Vertical Load Tests of Footings on Silt

D. P. LaGatta
Geotechnical Engineers, Inc., Winchester, Massachusetts

T. O. Keller
Geotechnical Engineers, Inc., Winchester, Massachusetts

Vertical Load Tests of Footings on Silt

D. P. LaGatta
Principal, Geotechnical Engineers Inc.

T. O. Keller
Engineer, Geotechnical Engineers Inc.

SYNOPSIS Vertical load tests were performed on two shallow spread footings founded on nonplastic silt. Maximum vertical loads of 500 kips were applied to the test footings which were about 24 x 12 x 4 ft in size. Instrumentation was installed to measure footing displacements, footing contact stresses, and soil displacements below the footings. Results of the load tests have been presented in graphic form. Comparisons have been made between measured settlements of the footings and predicted settlements based on standard penetration test results in the silt deposit.

INTRODUCTION

Data from standard penetration tests (SPT) are commonly used to estimate footing settlements in silts; however, the widely used empirical equations which relate blowcounts to footing settlement are based largely on blowcount data in sands, not in silts.

There is a lack of case histories of footing behavior on nonplastic silts, and consequently the design of footings on this material can require considerable judgment.

This paper presents the results of two vertical load tests of shallow spread footings founded on nonplastic silt. The load tests reported herein were performed as part of a larger overturning load test program of an H-frame transmission tower foundation. The test footings, about 24 ft x 12 ft x 4 ft in size, were constructed with a vertical soil anchor at each corner to resist uplift and overturning loads. The simultaneous proof testing of each anchor, using the spread footings as a reaction mat, enabled maximum vertical loads of 500 kips to be applied to each footing. Snow, LaGatta, and Lucia (1979) have presented a design method for estimating the overturning resistance of anchored footings on soil.

SUBSURFACE CONDITIONS

A simplified soil profile at the test site is shown in Fig. 1. An excavation was made to a depth of 4 ft for construction of the footings. A loose sand backfill was placed around the sides of the footings prior to load testing. The groundwater level was at the base of the footings during the load testing program. Descriptions of soil layers below the footings are presented below.

Sand Fill

A 6-in.-thick widely graded sand fill was placed at the bottom of the excavation and compacted with a hand-operated vibratory plate compactor.

Silt

A 20.5-ft-thick-layer of predominantly nonplastic silt was located below the 6-in. layer of sand fill. The silt was intensely stratified by color and contained varying amounts of fine sand. Typical grain-size

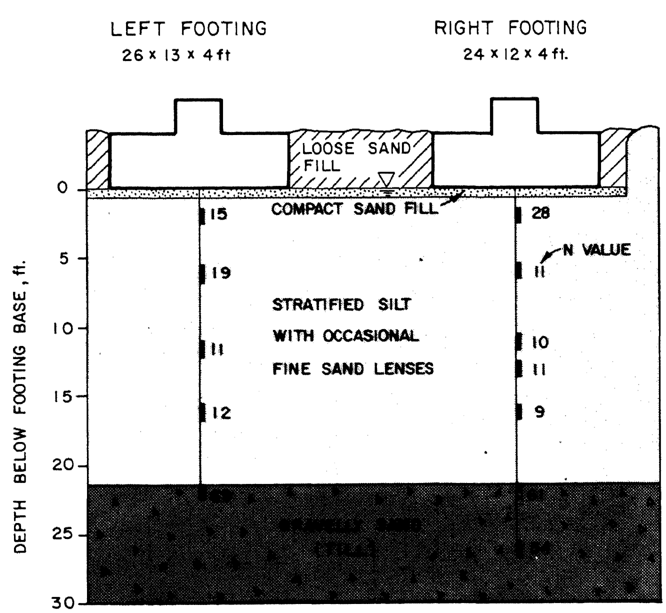

Fig. 1 Simplified Soil Profile at Test Site

curves of silt samples are shown in Fig. 2 together with Atterberg limits of selected samples. The plasticity index (PI) of silt samples ranged from 0 to 4 and the most representative sample of the silt deposit had a PI of 1.

