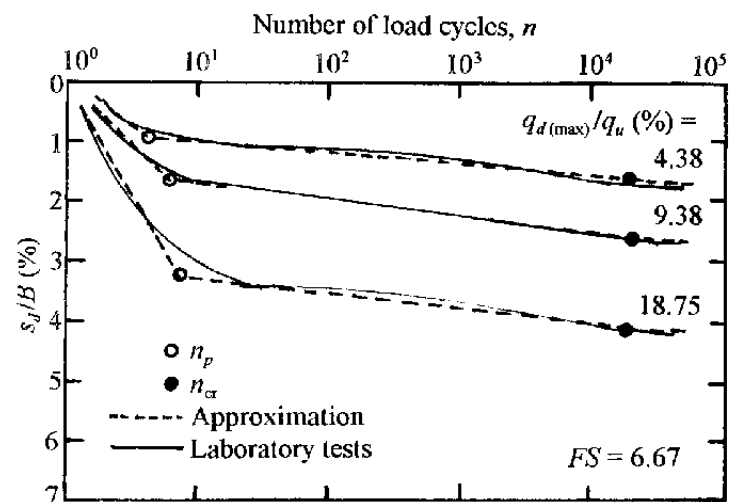


Fig. 4 Variation of s_d/B with n — $FS=6.67$

1. Primary Settlement Zone: This zone is between $n = 0$ to $n = n_p$. In this zone a major portion of the total permanent

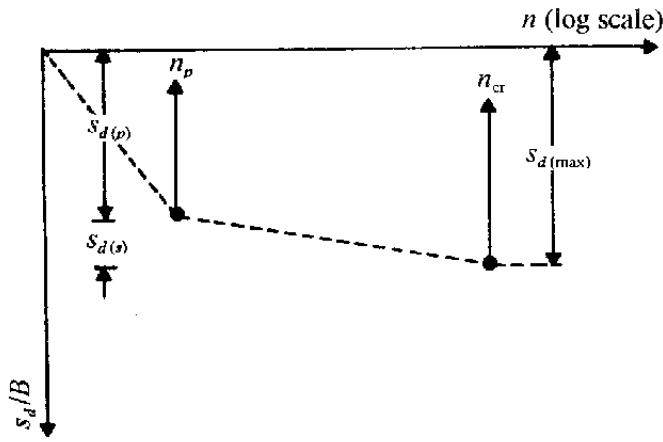


Fig. 5 General nature of variation of s_d/B with n for a given $q_{d(max)}/q_u$ and FS

settlement due to cyclic loading takes place rapidly. The total settlement anticipated in the zone is equal to $s_{d(\phi)}$.

2. Secondary Settlement Zone ($n_p \leq n \leq n_{cr}$): The rate of settlement with the number of load cycle application is smaller in this zone compared to the primary settlement zone. The total permanent secondary settlement is equal to $s_{d(s)}$.

3. Equilibrium Zone ($n > n_{cr}$): In this zone the permanent settlement of the foundation is practically negligible. Thus the total permanent settlement [$s_{d(max)}$] for any combination of q_c and $q_{d(max)}$ can be given as

$$s_{d(max)} = s_{d(\phi)} + s_{d(s)} \quad (2)$$

Based on Figs. 2, 3, and 4, the following general observations can be made:

1. The primary settlement is generally completed in the first ten to twenty cycles. For similar values of $q_{d(max)}/q_u$, the magnitude of $s_{d(\phi)}$ appears to decrease with an increase in FS .

2. Within the range of the present tests, the magnitude of n_{cr} varies between 15,000 and 20,000 cycles. This appears to be independent of FS and $q_{d(max)}/q_u$ combination.

3. For a given q_u/q_s , the total permanent settlement due to cyclic loading increases with the increase in the amplitude of the cyclic load intensity.

