CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Bridges and buildings are often supported on deep foundations. These foundations consist of groups of piles coupled together by concrete pile caps. These pile caps, which are often massive and deeply buried, would be expected to provide significant resistance to lateral loads. However, practical procedures for computing the resistance of pile caps to lateral loads have not been developed, and, for this reason, cap resistance is usually ignored.

Neglecting cap resistance results in estimates of pile group deflections and bending moments under load that may exceed the actual deflections and bending moments by 100 % or more. Advances could be realized in the design of economical pile-supported foundations, and their behavior more accurately predicted, if the cap resistance can be accurately assessed. An understanding of soil-pile-cap interactions and the mechanics of load transfer is necessary to develop a method that can be used to compute displacements, shears, and moments in pile groups.

The results of an extensive literature search conducted as part of this study indicates that over the past three decades only limited testing and research has been conducted in the area of pile cap resistance to lateral loads. These earlier studies provide evidence that the lateral resistance provided by pile caps is often significant, and that in many cases the cap resistance is as large as the lateral resistance provided by the piles themselves.

1.2 OBJECTIVES AND SCOPE OF RESEARCH

There is clearly a need for improved understanding of the factors that control the magnitude of cap resistance, and for rational analytical procedures to include cap resistance in the design of pile groups to resist lateral loads. An in-depth study was undertaken to address this need by accomplishing the following objectives:

1. Evaluate the state of knowledge with respect to the lateral load resistance of piles, pile groups, and pile caps.

2. Design and construct a field test facility to perform lateral load tests on pile groups with and without caps, and on individual piles.

3. Perform field load tests to evaluate the accuracy of theoretical and analytical methods for estimating the performance of pile groups, with caps embedded in natural soils, and with caps backfilled with commonly used backfill materials.

4. Perform laboratory and in situ tests to evaluate the properties of the natural soils encountered at the field test facility and on soils imported for use as backfill.

5. Develop an analytical method or procedure that can be used by practicing engineers for including the lateral resistance of pile caps in the design of deep foundation systems.

Chapter 2 provides a review of past experimental and analytical studies pertaining to lateral resistance, testing, and analysis of piles, pile groups, and pile caps. Included in the review is a discussion of the current state of knowledge with regard to pile cap resistance, an overview of methods available for analyzing the lateral response of single piles, and a synopsis of full-scale and model tests that have been performed over the last 50 years to evaluate the lateral load resistance of piles in closely spaced groups.

Piles in closely spaced groups behave differently than single isolated piles because of pile-soil-pile interactions that take place in the group. It is generally recognized that deflections of a pile in a closely spaced group are greater than the deflections of an individual pile at the same load per pile because of these interaction effects. The maximum bending moments in pile within a group will also be larger than for a single similarly loaded pile, because the soil behaves as if it has less resistance, allowing the group to deflect more for the same load per pile. The experimental and analytical studies that have been conducted to evaluate group interaction effects have been summarized in a series of tables, and selected studies relevant to this research have been reviewed in more detail. Results from these studies have been assimilated into design charts for evaluating group efficiencies and p-multipliers. These design charts are used in the analytical procedure that was developed as part of this study.

A field test facility was designed and constructed specifically for use in this project to perform lateral load tests on deep foundations and to investigate the lateral load resistance of pile caps. Developing this facility and conducting the load tests performed in it represent a major effort of this study. The facility is located at Virginia Tech's Kentland Farms, approximately 10 miles west of Blacksburg, Virginia. The test foundations consist of three pile groups, each with four piles. One group has a pile cap 18 inches thick and two have 36-inch-thick pile caps. The facility also includes two individual test piles, and a buried concrete wall (or bulkhead) with no piles. The piles are all HP10x42 steel sections ranging from 10 to 19 feet in length. Chapter 3 describes details of the in-ground facilities, the equipment that was used to apply horizontal loads to the foundations, the instrumentation that was used to measure deflections and loads, and the data acquisition system.

The site where the load test facility is located lies within the floodplain of the New River and is underlain by fine-grained alluvial soils. Chapter 4 describes the subsurface investigation and in situ tests that were conducted at the site to characterize the soil stratigraphy and to obtain soil samples for laboratory testing.

Chapter 5 describes the laboratory testing program conducted to develop soil parameters that were subsequently used in analyses of the lateral load tests. The laboratory tests included soil classification, unit weight, strength (UU, CU, and CD triaxial tests), and consolidation. Tests were performed on samples of the natural soil from the field test facility and on samples of imported materials that were used as backfill around the piles, pile caps, and bulkhead.

Lateral load tests were conducted at the field test facility from early June through October, 1998. Thirty-one tests were performed on three groups of piles with embedded caps, on two single piles, and on a buried concrete bulkhead. The results of the load tests are discussed in Chapter 6. Compressive loads were applied to the piles, pile caps and bulkhead using a 200-ton-capacity hydraulic ram. Displacements and rotations of the foundations were measured using electronic transducers, which provided sufficient data to evaluate displacements and rotations along three mutually perpendicular axes (parallel to the direction of loading, perpendicular to the direction of loading, and vertical).

Tests on the single piles were reviewed to examine the effects of the pile-head load connection, the effects of soil type and density, the effects of pile head rotational restraint, and the effects of cyclic loading. Tests performed on the pile groups and pile caps were used to compare the response of the pile foundation with cap resistance (cap fully embedded) and without cap resistance (soil removed from around the cap). In addition, the effects of cap side resistance, the effects of cap depth, the effects of pile length, the effects of cap backfill type and density , the effects of cyclic loading, and the effects of sustained loading were also evaluated using the test results.

Chapter 7 describes the procedure that was developed for analyzing the response of pile groups to lateral loads. The accuracy of the procedure was evaluated by comparing the computed response of the pile groups at the Kentland Farms load test facility to the results of the load tests discussed in Chapter 6. The method developed is called the "group-equivalent pile" (GEP) method The GEP method makes it possible to analyze a pile group using computer programs developed for analyzing single piles, such as *LPILE Plus 3.0* (1997). Each component of the method is described including the development of p-y curves for single piles, the modifications that are made to the single pile model to account for group effects, the development of a group-equivalent pile, and the method that was developed for calculating pile cap p-y curves.

Pile cap p-y curves are calculated using an *EXCEL* spreadsheet, called *PYCAP,* that was developed during this study. *PYCAP* contains a macro that is used to calculate passive pressures based on the log spiral earth pressure theory. The ultimate load resistance of the pile cap is determined by modifying the log spiral earth pressure force using three-dimensional correction factors from Ovesen's (1964) tests on embedded anchor blocks. The pile cap p-y curves are developed using a hyperbolic formulation, which is defined by the ultimate cap load resistance and the initial elastic stiffness of the cap. The cap's initial elastic stiffness is determined using elasticity equations developed by Douglas and Davis (1964) for estimating the horizontal displacement of a vertical rectangle in a semi-infinite homogenous elastic mass.

Chapter 8 contains a summary of the results, and the conclusion drawn from them. Recommendations are also given for future studies and research.