Borings were performed through the test footings at the location of the extensometers shown in Fig. 3. Nearly continuous samples (undisturbed thin-wall tubes and split spoons) of the silt were obtained and indicated that the silt contained occasional lenses of clean fine sand up to 2-ft thick. N values (SPT blowcounts as defined by ASTM D-1586) in the silt deposit averaged about 14 blows/ft. The one relatively high N value of 28 blows/ft directly below the right footing occurred in a lense of fine sand; the sand lense probably densified during compaction of the 6-in. sand layer.

Dry unit weights of undisturbed silt samples ranged from 87.7 to 109.5 pcf and averaged about 98 pcf. The specific gravity of a typical silt sample was 2.71.

Glacial Till

A dense layer of gravelly sand with boulders was located below the silt. N values in the glacial till were greater than 50 blows/ft.

TEST FOOTINGS AND LOADING PROCEDURE

Vertical load tests were performed on two reinforced concrete footings which eventually served as the foundation for a 61-ft-high H-frame transmission structure. The sizes of the footings were 26 ft x 13 ft x 4 ft (left) and 24 ft x 12 ft x 4 ft (right). The distance between footings was 11 ft.

Vertical soil anchors were installed through the corners of each footing to depths ranging from 41 to 58 ft below the footing bases. The purpose of the anchors was to resist design overturning moments from the transmission structure. Each anchor consisted of four 1/2-in.-dia. cables grouted into soil. The cables were covered with a polyvinyl chloride sheath to a depth of about 5 ft below the footing base and the top of the grout column was intentionally stopped about 2 ft below the footing base.

Proof testing of each anchor was required to verify that they had the required load capacity. The four anchors of each footing were tested simultaneously causing a symmetrical vertical load to be applied to each footing.

Anchors were loaded and unloaded in increments by means of hydraulic jacks. Nominal vertical loads applied to each footing during the test program were, in order: 0, 100, 200, 300, 400, 500, 400, 200, 0, and 200 kips.

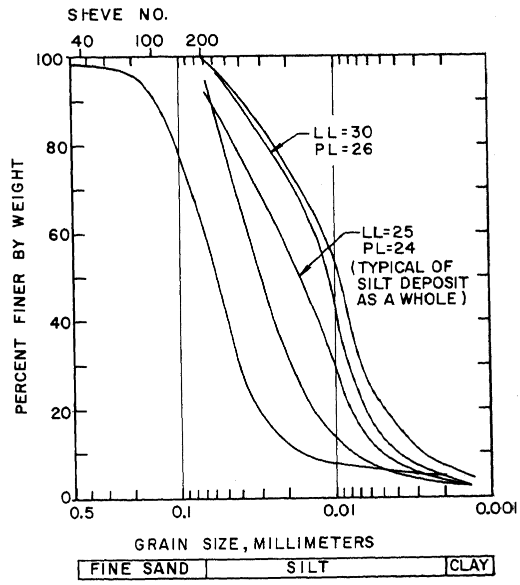

Fig. 2. Grain-Size Curves of Silt Samples

Anchor loads were measured by load cells and maintained at the desired value by periodic adjustment of the hydraulic pressure in each loading jack. For each increment of load, measurements were taken of footing displacements, soil stresses under the footings, and soil displacements with depth below the footings.

INSTRUMENTATION

A significant effort was made in designing th instrumentation system to insure a high degre of confidence in the accuracy of the data obtained during the test program.

The parameters measured during the load tests are listed below with discussions of the instruments used.

Anchor Loads

Anchor loads were measured by 300 kip capacit load cells manufactured by Terrametrics, Inc. In general, load measurements could be made t an accuracy of ± 3 kips. The total vertical load on a footing was equal to the summation of loads in the anchors at each corner of the footing.

