High Capacity Load Tests on Large Diameter Piles

Essais avec Charges Elevées sur Pieux de Grand Diamètre

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SYNOPSIS This paper describes the use of special test methods utilizing an anchored tie back system for the performance of vertical load tests up to 1750 metric tons on 60 meter long, 1.80 meter diameter reinforced concrete piles constructed for the foundations of the Presidente Costa e Silva Bridge (Rio-Niteroi Bridge) across Guanabara Bay in Brazil. Also described is a 100 ton horizontal load test performed on two similar type foundation piles with the resulting lateral deflections measured with depth by means of slope indicator equipment. The paper presents a brief description of the subsurface conditions across the Bay, the characteristics of the piles tested, a description of the testing apparatus, the field results obtained, an analysis of the determination of the horizontal soil modulus factors and a comparison of the measured lateral deflections below the mud line with those computed by elastic methods assuming a horizontal soil modulus varying linearly with depth.

SUBSURFACE CONDITIONS AND TYPE FOUNDATIONS

The typical subsurface profile across the Bay of Guanabara basically consists of a highly irregular surface biotite gneiss overlain by discontinuous sedimentary strata varying from very soft organic clayey silts to stiff clays and loose to very compact sands and gravels increasing in density with depth. The upper portion of the gneiss bedrock exhibits various transition zones of decomposition gradually altering from a compact residual soil derived from the parent bedrock to fractured and ultimately sound rock encountered at depths varying from 15 to 70 meters. The depth of water across the Bay varies from a minimum of 6 meters at the Rio shore to 23 meters in the area of the main navigational spans.

The 1.8 meter diameter foundation piles subjected to load tests consisted of two types. Type A consists of a cast in place reinforced concrete unit extending down to the top of decomposed rock followed by an external concrete plug socketed into rock. The Type B unit consists of a cast in place reinforced concrete pile supported on 5-12" H (150 kg/m) steel sections previously driven to the top of decomposed rock and extending up to the top of the pile. Both type piles incorporated the use of a permanent 10 mm thick steel shell and all concreting was performed by use of tremie methods. The design working load for these foundation piles varied from 650 to 1000 metric tons depending on the loading conditions.

VERTICAL LOAD TEST METHODS AND RESULTS

Along the portion of the bridge crossing the Bay a total of 5 vertical and 12 horizontal load tests were performed. This paper reports the results of 2 of the vertical and 1 of the horizontal tests.

1000 Ton Vertical Load Test

This load test was performed in the area of the main navigation spans (Pier 99) on a representative Type A pile as described above. The total foundation for this pier consisted of 32 such piles. The physical system used in accomplishing the load test consisted basically in the jacking of the test pile against a pre-cast concrete reaction block by means of 4 hydraulic jacks. The reaction loads to be applied to the test pile were provided through a series of 20 groups of 12-8 mm tie back cables which were fixed to the top of the reaction block, extending along the entire length of the test pile and ultimately anchored into the underlying bedrock material by grouting. Refer to Fig. 1a.

Although theoretical considerations and previous field experience indicated that the influence of the anchor loads on the settlement behavior of the test pile during the test was negligible, it was nevertheless decided to isolate the cables by wrapping them in plastic tape down to a distance of approximately 6.5 meters below the pile tip elevation. Below this level the uncoated cables were pressure grouted to a depth of approximately 15 meters. Each set of the tie back cables was pre-tested up to 1.2 times the maximum load to be applied during the test. The resulting top of pile movements was measured by the use of extensometers with an accuracy of 0.01 mm. For safety purposes the elongation of the tie back cables was also monitored. A special "tell tale" device was also installed to monitor the deformation at the tip of the test pile using a fixed working platform as a reference. The top of pile settlement results obtained. during the load test are shown in Fig. 1c.

1750 Ton Vertical Load Test

This load test was performed at Pier 56 on a representative Type B pile.The test pile was one of 12 such piles which formed the foundation unit at this pier.As shown in Fig. 1b and for purposes of the test,the pile was free of the footing block. The test loads were applied by means of 6 hydraulic jacks reacting against a pre-cast concrete reaction block anchored to the existing pier footing block. The top of pile settlements were measured by means of extensometers with an accuracy of 0.01mm using the footing block as a fixed reference. In addition, any movement of the block itself was monitored with reference to an independent bench mark which was deeply anchored in the underlying bedrock. The results of this load test are indicated in Fig. 1c.

100 TON HORIZONTAL LOAD TEST

In an attempt to determine the in-place horizontal soil modulus factors so as to better evaluate the pile foundation behavior for the critical design condition of horizontal forces resulting from possible ship impact against the completed bridge piers,a 100 ton horizontal load test was performed on a representative Type A pile specially constructed in the area of the main navigational spans. Special inclinometer instrumentation installed within the constructed pile enabled the direct measurement of pile deflections with depth under the various load increments.

