Horizontal load test on free head pile

Essai de charge horizontale sur pieu à tête libre

F.A.GUEDES DE MELO, Laboratório Nacional de Engenharia Civil, Lisboa, Portugal
M.ESTEVES FERREIRA, Laboratório Nacional de Engenharia Civil, Lisboa, Portugal

SYNOPSIS: The foundation of the two main piles of the international bridge over Guadiana river consists of groups of large diameter piles crossing the thick alluvial layer. In order to give support to the design studies concerning the effect of horizontal loads an in situ test was carried out on a concrete pile, 0.80 m diameter, exclusively built for that purpose. Details on the test performance as well as on the interpretation of results obtained are supplied.

1. INTRODUCTION

The international bridge over the Guadiana river between Vila Real de Stº Antônio (Portugal) and Ayamonte (Spain) is a 660 m long cable-stayed structure with a central span 324 m long, two lateral, also suspended, spans 135 m long and two short spans, 36 m long, in connection with the abutments.

The deck is a continuous concrete frame which is, on one hand, suspended by cables from two towers and on the other hand is supported on the tower beams, on pillars existing at the end of the lateral spans and also on the abutments.

The geotechnical conditions existing at the foundation of the two towers, namely the presence of a thick layer of an alluvial deposit, compelled designers to adopt a deep foundation solution. During the preliminary studies a set of type solutions were analysed including piers, piles of different diameters and diaphragm wall elements. The final option was adopted by a Portuguese-Spanish Technical Committee and corresponds to a solution with 1.5 m diameter concrete piles.

Through the geotechnical characterization of the local conditions the definition of the design values of the parameters was achieved. Even so it was considered advantageous to base the design analysis concerning the behaviour of the piles under horizontal forces on experimental results obtained through an in situ pile test. With this objective a pile was especially built near the site of one of the two towers.

In the present paper some details concerning the local geotechnical conditions, the pile characteristics and the type of instrumentation used are presented. Also some aspects related to the interpretation of results are emphasized.

2. GEOLOGICAL CONDITIONS

From the geological point of view the site of Guadiana bridge is an alluvial valley excavated into a rock formation of schist and graywacke actually filled with a recent alluvial deposit of mud, sandy mud and silty sandy mud, with a maximum thickness of about 70 m.

To provide adequate knowledge of the site subsurface conditions an exploration program was performed, giving particular attention to the characterization of the alluvial behaviour. This program included: seismic exploration, boreholes, SPT and CPT tests, vane tests and also laboratory tests.

The interpretation of the whole information concerning the particular zone of the Portuguese tower, where it was decided to perform the test, led to the geotechnical design model presented in figure 1.

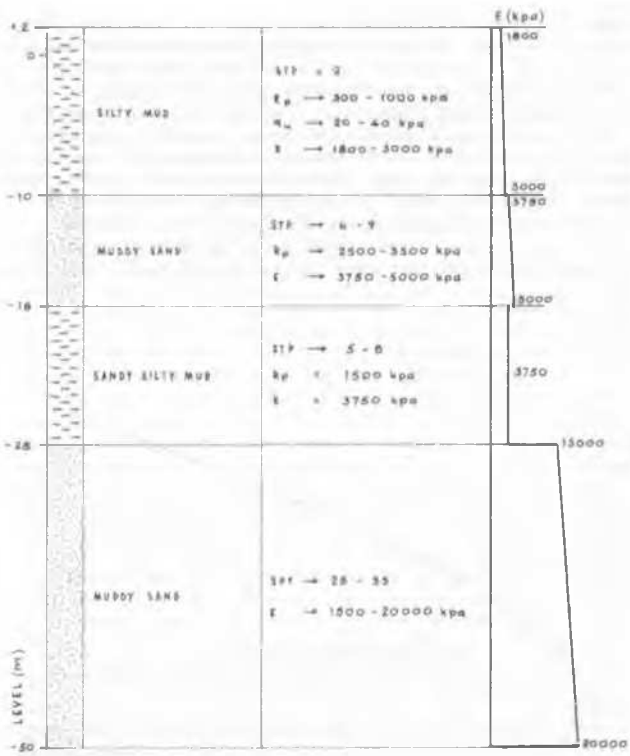

Figure 1. Geological-geotechnical model at the site of the pile test.

3. PILE CHARACTERISTICS

The tested pile was a cast-in-place element crossing all the alluvial thickness, which gives a total length of about 42 m. As the pile diameter foreseen by the design team was 1.5 m this was naturally the most appropriate value also for the test pile diameter. However due to the high cost involved in setting out an adequate site to build only one pile of such a large diameter, it was decided to perform the test on a 0.80 m diameter pile.

The reinforcement of the pile was 6 ø 20 mm + + 6 ø 16 mm.