Footing Displacement

A precise leveling technique was used to measure the vertical displacements of 14 points on each footing at locations shown in Fig. 3. A precision tilting level with an optical micrometer was used to take level measurements. The level was mounted on an

8-ft deep, 1.5-ft.-dia. wooden post installed about 25 ft away from the nearest point on the test footings. The level was protected from sun, wind, and precipitation by a wooden shelter. A special measuring scale for taking readings was mounted on an aluminum rod fitted with a rod level. Hardened ball bearings embedded in each footing were used as measuring points and allowed elevations to be repeated with a high degree of accuracy. This leveling system enabled vertical displacement to be measured during the load tests to an accuracy of about ± 0.003 in.

Footing Contact Stresses

A total of ten Carlson™ soil stress meters were installed flush with the bottom of the footings at locations shown in Fig. 4. The meters were chosen for their reliability under adverse field conditions. Each meter was calibrated hydrostatically by the manufacturer and also calibrated one-dimensionally in a loading frame by Geotechnical Engineers Inc. (GEI). GEI calibrations were used for analysis because the footings applied one-dimensional loads to the meters. The stress meters were placed on a leveled sand surface and concrete was carefully hand placed around them to prevent disturbance to the meters during construction.

Soil Displacements Below Footings

An extensometer developed by GEI was installed below each footing at locations shown in Fig. 3. The extensometers consisted of six 5-ft sections of slope inclinometer casing separated by telescoping coupling. The mid-points of the casing sections were at depths of about 3.5, 9.0, 14.5, 20.0, and 25.5 ft below the base of each footing. Wire cables attached to the inside of each casing section were used to measure movements of each section. A measurement was made by applying a constant tension to each cable and measuring the position of a fixed reference on the cable with a dial gauge mounted to the footing. The repeatability of the readings for this extensometer was on the order of ± 0.005 in.

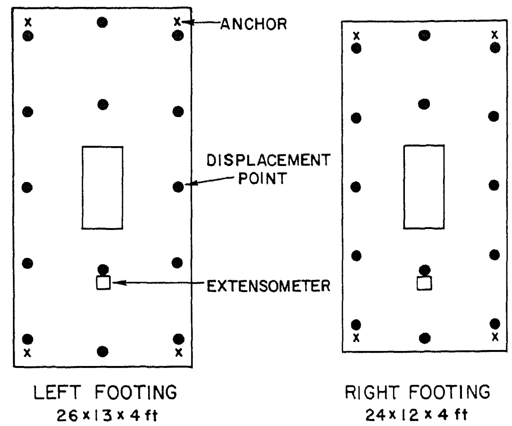

Fig. 3 Locations of Displacement Measuring Points and Extensometer

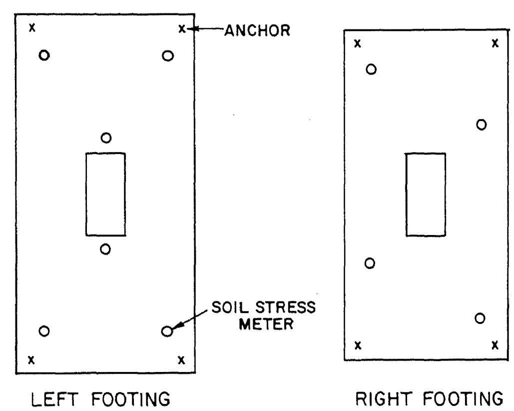

Fig. 4 Locations of Soil Stress Meters Installed at Base of Footings

TEST RESULTS

The simultaneous loading of each anchor at the corner of a footing enabled a maximum vertical load of 500 kips to be applied to each footing. This loading corresponds to an average applied vertical stress to the soil below each footing of about 1.5 kips/ft^2 (left footing) and 1.7 kips/ft^2 (right footing) above the existing stress of 0.6 kips/ft^2 induced by the footing weight.

Plots of footing displacement vs vertical stress for both the left and right footings are shown in Fig. 5. In Fig. 5, vertical stress is defined as the summation of anchor loads divided by the footing area; displacements are averages for the entire footing. All displacements shown in Fig. 5 correspond to those measured after the vertical stress had been applied to the footings for 20 minutes. Footing displacements vs time are discussed later.

