AN INVESTIGATION OF THE INTERACTION BETWEEN BORED PILES AND SOIL

RECHERCHES SUR L'A TION RECIPROQUE PIEUX FORES-SOL

L.C. REESE, B.S., Ph.D., Professor
W.R. HUDSON, B.S., Ph.D., Associate Professor
The University of Texas at Austin, USA

V.N. VIJAYVERGIYA, B.S., Ph.D., Engineer
McClelland Engineers, Houston, Texas, USA

SYNOPSIS Large-diameter bored piles are used extensively to support axial loads; however, the behavior of these piles is not well understood. Frequently, they are designed as point-bearing piles only, with no account being taken of the load distributed along the sides of the pile. This paper describes a comprehensive investigation in which a 30-inch by 28-foot bored pile was instrumented with load-measuring gauges. The pile was subsequently tested under axial load. The bored pile has been tested four times with loads ranging up to almost 1,000 tons.

Analyses of the test data were performed to obtain curves giving distribution of the axial load along the pile and curves showing load transfer at various depths as a function of the downward movement of the pile. Results of these analyses were correlated with soil properties obtained from in situ testing. A tentative design procedure is proposed.

INTRODUCTION

Several different procedures are presently used in the design of bored piles. Some procedures assume load to be transmitted through point bearing only, while others assume load to be transmitted through side resistance and point bearing. Various methods have been proposed for computing the bearing capacity of the point of the pile and for computing the load transfer along the sides of the pile. Because of the lack of data concerning the interaction of a bored pile with the supporting soil, particularly data obtained from full-scale load tests of instrumented piles, no design procedures are presently available which treat rationally all of the significant parameters in the bored-pile problem.

The object of the research work described in this paper was to gain information about the interaction of a bored pile with the supporting soil in order to improve design procedures. As a part of the research it was necessary to design, construct, and test instrumentation capable of measuring axial load along a bored pile; and to develop, with the aid of full-scale load testing, a technique for analyses of observed data, and to correlate the observed data to the soil properties. The test pile was 30 inches in diameter and 28 1/2 feet long.

SOIL CONDITIONS

The test site was located near San Antonio, Texas, a short distance from the intersection of Southwest Military Drive and U. S. Highway 90, in Bexar County. Six borings were made to outline the subsurface conditions, to obtain soil samples, and to conduct the Texas Highway Department cone penetration tests. The borings showed the upper 18 feet of the soil to be a gray to yellow clay. There was so much gravel in this stratum that it was difficult to secure undisturbed samples. Underlying the clay was a stratum of brown clay shale with sandstone layers. This stratum extended to the full depth of the boring at 36 feet. Undisturbed samples also could not be obtained from the clay shale. The water table was below the depth of the boring.

Natural water content and index properties are shown in Fig. 1. From the few undisturbed samples that

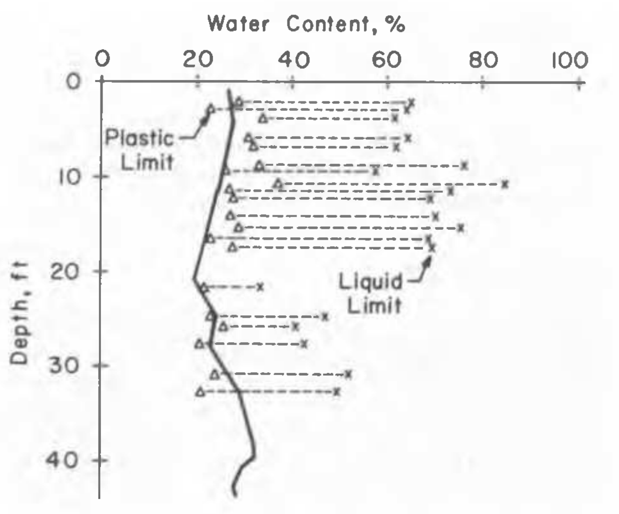


Fig. 1 Moisture Content, Liquid Limit and Plastic Limit Versus Depth

could be taken from the upper stratum, the unconfined compressive strength ranged from about two tons per square foot to about eight tons per square foot. This large scatter is probably due to the nonhomogeneity of the soil. A better indication of the shear strength in this soil can be obtained from the results of the penetration test. In this test (Texas Highway Department, 1964), a 3-inch-diameter cone was attached to the bottom of the 2 3/8-inch outside diameter drill rod and lowered to the bottom of a 4-inch-diameter hole. A 170-pound weight, falling two feet, was used to drive the cone. After 12 blows for seating, the blows were counted to drive the cone one foot. The results of the cone penetrometer test along with the soil profile are shown in Fig. 2.