4. LOADING DEVICE

The loading device included a second pile only for reaction purposes and a metallic frame involving the two piles whose axes were 2.4 m distant. At the central part of this metallic structure there was a 32 mm steel bar crossing not only the transverse frame elements but also the two piles. The horizontal forces are applied by a jack existing at the end of this steel bar.

5. PILE MONITORING

The theoretical analysis of the expected pile behaviour on account of the alluvial soil characteristics leads to the conclusion that it will practically be without bendings for depths larger than 12 m. So it was considered sufficient monitoring only the first 20 m of the pile length.

The purpose of monitoring was to measure the horizontal displacements, rotations and strains.

The horizontal displacements were measured by an electrical inclinometer operating inside a metallic tube embedded into the concrete of the pile. The pile head displacements were also simultaneously measured by topographic methods.

The rotations along the pile were measured also by the inclinometer but those corresponding to

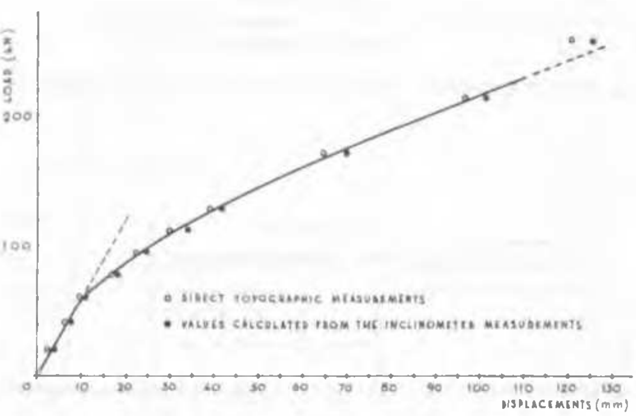

Figure 2. Horizontal head pile displacements using topographic methods and inclinometers

the pile head were simultaneously measured with high accurate clinometers.

An attempt was made to measure strains by means of electrical strain gages glued directly to the bars of the reinforcement. Two steel bars with strain gages (20 strain gages, 1 m apart on each bar) were installed at positions at diametrically opposite on the plane of the acting forces. As dummy gage of each Weathstone bridge 40 other strain gages were glued on a bar placed into a metallic tube also embedded in the concrete of the pile.

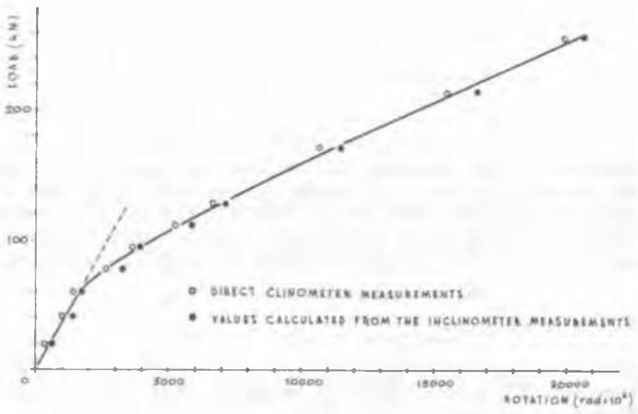

Figure 3. Head pile rotations using clinometers and inclinometers

6. TEST PROGRAM

Successive loading and unloading cycles were applied to the head of the piles making them move in opposite directions. The number of load steps was 38 and the maximum load applied was 2500 KN.

7. ANALYSIS AND INTERPRETATION OF RESULTS

The analysis of the results showed that the values of the pile head horizontal displacements and rotations, when measured with an inclinometer, were very

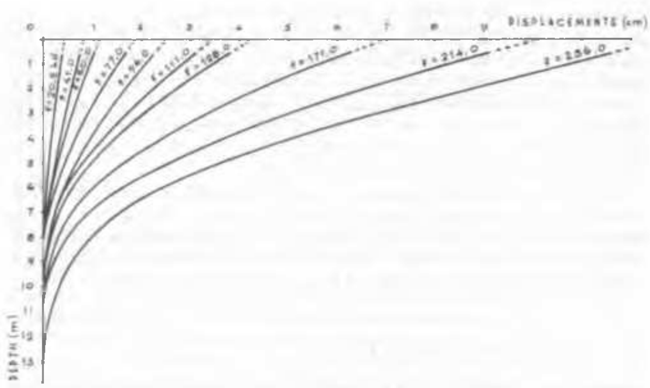

Figure 4. Horizontal pile displacements using inclinometers

close to those obtained by topographical methods and clinometers respectively, as we can see in figures 2 and 3. This fact was very important for the interpretation of the test results because once the reliability of the pile head values was obtained there would be a good support for assuming the same reliability for all the sections along the pile.

The horizontal displacements at each applied load step are presented in figure 4.