The settlement of the left footing under the maximum vertical stress of 1.5 kips/ft^2 was 0.16 in. after 20 minutes of loading. The settlement of the right footing under the maximum vertical stress of 1.7 kips/ft^2 was 0.25 in. after 20 minutes of loading.

The distribution of stress at the base of each footing is shown in Fig. 6 for each increment of load up to the maximum load. The stresses in Fig. 6 are the averages below the longitudinal section of the footings. The soil stress meters located 2 ft from the footing edges measured the highest stresses and the meters near the center of the footing measured the lowest stresses. The higher stresses near the edges of the footing reflect the fact that point loads were applied near the corners of the footings.

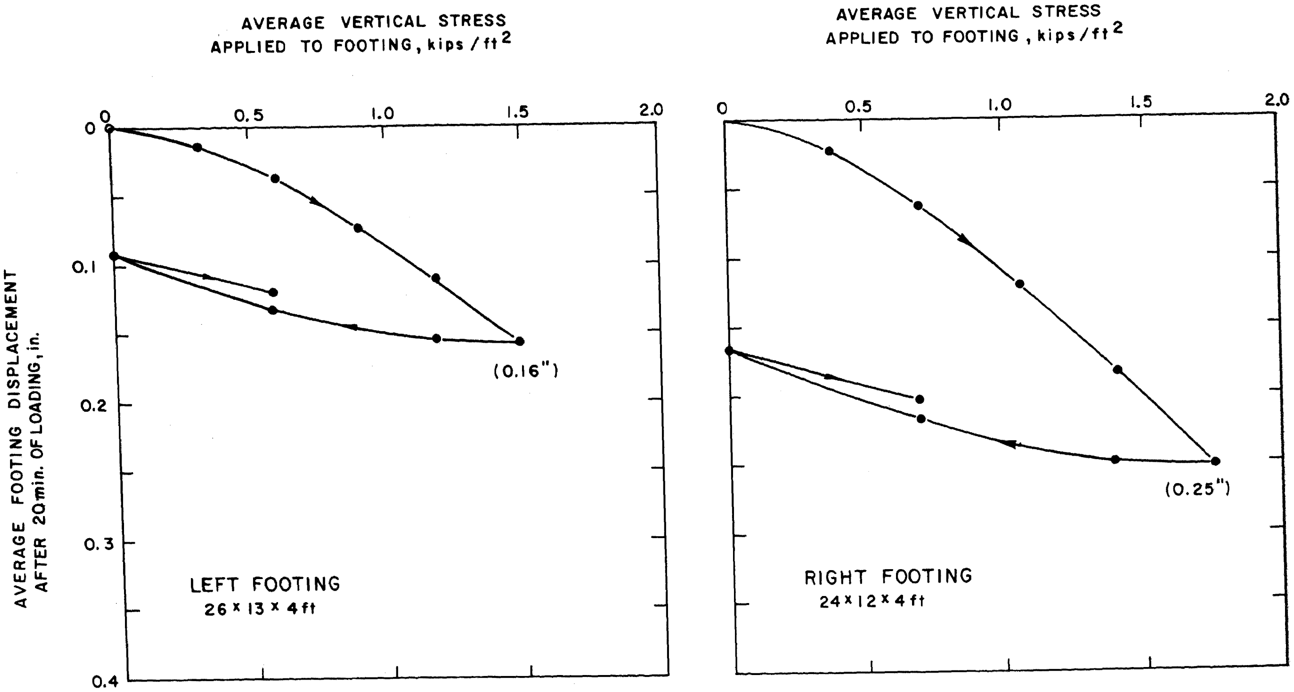

Fig. 5 Footing Displacement vs Average Vertical Stress Applied to Footings

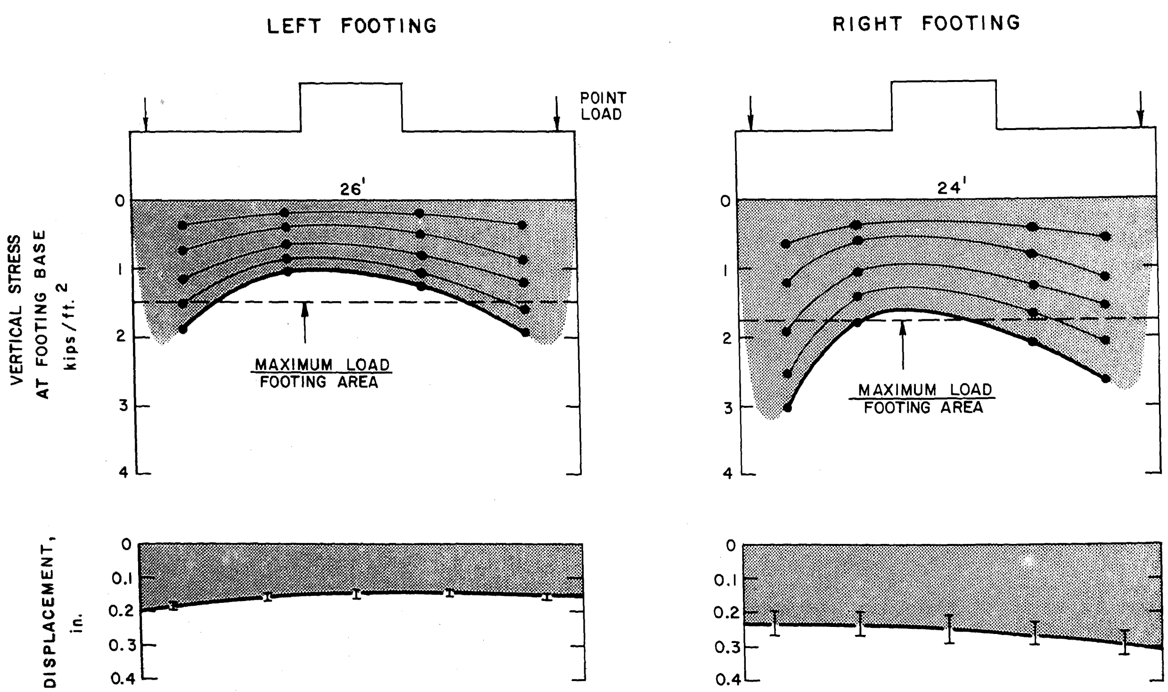

Fig. 6 Vertical Stress and Displacement Profiles. Vertical Stress Profiles are shown for Load Increments of 100, 200, 300, 400, and 500 kips. The Range of Footing Displacements Across the Footing Width are shown for the Maximum Applied Load of 500 kips. Displacements Correspond to a Loading Time of 20 minutes.