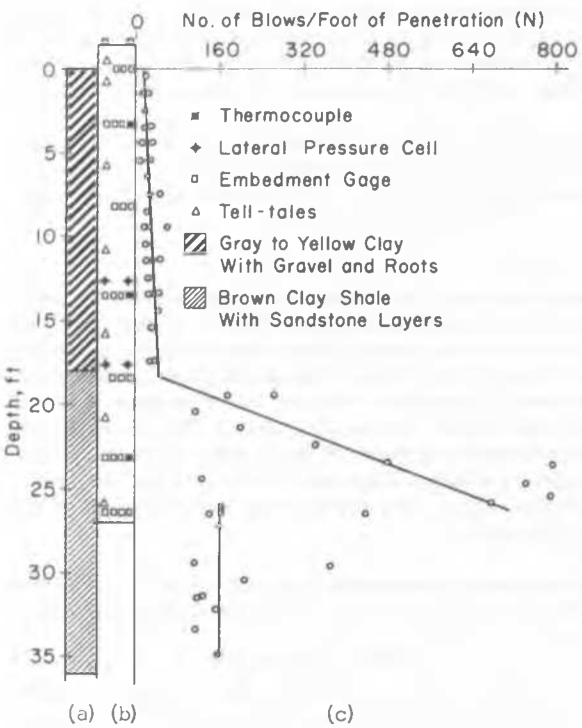


Fig. 2 (a) Soil Profile (b) Location of Instrumentation (c) Penetration Resistance as a Function of Depth

INSTRUMENTATION

Embedment electrical strain gages of type PML-60 were used to measure axial load distribution along the pile. A PML-60 strain gage consists of a fine wire inserted between two pieces of resin plate having overall dimensions of 125 millimeters by 13 millimeters by 5 millimeters. Each strain gage was placed in a cement mortar block with dimensions of 7 inches by 3 inches by 1 inch. Strain gages were installed on the reinforcement cage at seven different depths, with three gages being placed at each location. The gages were placed equal distances from the vertical axis and 120° apart. A dummy strain gage, consisting of a PML-60 strain gage, placed on unstrained material, was used at each location for the compensation of the effects of temperature.

A mechanical device called a "tell-tale" was also used in the measurement of axial deformation of the pile. The tell-tale consisted of a one-half-inch-diameter rod screwed to a 3-inch-diameter steel plate one-half-inch thick. An outer tube with inside diameter of three-fourths-inch was used to protect the rod from contact with the concrete. Thus, relative displacement measured between the top of the pile and the top of the rod gave the deformation of the pile over the length of the tell-tale. Tell-tales of seven different lengths were used. (For details, see Vijayvergiya, 1969)

Lateral pressure cells (Brown, 1967) were used for the measurement of lateral earth pressure. These cells use a full-bridge diaphragm gage. The locations of embedment strain gages, tell-tales, and lateral pressure cells are shown in Fig. 2(b).

