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Numerical Modelling and Evaluation of the Osterberg Cell Test Results

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(STRUCTURAL ENGINEERING)

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Abstract of M.Sc. Thesis submitted by:

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ABSTRACT

The use of Osterberg cell (O-cell) in axial pile load testing has been increased around the world due to the increase in construction of large diameter piles. O-cell is a sacrificial hydraulic jack(s) typically buried within the lower part of an instrumented pile to measure skin and bearing stresses.

Three case studies of full scale O-cell pile load test that have been carried out on rock socketed bored piles with diameters ranged from 1.0m to 2.50m were presented in this research. These piles were socketed in rocks with different degrees of weathering ranged from highly decomposed rock to competent rock. The related geotechnical data are described in detail in terms of: geological conditions, pile configuration, construction records, and testing procedure. The factual field data of these cases were back analyzed to interpret the skin friction, end bearing and pile load-movement behavior.

In this study, an axisymmetric finite element numerical model (FEM) was used to simulate and analyze the pile-rock interaction problem of O-cell pile load test using PLAXIS 2D finite element code.

The measured load-movement curves, unit skin friction, unit end bearing and load-transfer curves along the piles were compared with FEM simulation results revealing reasonable agreement. Afterwards, the head-down pile load test was simulated using the verified numerical models.

A sensitivity analysis was performed using FEM to study the model sensitivity to strength parameters and to refine interpretation of rock strength parameters.

Finally, the pile load-movement behavior and the ultimate capacity components (skin friction and end bearing) derived from the verified FEM model were compared with the available national and international used norms and standards, to study the accuracy of prediction of these methods (i.e. pile behavior and ultimate capacity).

Keywords: Osterberg cell, O-cell, Large diameter piles, Finite element modelling, Load-settlement curve, Pile load-movement curve, Single pile, Conventional pile load test, Pile-soil interaction, Rock socketed piles.

CHAPTER (1)
INTRODUCTION

1.1 General

The use of piles back can be to the ancient Egyptians which traced used timber vertical elements to fix docks into Nile bed (Hussein and Goble, 2004). Later, bridges across rivers were constructed by Romans using the same technique. These timber elements are called now “piles”. The usage of piles was developed over time; nowadays, piles are used to support coastal structures, high rise buildings, piled embankments, and offshore platforms.

The testing of deep foundations is an important activity for the piles deign and more over it affects the construction of piles. Based on the results of pilot piles the design criterion and also the construction procedure may be changed or verified. There are different testing techniques are known around the world such as: static pile load testing where a full scale pile is loaded from top and the pile deformation and behavior being monitored, Statnamic pile load test, dynamic pile load test in which a weight being freely dropped from a certain distance to hammer the pile and the pile is monitored, psedue-static pile load test. Finally, the O-cell pile load test (pile is loaded in two opposite directions up and down using a cell embedded in the pile

Non-destructive pile tests are available in the market to measure the pile continuity and as a quality control for the construction of piles, such as:

- Integrity tests, which use wave propagation techniques to measure the pile structural continuity and section variations along pile entire length.
- Cross-hole sonic logging “CSL”, which use waves with sender and receiver to measure the pile defects and miss-construction problems.
- SoniCaliper pile profile, which measure the pile diameter in increments along the pile length to get the excavated pile profile.

The following are the most essential information could be provided from pile test:

1) The pile load transfer behavior;
2) The pile load-movement behavior;
3) The pile ultimate geotechnical capacity;
4) The pile structural integrity, pile defects and profile of excavation as constructed.

The provided information may be used to verify the pile design assumptions and obtaining data about pile-soil interaction in a particular soil formation which allow more cost effective and more confident design of single pile and pile group in a particular soil formation.

Static pile load test method is the tradition method of deep foundation testing and the most known around the world. In the method the pile is statically loaded from the top and the pile deformations are measured. The static testing method a reaction frame system is mandatory. The common limitation/disadvantages of this method are: 1) high cost engaged with high load, 2) reaction system is required, 3) safety hazards in case of test failure, 4) limited information about the pile-soil interaction.

1.2 Nature of The Problem

Since, the Osterbeg-cell is an innovative pile load testing method, the evaluation of the test results and interpretation of pile performance from factual data are not commonly well known for all the geotechnical engineers. However, the interpreted pile load-movement curves, pile skin friction capacity and pile end bearing capacity are affected by the load test set-up and load application direction. The effects of load application direction on the interoperated pile-soil stiffness/strength behavior are of major concern. Most engineers are not familiar with the O-cell results. Hence, the pile conventional load movement curve shall be interpreted from the O-cell results. The effects of the interpretation assumptions on the interpreted behavior shall be studied. For the socketed in rock piles the estimated pile capacity during the design stage is about 10% of the measured pile capacity (Schmertman and Hayes, 1997). Hence, the used international standards and norms are highly under predict the rock socketed pile capacity.