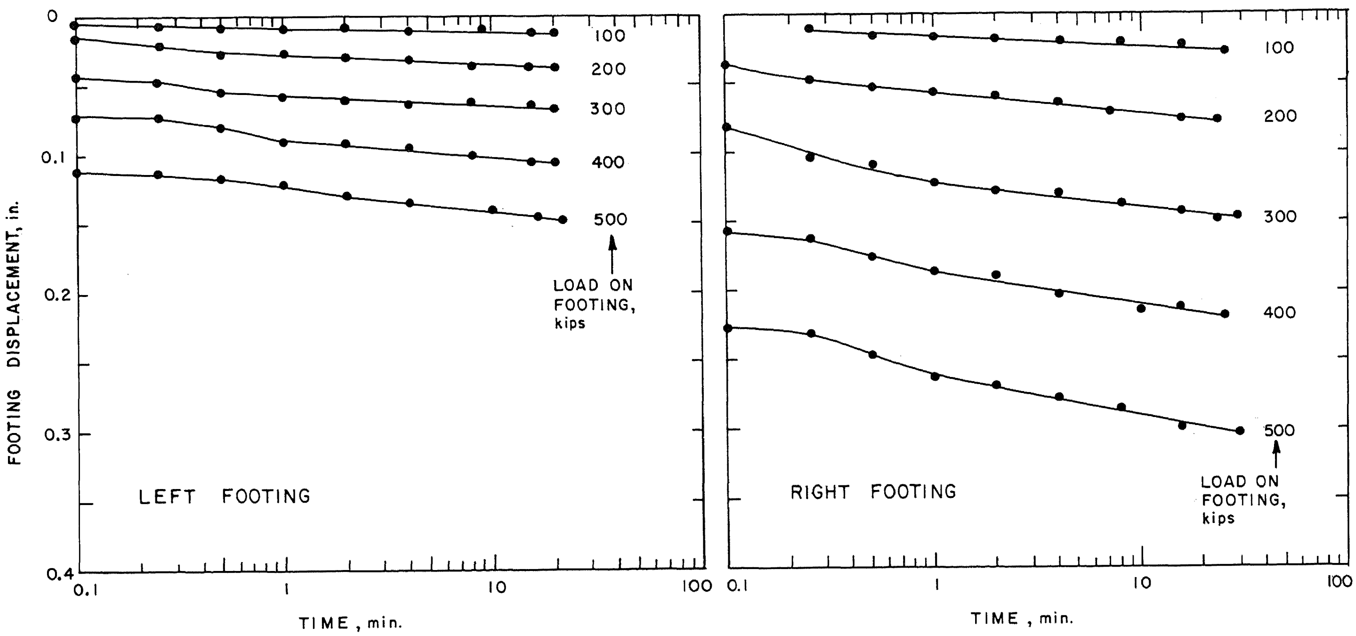

Fig. 7 Footing Displacement vs Time for Each Increment of Load Up to the Maximum Load

In Fig. 6, the soil stresses are shown dropping to a lower value at the footing edges; this is because high vertical stresses cannot exist in cohesionless soil at the edge of the footings due to the relatively low soil confinement at the edge. The average vertical stress applied to each footing under maximum loading is shown by a dashed line in Fig. 6. The average applied stress corresponds well with the average vertical stress measured by the soil stress meters. The footing displacement profile under the maximum applied vertical stress is also shown in Fig. 6.

One displacement point on each footing was monitored as a function of time under each load increment (the point next to the extensometer). The displacements of the test footings vs time for each load increment are shown in Fig. 7. Settlement of the footings occurred at a constant rate vs log time after the first minute of loading. If the log time rate of settlelment is used to estimate settlement after one year, the left footing would settle 0.24 inches and the right footing would settle 0.36 inches under the maximum load of 500 kips.

The displacement of soil with depth below each footing is shown in Fig. 8 for each increment of load up to the maximum load. The displacements shown in Fig. 8 correspond to those measured after loads had been applied for about 20 minutes. The footing displacements measured by the extensometer are in excellent agreement with the footing displacements measured by the precise leveling method. The extensometer measurements indicate that all displacements occurred in the silt layer.

PREDICTED VS ACTUAL SETTLEMENTS

The actual settlement of the test footings under the maximum applied vertical stresses are summarized in Table I.

TABLE I. Summary of Footing Settlements

Footing	Maximum Vertical Stress (ksf)	Average Settlement (in.) After 20 Minutes	Average Settlement (in.) After One Year
Left	1.48	0.16	0.24
Right	1.74	0.25	0.36

Settlements of the footings were monitored for a period of about 20 minutes during each load increment. The one-year settlements were determined by extrapolation of settlement vs log time data.

Predictions of footing settlement were made using two methods which employ SPT data, both of which are used for predicting settlements at cohesionless soil sites. The methods are those suggested by Peck et al (1974) and by Meyerhof (1965), both of which are modified versions of the method originally proposed by Terzaghi and Peck (1948). Terzaghi and Peck's original method was based on conservative correlations between blowcount data and footing settlement data obtained at predominantly sand sites.