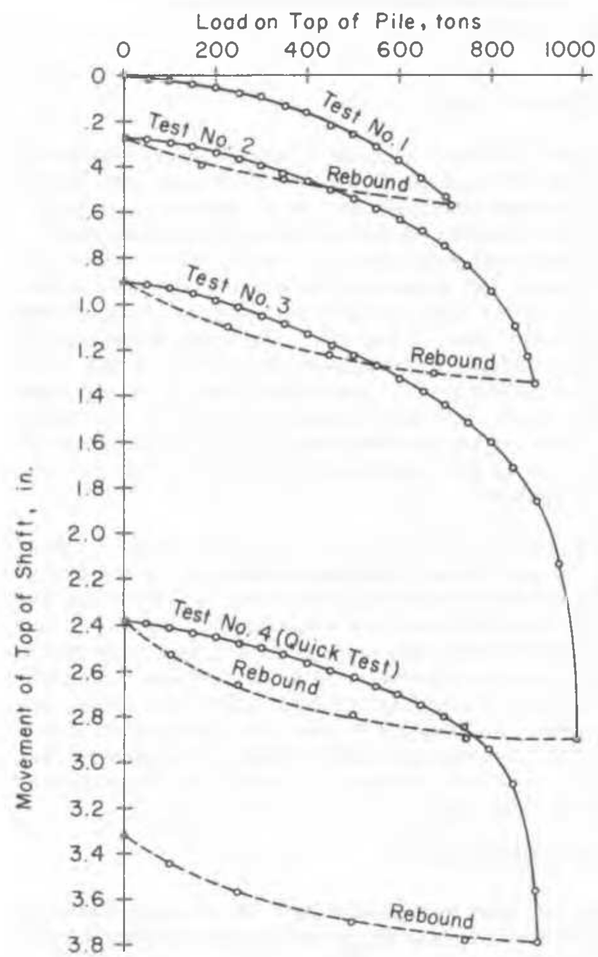


Fig. 3 Load Settlement Curves

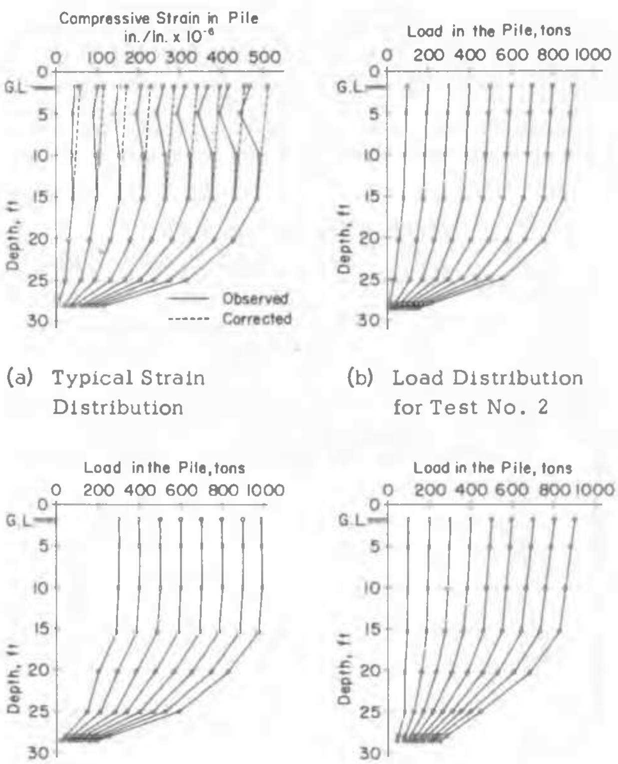
A hole of 30-inch diameter and about 27 feet deep was made by auger drilling. The instrumented reinforcement cage was hoisted up carefully and lowered into the hole. Cement concrete was poured into the hole with the help of a tremie.

LOAD-SETTLEMENT CURVES

Four full-scale load tests were run on this pile. Each load test was conducted either at night or in the early morning to minimize the temperature variation during the test period. During tests Nos. 1, 2, and 3, the load was increased by 50 tons every 12 minutes. The data were recorded for settlement, tell-tales, and strain gages for each loading increment. Test No. 4 was run according to the "Standard Quick Test" of the Texas Highway Department. During this test, the load was increased in increments of 50 tons every 2 1/2 minutes. The results of these tests are shown in Fig. 3.

VARIATION OF STRAIN IN THE PILE

The strain gages located at the ground level were used for the purpose of load calibration. Typical strain distribution along the length of the pile, as obtained from the observed strain, is shown in Fig. 4(a). Because of the erratic indication of strain near the top of the pile, some adjustment was necessary. The adjustment was made so as to be consistent with the general trend of strain distribution in the pile, and it is indicated by a broken line. The number on each curve corresponds to the load on top of the pile in tons.