1.3 Objectives of The Research

The purpose of this research is to evaluate the Osterberg-cell static pile load test results and interpretations. In addition to investigate the influence of the load application direction on the interpreted pile-soil strength/stiffness behavior and to compare the difference in pile behaviors between the O-cell test and top-down conventional pile load test. The measured pile-soil behavior, skin friction and end bearing capacities are compared against the estimated based on national and international codes.

The main objectives of this research involve the following points:

1- Performing a literature review on previous research studies carried out in areas relevant to the research topic such as; pile load testing using Osterberg-cell technique and conventional technique; evaluation of O-cell test results and finite element modeling for pile testing.

2- Investigate the available worldwide used methods to interpret the pile-soil behavior and pile capacity from O-cell test factual data.

3- Develop finite element model (FEM) to simulate O-cell tests for three case studies, studying the influence of different execution problems on pile upward and downward movements, mobilized skin friction and mobilized end bearing.

4- Evaluate the conventional method to estimate the equivalent top-loading curve from the O-cell results for different soil stratigraphy.

5- Study and investigate rock socketed piles behavior using O-cell pile load testing.

6- Compare measured and simulated pile-rock behavior and pile skin friction and end bearing capacities with the available methods to estimate pile load-movement behavior and pile skin friction and end bearing capacities based on national and international codes such as: AASHTO LRFD 2014, Canadian manual 2006 and Egyptian geotechnical design code (ECP) 2005.

1.4 Outline of The Thesis

This thesis is organized in seven chapters. The contents of each chapter can be summarized as follows:

Chapter (1): This chapter provides an introduction to the problem, objectives of the study, and thesis organization.

Chapter (2): presents a summary of the literature review performed on the conventional top-down and Osterberg cell pile load tests. Also, the available previous studies on O-cell test evaluation and modeling.

Chapter (3): This chapter provides a brief description of the (FEM) finite element method. Also, the available different constitutive laws in geomechanics are illustrated. As well as, a detailed description of the material models used in this study is presented. In addition, the utilized numerical model in analysis is explained in details. Furthermore, the implemented methodology and procedure that will be used in this research to study and evaluate the O-cell test results and to compare between the O-cell and conventional pile load tests FEM results was described in detail.

Chapter (4): This chapter contains a back analysis for three (3) well documented case studies for O-cell pile load tests for rock socketed piles. In addition to, discussion regarding the commonly used method to generate the top-down load movement curve from O-cell test results.

Chapter (5): This chapter contains FEM modeling for the three (3) well documented case studies of O-cell pile load tests for rock socketed piles. In additions, finite element modeling (FEM) verification for the O-cell test for the three cases is presented. Moreover, a conventional top-down load test is simulated using the verified soil/rock and pile configurations. Finally, a sensitivity analysis was performed using FEM to study the model sensitivity to strength parameters and to reasonably interpret rock strength parameters.

Chapter (6): This chapter presents study and comparison for the three cases, the estimated equivalent top-loading curve from O-cell results with the computed from FEM. In addition, comparison of the measured pile strength/stiffness behavior against the estimated based on national and international codes is illustrated.

Chapter (7): presents summary, conclusions of the outcome of this research, and recommendations for the future studies.

CHAPTER (2)
LITERATURE REVIEW

2.1 Introduction

Deep foundations are adopted when relatively weak or otherwise unsuitable soil exists near the ground surface and vertical loads must be transferred to rock or strong soils at depth. Deep foundations have many other uses, such as to resist scour, to control settlement, to serve as breasting and mooring dolphins in marine works, to sustain axial loading by side resistance in strata of granular soil or competent clay, to support lateral loads, to allow above-water when piles are installed to support the temporary construction offshore platforms, to improve the stability of slopes, …… etc. There are many types of deep foundations. However, the main techniques of installing deep foundations are driven piles and drilled shafts (Rees and Lymon, 2006).

Drilled shafts are kind of deep foundations that are constructed by drilling a hole and placing fluid concrete inside. Reinforced steel can be placed in hole prior to placing the concrete as required. Axial and lateral loads can be resisted by drilled shafts (Reese and O’Neil, 1999).