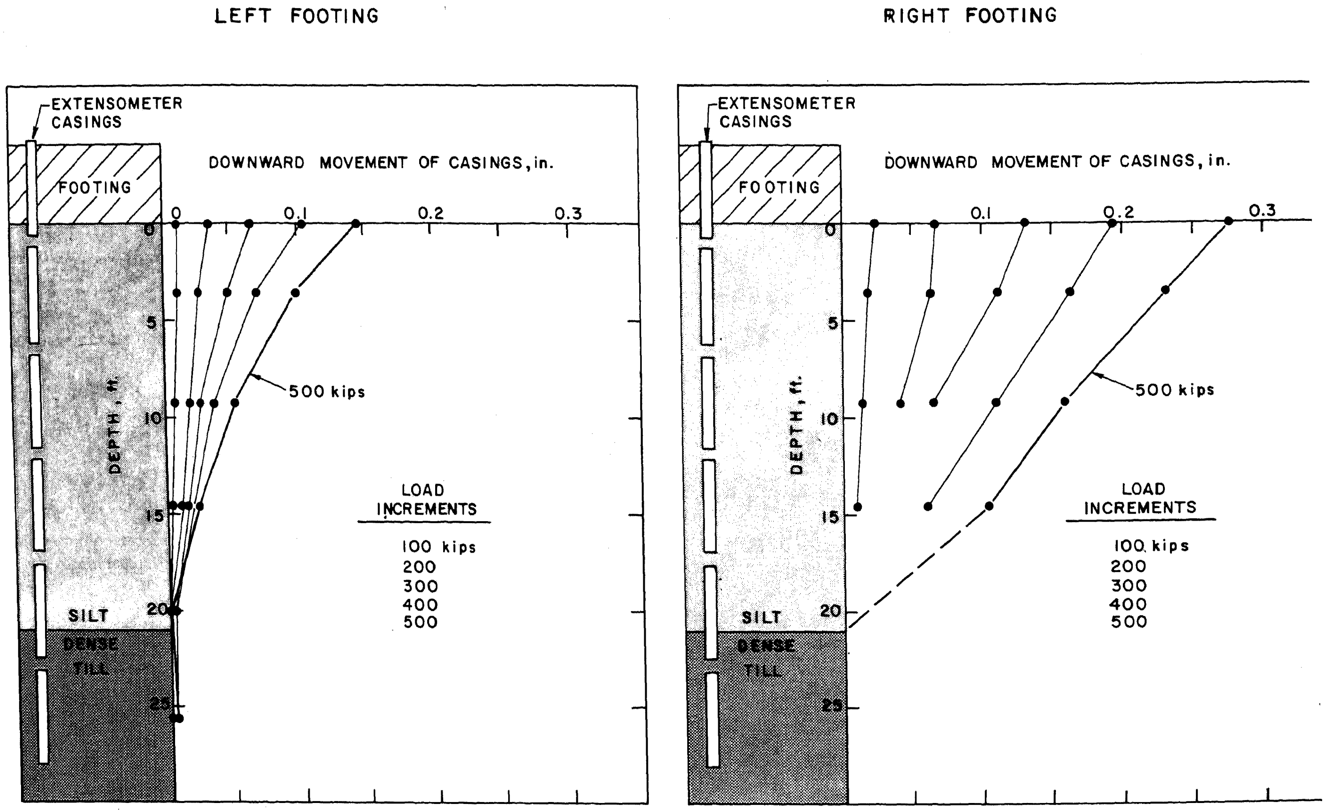

Fig. 8 Displacement of Soil With Depth Below Footings for Each Increment of Load Up to the Maximum Load. Displacements Correspond to a Loading Time of 20 Minutes.

Peck Method (1974)

In the latest edition of **Foundation Engineering**, charts are presented for estimating settlements of large footings on sand and nonplastic silt. The following equation for computing footing settlements is derived from the charts:

$$S = \frac{q}{0.22\ N_1 C_w} \qquad (1)$$

where S = footing settlement, inches
q = bearing pressure, kips/ft^2
N_1 = average of the corrected N values within a depth B (footing width) below the base of the footing. Each N value obtained in the field must be multiplied by an overburden correction factor, C_n.
C_w = correction factor for the position of the water table

The equations given for the correction factors, C_n and C_w, are as follows:

$$C_n = 0.77 \log_{10} \frac{40}{\bar{p}} \qquad (:$$

$$C_w = 0.5 + \frac{0.5\ D_w}{D_f + B} \qquad (:$$

where $\bar{p}$ = effective overburden pressure at the elevation of the standard penetration test at the time the test was performed, kips/ft^2
D_w = depth of the water table from th surface of the surcharge surrounding the footing, ft
D_f = depth to base of footing, ft
B = footing width, ft

The N_1 values below the left and right footings are 19 and 21, respectively. The value of C_w for both test footings is about 0.62.