(a) Typical Strain Distribution

(b) Load Distribution for Test No. 2

(c) Load Distribution for Test No. 3

(d) Load Distribution for Test No. 4

Fig. 4 Strain and Load Distribution Curves Along the Length of the Pile

LOAD DISTRIBUTION ALONG THE PILE

The load distribution along the pile, as a function of depth, was determined from the knowledge of the load-calibration curve and strain distribution. The load distribution obtained for the various tests is shown in Fig. 4. It can be seen from these curves that the load at the bottom of the pile varied from 15 to 25 per cent of the load at the top. Somewhat higher tip load is indicated by the quick test (Test No. 4) than for the other tests.

LOAD-TRANSFER RELATIONSHIP ALONG SIDES OF THE PILE

The importance of the sides of the bored pile in transferring load to the supporting soil may be seen from Figs. 4(b) through 4(d). The remainder of this paper is devoted to the study of phenomena associated with load transfer along the sides of the bored pile.

The load transfer T , in tons per square foot, for each loading increment was computed from the relationship;

$$T_x = \frac{(P_1 - P_2)}{A_p} \quad \ldots\ldots\ldots (1)$$

where

T_x = load transfer at depth x , in tons per square foot;

P_1 = load in the pile at depth L_1 , in tons;

P_2 = load in the pile at depth L_2 , in tons;

$x = \frac{L_1 + L_2}{2}$; and

A_p = peripheral area of pile between depths L_1 and L_2 .

A computer program was used for the computations of the load transfer at various depths and the movement of the pile at the corresponding depth. The relationship between load transfer and movement of the pile at these depths is shown in Fig. 5. It is observed from these curves that the load transfer increases rapidly for small movements. Gradually, it reaches a maximum value. Similar results on miniature piles in clay have been reported by Coyle and Reese (Coyle and Reese, 1966). If curves showing T_x at depth x versus downward movement s can be predicted, a load-settlement curve for a pile can be readily computed. Thus, it is of interest to study the possibility of predicting curves, such as those shown in Fig. 5, from soil properties and pile dimensions.

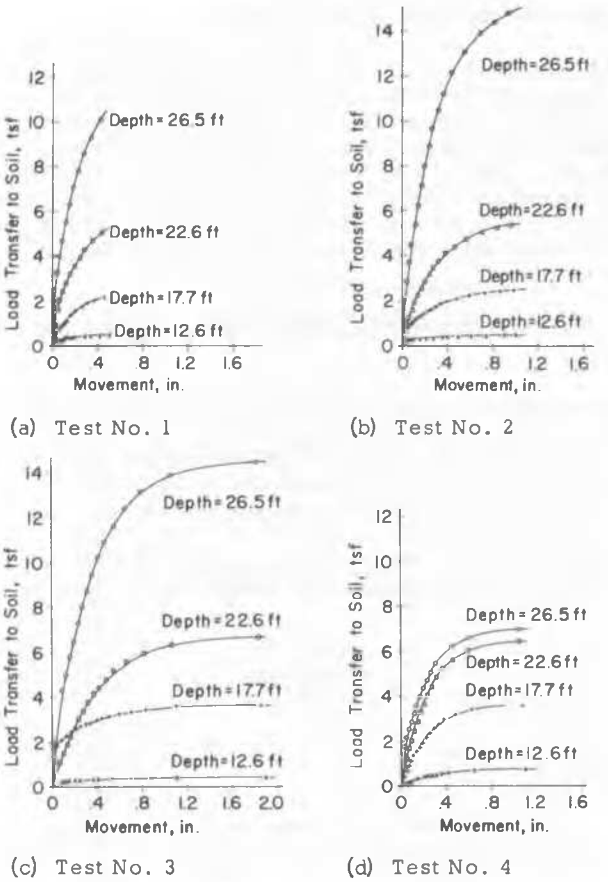


Fig. 5 Load Transfer Curves as Function of Movement

A curve-fit analysis was run to obtain the relationship between the load transfer T_x at depth x and the movement x at the same depth. It was found that T_x can be expressed as

$$T_x = K \left[2.0 \sqrt{\frac{s}{s_o}} - \left(\frac{s}{s_o} \right) \right] \quad . \ . \ . \ . \ (2)$$

where

T_x = load transfer at depth x , in tons per square foot;

K = load-transfer factor; in tons per square foot;

s_o = 2Dϵ , in inches;

D = diameter of pile, in inches;

ϵ = average failure strain in per cent, obtained from stress-strain curves for unconfined compression tests run on soil samples near the pile tip; and

s = downward movement of pile at depth x , in inches.