2.2 Review of Pile Load Test

According to Fuller and Hoy (1970) the pile load testing purpose can be: to develop a criteria to be used for pile foundation installation and design, or to prove the adequacy of the pile-soil system for the proposed pile design load. The pile testing plays a functional role in the deep foundation design process. The pile load test can be performed by static or dynamic methods to provide information about the following key issues in deep foundation design and behavior: (Poulos, 1998)

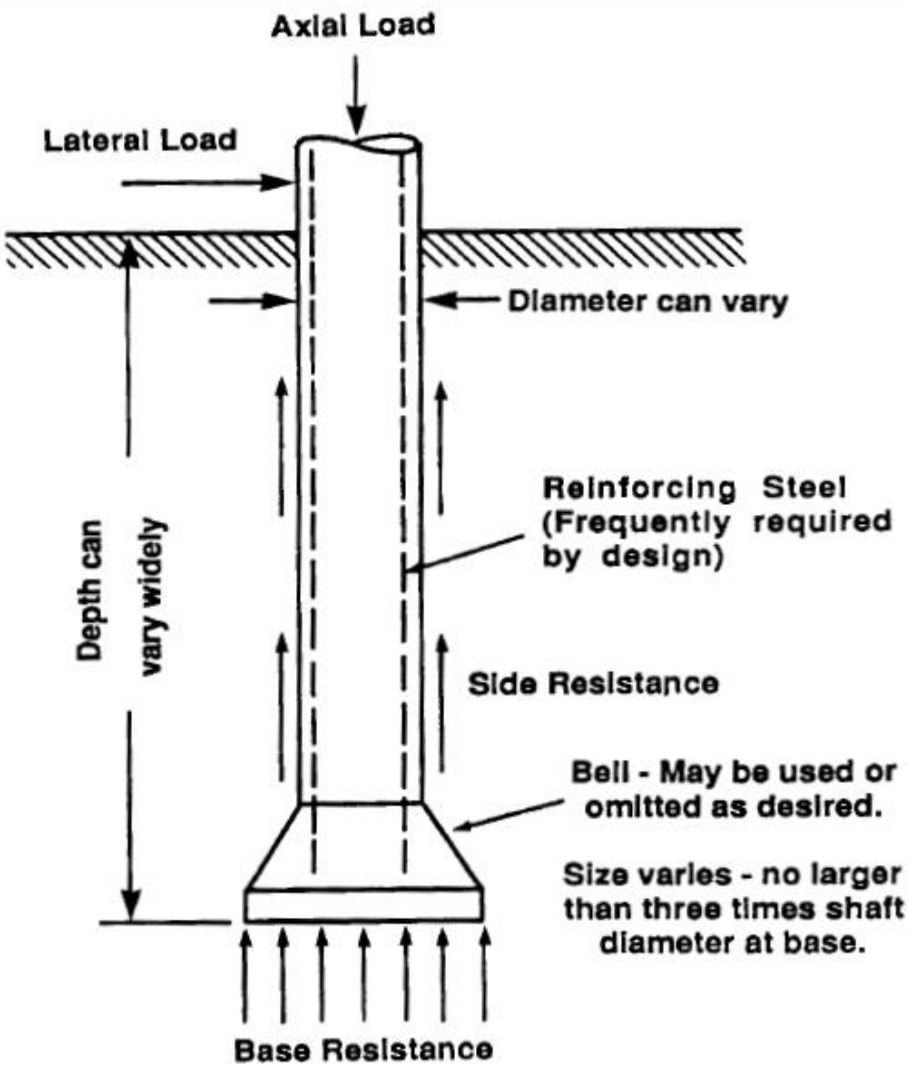


Figure (2.1) Drilled shaft details (After Reese, 1999).

In order to verify the pile capacity and the load movement performance of the tested pile, the pile always statically loaded.

The following will be required:

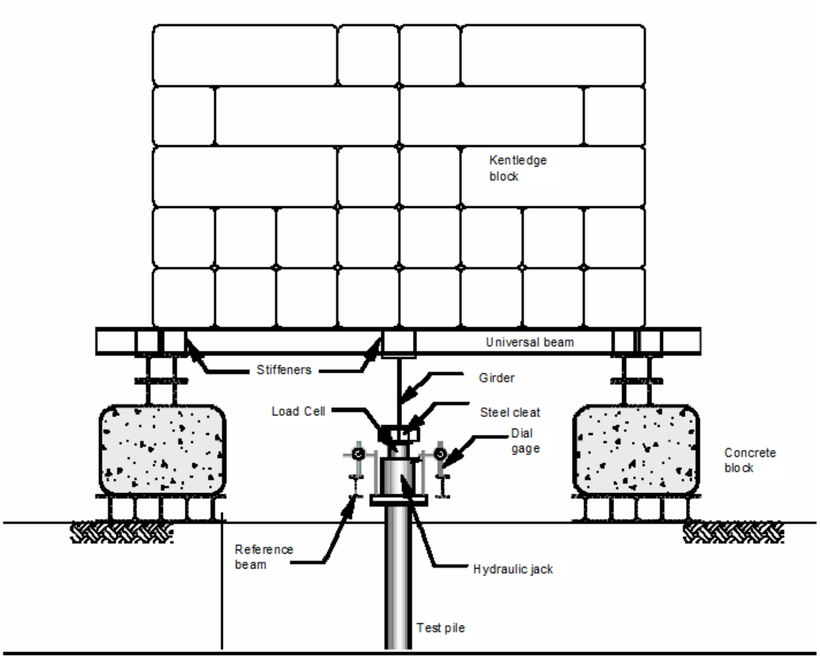
- Adequate subsurface exploration (distribution and depth).
- Well-defined subsurface profile.
- Adequate soil/rock field and laboratory testing to determine engineering properties.
- Static pile analysis results to rationally select pile type and pile length, as well as the load test site(s).