According to figures 2 and 3 for load steps up

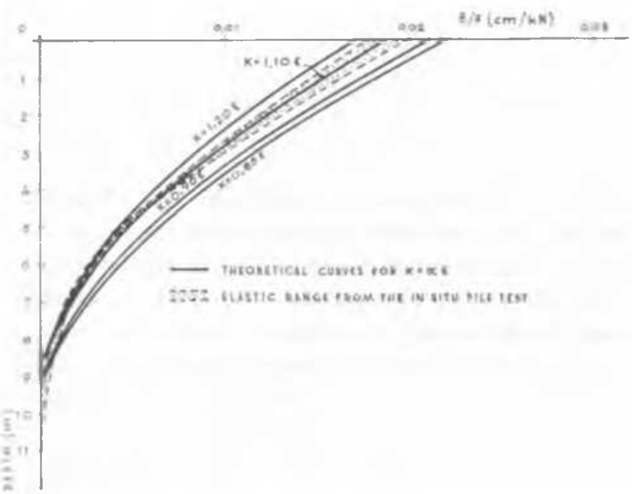

Figure 5. Theoretical and measured horizontal displacements along the pile

to 60 KN the pile soil behaviour was approximately elastic. In figure 5, where the evolution of the displacements under unit force (d/F) along the pile is presented, the zone corresponding to F<60 KN is clearly shown. In the same figure the theoretical diagrams corresponding to Winkler model solution are presented, each diagram corresponding to a particular reaction modulus K. The values of K were obtained by multiplying the elasticity modulus (previously defined for the different geological formations identified through th geotechnical studies) by a parameter α ($K = \alpha E$). As

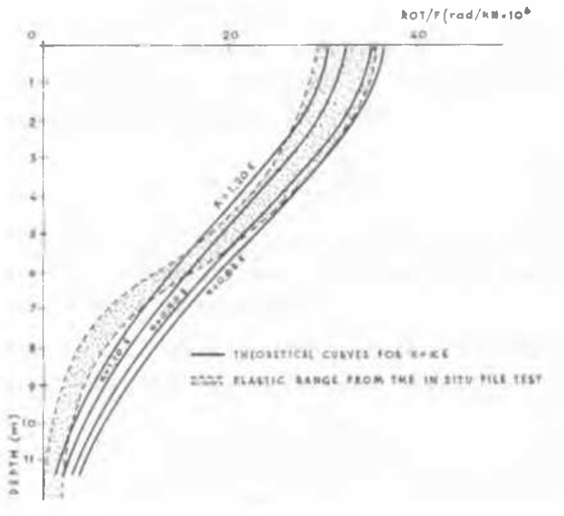

Figure 6. Theoretical and measured rotations along the pile

we can see the curve obtained for $\alpha = 1.10$ lies approximately at the center of the zone corresponding to loads at 60 KN, mainly at the upper part of the pile.

A similar analysis for the rotation values, is presented in figure 6. In this case the approach is also quite good though only at the upper part.

The horizontal displacements and rotations show that the pile behaviour is practically without bendings for a depth over about 13 m, even for the highest steps of load applied (figure 4).

The strains obtained from the electric strain gages did not permit an adquately based interpretation. The reason is not well established but an important role may be played by problems related with the particular technique used for gluing and isolating the strain gages and by the influence of the bad weather conditions on the data acquisition system used.

8. CONCLUSIONS

The most important conclusions derived from the test are the following.

a) Suitable design of the load system, showing very good performance throughout the test.

b) Remarkable quality of the inclinometer information, as was confirmed by values of the direct measurement of horizontal displacements of the head pile using topographic apparatus and of the rotations using high accuracy clinometers.

c) Very poor results obtained with the electric strain gages which did not permit any practical interpretation.

d) In what concerns the overall interpretation, emphasis must be laid upon the good compatibility between the geotechnical information obtained through the usual test and the pile test results. This points to a remarkable reliability of the design parameter values that had been obtained previously through the interpretation of the geotechnical tests.

e) In spite of the great value of the information obtained through the pile test and its importance for the design of the bridge foundation, we must recognize that this information would have been much more important if the strain gage measurement system had worked well.

The soil-pile deformation process can only be well controlled if a very accurate system of measurements is used. In what concerns the measurements corresponding to the pile head section it is possible to use highly reliable alternatives. However for other sections along the pile those alternatives are usually impracticable and so the use of strain gages seems to be a very promising way namely for studying the pile-group effect. For these reasons LNEC has improved the strain gauge measurement technology for piles, using electrical strain gauges glued inside a steel tube similar to the bars of the reinforcement and designing a new data acquisition system. This new technology was very recently used with good results in a pile test performed for the purpose of designing a bridge foundation. Detailed information on the matter will be furnished in a future paper.