The load-transfer factor K is the maximum load transfer that can take place at any depth. If the full value of shear strength were transferred, K would then be equal to the shear strength.

It was not possible to evaluate the shear strength over the length of the pile by laboratory testing of undisturbed samples. Therefore, in this study K was related to N , the number of blows required for 12 inches of penetration of the Texas Highway Department cone penetrometer, by means of a regression analysis. The resulting expression for K where K is in tons per square foot, was found to be

$$K = \frac{N}{35} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ (3)$$

Assuming the full strength of the soil to be developed in load transfer, this study shows that the shear strength in tons per square foot can be computed by dividing N by 35. The Texas Highway Department recommends the use of a factor of approximately 38 for this conversion instead of the 35 found in this study.

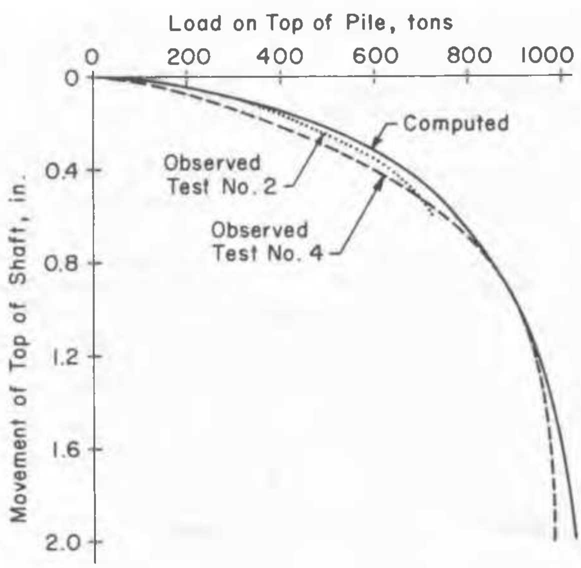


Fig. 6 Comparison of Computed and Observed Load Settlement Curves

Using the relationship developed in Equation 2, a load-settlement curve was computed and compared to the observed curve. The computed curve seems to be in good agreement with the actual observed load-settlement curve, as shown in Fig. 6.

Elastic deformation of the concrete pile corresponding to various lengths of tell-tales was computed from the strain gage data. The computed deformations were found to be in close agreement to the deformations observed directly with the aid of tell-tales.

CONCLUSIONS

1. The instrumentation used to obtain the distribution of load along the bored pile worked satisfactorily. The favorable response of the tell-tales was due in part to the fact that the bored pile sustained a load of large magnitude, which resulted in sizable deformations in the pile.

2. The transfer of load from the pile to the soil at any depth is not only a function of the soil shear strength at that depth, but also depends on the movement of the pile at that depth.

3. The load transfer equation, Equation 2, predicted with reasonable accuracy the transfer of load from the sides of the bored pile to the supporting soils. However, further study of the equation will be necessary to prove its validity for a wide variety of soils.

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NOTATIONS

The following symbols are used in this paper:

A_p = peripheral area of pile between lengths L_1 and L_2, in square feet;

D = diameter of pile, in inches;

K = load transfer factor, in tons per square feet;

L = depth of any point in the pile below the top of the pile, in feet;

N = the number of blows required for 12 inches of penetration of the Texas Highway Department cone penetrometer;

P = load in the pile at any depth L, in tons;

s = downward movement of pile at depth x, in inches

s_o = estimated maximum settlement of pile, in inches;

T_x = load transfer at depths x

ϵ = average failure strain in per cent, obtained from stress-strain curves for unconfined compression tests run on soil samples near the pile tip.

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