The below are some advantages for load testing of piles:

- Allow a more “rational” design. The pile-soil interaction performance and behavior can be determined much more reliable by applying field load test than from analytical assumptions or laboratory tests.
- Allow to use lower factor of safety. A factor of safety of three may be used in design of many pile foundations. Engineers are allowed to used factor of safety less than three based on the test results and according to international standards which translates into cost saving.
- Improve knowledge regarding pile-soil behavior. Which, may leads to reducing the number of used piles or the single pile length with corresponding saving in foundation costs.
- Verify that the designed load can be reached at the selected tip elevation.

2.2.1 Static pile load testing

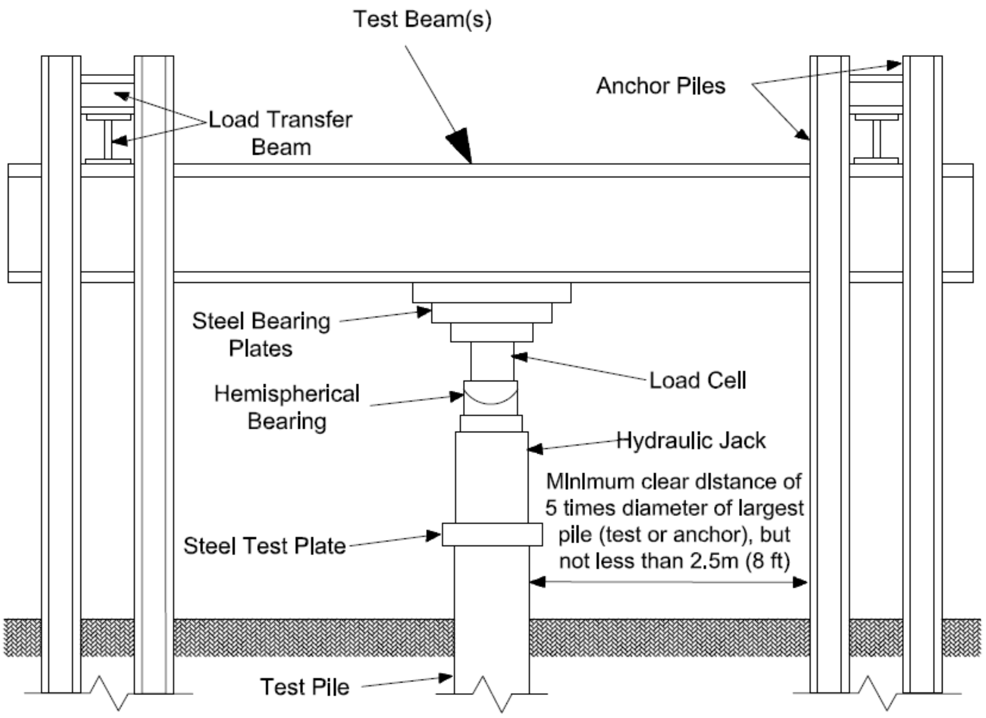
In the static testing of pile the pile is loaded from top to down and this method is the most reliable method and more representatives of the real conditions. In the real conditions the pile is loaded by the structure itself from top of pile. Different method/standards are now available for static testing procedure such as: CIRIA ISBN 086017 1361 and ASTM D1142. The ASTM method is the most known one and called “Quick method for single pile static load testing”. Many reaction systems are known and famous in the market. Figure 2.3 presents some of the most known reaction systems. Kenteldge reaction system where a reaction body is used as a support and reaction beam is used. In the tension pile system, pile are used as used a reaction systems.



(a) Schematic set-up using Kentledge reaction system.

(b) Area of 15m x 15m is required for 3 MN Kentledge system.

Figure (2.2) Kentledge as a reaction system.



(a) Schematic set-up using tension pile reaction system

(b) Reaction frame for 30 MN reaction pile test.

Figure (2.3) Tension piles as a reaction system.