Test Methods

The horizontal test loads were applied to the test piles in increments by means of two Freyssinet jacks mounted on one pile and stressing a cable consisting of 12-12.7 mm diameter steel strands such that the two test piles spaced approximately 10 meters apart were drawn towards each other. The loading sequence utilized was 15, 23, 31, 48, 57, 69, 75, 87, 93 and 100 metric tons. All loading and unloading stages were initiated only after the measured deflections under the previous increment had stabilized.

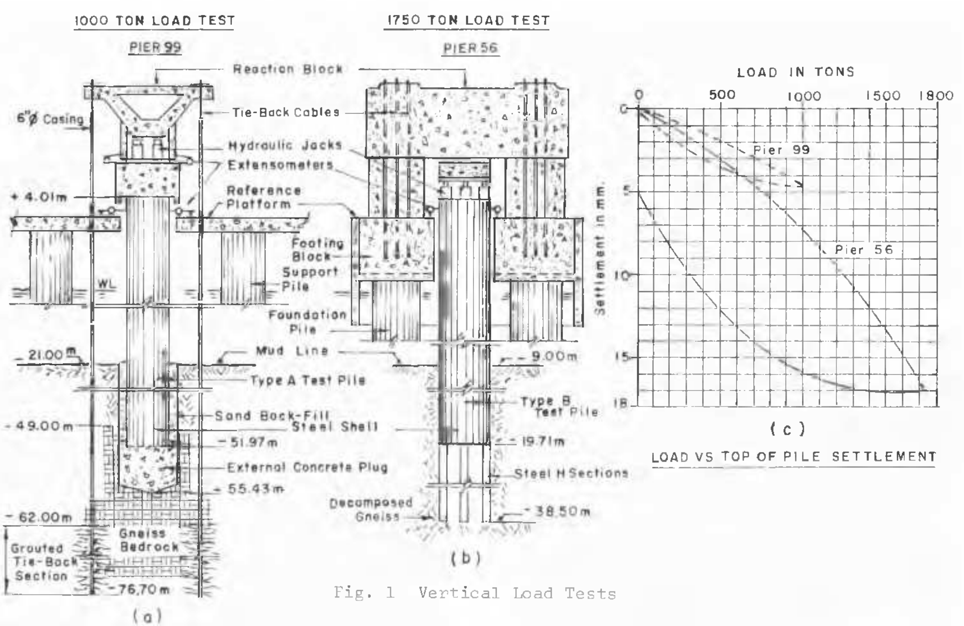

Fig. 1 Vertical Load Tests

Deflections along the length of the test piles during testing were obtained for all load and unload increments at depth intervals of 1.5 meters along the length of the test piles both above and below the mud line. The individual top of pile deflections were also monitored by theodolite readings on graduated fixed beams extending out from each of the test piles. In addition, the cumulative top deflection of the piles was graphically recorded on an oscilograph installed on top of one of the test piles.

Figure 2 illustrates the typical test set up, the slope indicator deflections curves for the test piles and the soil profile in the critical area below the mud line. As indicated, the soil surrounding the test piles consists essentially of medium to compact sedimentary sands with sporadic layers of organic silts and clays.

Method of Analysis and Test Result

The theoretical horizontal deflections varying along the length of the test piles were determined by use of non-dimensional coefficients and elastic solution proposed by Reese and Matlock for the condition of a horizontal soil modulus E_s varying linearly with depth, x, below the ground line for a pile free to rotate at the ground (mud) line at which point the load is considered applied.

$$E_s = kx$$

where

E_s = horizontal soil modulus (tons/m^2)

k = coefficient of soil modulus variation (tons/m^3)

x = depth below the mud line (m)

The analysis was initiated by determining values of k by fitting the slope indicator measured deflections at the mud line (x = o) to those computed by the elastic method. Superposition methods were employed by substituting a horizontal shear force P_t and a moment M_t at the mud line for the actual horizontal test load increments which were applied at the upper end of the free standing test piles at Elev. + 2.65m. Based on this type analysis the resulting theoretical deflections at the mud line were determined as the sum of the individual deflections contributed by both the horizontal force P_t and the moment M_t. These deflections were