The magnitude of $s_{d(max)}/s_u$ (where s_u = settlement at ultimate load during the static tests) for various combinations of FS and $q_{d(max)}/q_u$ were determined from the straight-line approximations shown in Figs. 2 through 4 and are shown in Fig. 6. From the figure, it can be seen that

$$s_{d(max)}/s_u = a[q_{d(max)}/q_u (\%)]^b \quad (3)$$

where a and b are constants and functions of FS . The variation

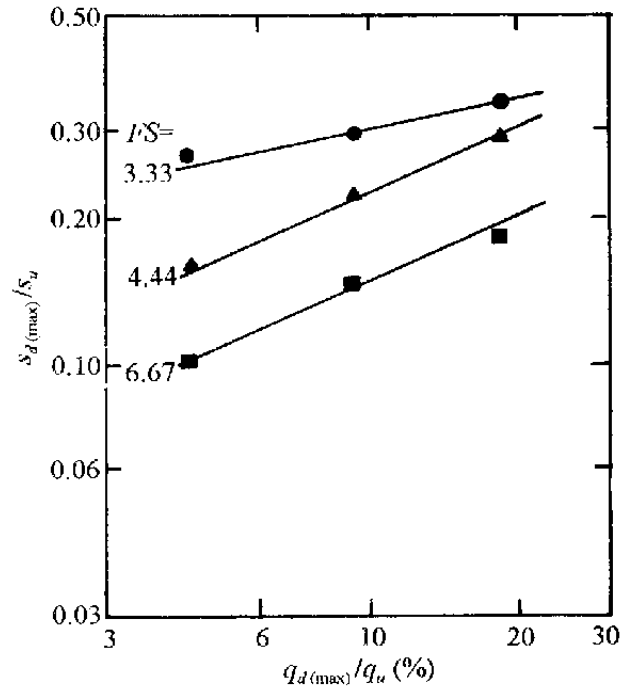


Fig. 6 Plot of $s_{d(max)}/s_u$ versus $q_{d(max)}/q_u$

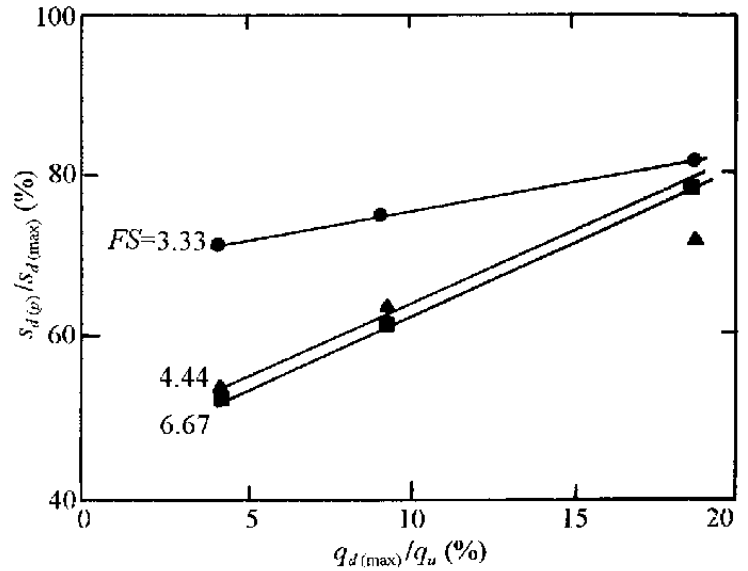


Fig. 7 Plot of $s_{d(\phi)}/s_{d(max)}$ versus $q_{d(max)}/q_u$

of b with FS can be approximated as

$$b \approx 0.043(FS)^{1.4} \quad (3)$$

Figure 7 shows plots of $s_{d(\phi)}/s_{d(max)}$ versus $q_{d(max)}/q_u$ for various values of FS . Based on these plots it appears that, for a given static loading, $s_{d(\phi)}/s_{d(max)}$ bears a linear relationship with $q_{d(max)}/q_u$. If the static load intensity increases (for similar intensity of cyclic load amplitude), the percentage of total settlement during the initial rapid period also increases. Although not substantiated by laboratory tests, it appears from Fig. 7 that, for

any given value of FS and $q_{d(max)}/q_u$, the limiting value of $s_{d(\rho)}$ may be about $0.8s_{d(max)}$.

CONCLUSIONS

Laboratory model test results on the permanent settlement of a surface strip foundation supported by saturated clay soil and subjected to static load and superimposed by a cyclic load of low frequency were presented. Based on the model test results, the following conclusions can be drawn:

1. For a given combination of q_s and $q_{d(max)}$, there is an initial rapid primary settlement following by a slower secondary settlement period.
2. The primary settlement due to cyclic load application takes place during the first ten to twenty cycles of loading, constituting about 60% to 80% of the total permanent settlement. An equilibrium period is reached after about 15,000 to 20,000 cycles.
3. For a given value of $q_{d(max)}$, the total permanent settlement increases with the increase in the static load intensity.