Meyerhof Method (1965)

Meyerhof suggests the following equation for computing settlements of large footings on sand and silty sand:

$$S = \frac{4q}{N_2} \left(\frac{B}{B + 1}\right)^2 \qquad (4)$$

where S, q, B = as defined previously
N_2 = average of the corrected N values within a depth B below the base of square footings and 2B below the base of strip footings.

Meyerhof suggested that the following equation be used to correct N values when the standard penetration test was performed in dense, submerged silty sand:

$$N_e = 15 + 1/2\ (N-15) \qquad \text{for } N > 15 \qquad (5)$$

where N_e = equivalent penetration resistance
N = standard penetration resistance obtained in field

After applying the above correction to all N values in the silt deposit at the test site, the value of N_2 for both the left and right footings is about 14.

Comparison

The computed settlements of the left and right footings are compared to the load test results in Table II.

Both Peck's method and Meyerhof's method result in predictions of footing settlement which are greater than the measured footing settlements under a vertical load of 500 kips. Footing settlements estimated using Meyerhof's method were closer to the measured footing settlements (extrapolated to one year of loading).

TABLE II. Comparison of Footing Settlements

Footing	Actual Settlement (in.) (After One-Year)	Predicted Settlement (in.)	
		Peck Method	Meyerhof Method
Left	0.24	0.57	0.36
Right	0.36	0.61	0.42

CONCLUSIONS

Vertical load tests were performed on two shallow spread footings founded on a 20.5-ft-thick layer of nonplastic silt. The footings, about 24 x 12 x 4 ft in size, were subjected to a maximum vertical load of 500 kips (1.7 kips/ft^2).

Predictions of footing settlement were made using Peck's method and Meyerhof's method, both of which employ SPT data. These methods are based on correlations between footing settlement and N values at predominantly sand sites. At the nonplastic silt test site, the measured footing settlements under a vertical load of 500 kips were less than the footing settlements which would be predicted using either Peck's method or Meyerhof's method.

The case history presented provides test data which supports the use of standard penetration test data to estimate the settlement of footings at nonplastic silt sites. Additional field load tests of footings on silt, together with settlement measurements of structures on silt, should be performed to improve our ability to predict footing settlements. This will lead to more cost-effective designs of footings on silt.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Boston Edison Company for sponsoring the anchored footing load test program. In addition, five area utility companies shared the expense of the load test program with Boston Edison. These companies were Central Maine Power Company, New England Power Service Company, Northeast Utilities Service Company, Orange and Rockland Utilities, Inc., and Vermont Electric Power Company.

We would also like to thank A. A. Snow and P. C. Lucia, who along with the first author, were responsible for the design of the anchored footings.

REFERENCES

Meyerhof, G. G. (1965), "Shallow Foundations," **Journal of the Soil Mechanics and Foundation Division**, ASCE, Vol. 91, No. SM2, March 1965, pp. 21-31.

Peck, R. B.; Hanson, W. E.; and Thornburn, T. H. (1974), **Foundation Engineering**, Second Edition, 514 pp., John Wiley & Sons, Inc., New York, NY.

Snow, A. A.; LaGatta, D. P.; and Lucia, P. C. (1979), "Anchored Footings For Transmission Towers," Paper of the IEEE Power Engineering Society presented at the IEEE PES Winter Meeting, New York, NY, Feb. 3-8, 1979. (CH1523-4/80/0315)

Terzaghi, K. and Peck, R. B. (1948), **Soil Mechanics in Engineering Practice**, 566 pp., John Wiley and Sons, New York, NY.