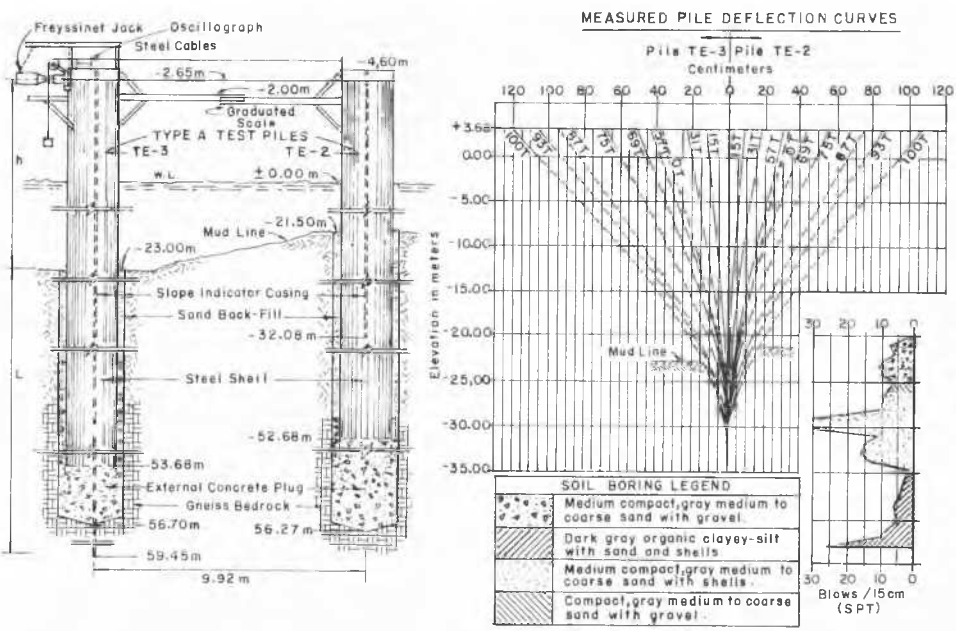

Fig. 2 100 Ton Horizontal Load Test

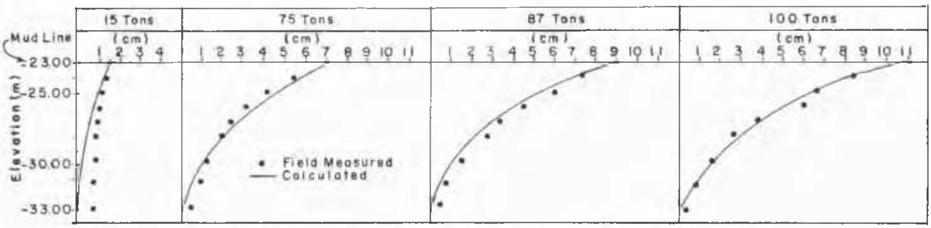

Fig. 3 Lateral Load Test Deflections - Test Pile T-3

obtained by use of the following expression:

$$y_{tc} = y_A + y_B = A_y \frac{P_t T^3}{EI} + B_y \frac{M_t T^2}{EI}$$

where

y_{tc} = total lateral deflection computed at the mud line (m)

y_A, y_B = deflection at x = 0 caused by P_t and M_t respectively (m)

A_y, B_y = non-dimensional coefficients related to P_t and M_t respectively

P_t = shear force at the mud line (tons)

M_t = $P_t h$ = moment at the mud line (ton·m)

h = unsupported height of pile (m)

T = $\left[\frac{EI}{k}\right]^{1/5}$ = relative stiffness factor (m)

EI = pile stiffness (ton·m^2)

Based on the individual test loads, the computed values of k at x = 0 (mud line) varied from 300 to 400 tons/m^3 for an average of 342 tons/m^3. For depths below the mud line ($x > 0$) the theoretical values of pile deflection were computed using increasing values of the non-dimensional Depth Coefficient, Z,

where $Z = \frac{x}{T}$ and $Z_{max} = \frac{L}{T}$

with L being the length of the embedded pile below the mud line. The computed deflection values for four of the test loads for test pile TE-3 are presented in Fig. 3 for a depth of 10 meters below the mud line. Also indicated are the corresponding lateral deflections obtained from the field measurements.

CONCLUSIONS

The use of anchored tie backs systems permits the performance of high capacity vertical load tests which offer the advantages of safety, easy set-up, savings in construction time and lower costs.

The 342 tons/m^3 computed as the average value of the coefficient of soil modulus variation, k, using the mud line deflection fitting analysis compares favorably with the value of 441 tons/m^3 proposed by Terzaghi for the medium compact submerged granular type soils similar to those encountered in the load test area.

Comparison of the measured deflections with the computed values indicates the validity of using a soil modulus E_s analysis varying linearly with depth.

Considering the resulting permanent set (3.9 cm) at the mud line following final unloading and the close correlation in the computed and observed deflections for test loads up to 100 tons, it appears that the Reese-Matlock type solution may have application to instances where the surrounding soil medium is behaving beyond the elastic range; an observation made by the authors in their original paper.

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