CHAPTER-1

INTRODUCTION

Bridges and buildings are often supported on deep foundations. The design of pile foundations is often controlled by the ability of the foundation to resist lateral loads. These lateral loads may be generated by earthquakes, waves, wind, ice flow, debris flow, river flow, earth movement, structural expansion and impacts. These transient loading conditions which may involve cyclic loading contribute to the complicated interaction between the structural foundation components and the surrounding soil. To safely and economically design such foundations, the engineer must incorporate effects of cyclic loading and gap formation on the lateral resistance of pile caps and the surrounding backfill soils (Randolph, 1981; Rollins *et.al.*, 1998).

The lateral load capacity of pile foundations is critically important in the design of civil structures which may be subjected to earthquake motions. Although fairly reliable methods have been developed for predicting the lateral capacity of single piles under static loads, there is very little information to guide engineers in the design of closely spaced pile groups with spacings less than about 6 pile diameters particularly under dynamic loads. Because of the high cost and logistical difficulty of conducting lateral load tests on pile groups, only a few full-scale load test results are available that show the distribution of load within a pile group (Brown *et. al.*, 1987; Brown *et. al.*, 1988; Meimon *et. al.*, 1986; Rollins *et. al.*, 1998; Ruesta and Townsend, 1997). These tests involved static or quasi-static loadings. Nevertheless, the data from these limited field tests indicate that piles in groups will undergo significantly more displacement and higher bending moments for a given load per pile than will a single isolated pile. The tendency for a pile in a trailing row to exhibit less lateral resistance because of interference with the failure surface of the pile in front of it is commonly referred to as "shadowing". This shadowing or group interaction effect is thought to become less significant as the spacing between piles increases and there is less overlap between adjacent failure planes.

The deep 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 foundation and their behaviour 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. Pile caps are constructed to provide a connection between a structure and multiple single piles and are often subjected to vertical and lateral loads as well as overturning moments. Resistance to these loadings is provided by pile-soil-pile interaction, base and side friction along the concrete-soil interface, rotational restraint provided by the pile-to-pile cap connection, and passive earth resistance. Research involving model tests, centrifuge tests, and full-scale tests has been conducted to study the lateral resistance of pile groups. However, of these studies only a few focus on the contribution of a pile cap with backfill soil to the lateral resistance. Of these limited studies, the results have shown that neglecting pile cap resistance may result in estimates of deflection and bending moment that are double the actual values (Mokwa and Duncan, 2001). Several of the more detailed studies on pile caps have provided significant insight regarding the lateral resistance of pile caps. Full-scale testing by Kim *et. al.* (1979) on three different 2×3 pile groups indicated that pile cap deflections were "nearly double" for the same lateral loads with the pile cap base friction component removed. Rollins *et. al.*(2001) and Rollins and Sparks (2002) tested a full-scale 3×3 pile group under static and dynamic loads and found that passive resistance and base friction provided 40 and 15% of the total resistance, respectively. In addition, the dynamic passive resistance was 225% higher than the static passive resistance. Mokwa and Duncan (2001) performed several full-scale tests on three different 2×2 pile caps and found that the passive resistance depends on the strength and stiffness of the soil along with the depth of cap embedment. Passive resistance contributed up to 50% of the total lateral resistance.

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.

1.1. PROBLEM IDENTIFICATION

The influence of lateral load on a pile group is a complex phenomenon. Pile foundation under lateral load is undoubtedly important for structures situated in highly seismic zones.

Few researchers has reported that the lateral load resistance provided by pile caps can be very significant, and that in some cases the cap resistance is as large as the resistance provided by the piles themselves (Mokwa, 1999). Till now, few study of pile cap resistance against lateral load is found in the literature. Therefore, detailed study of this phenomenon is important for both safety as well as economic point of view.

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:

There are two distinct objectives of this study. These are

(1) Study of behaviour of pile group under lateral load and

(2) Study of resistance of pile cap under the lateral load.

1.3. METHODOLOGY

Two distinct approaches are followed to fulfil to achieve the objective of the study. These are as follows

1.3.1. Behaviour of Pile Group under Lateral Load

The performance of a pile group under lateral load is a complex phenomenon. For the last seventy years researchers studied various aspects related to this phenomenon. It was already established that many influencing factors are there for pile-soil-pile interaction (*PSPI*) under lateral load. The spacing of pile is one of the important parameters that play an important role in *PSPI*. Most of the analytical approaches were expensive in terms of time and computation. Here an attempt has been made to develop a computer code in C++ to study influence of spacing in pile group.

The characteristic load method (*CLM*) is chosen to study the phenomena as this methods found to be simple, straight-forward and reasonably accurate. Then develop a computer code for the mathematical model. Observe the changing pattern of deflection and bending moment of a single pile and pile group with different spacing for different type of sand and clay.

1.3.2. Resistance of Pile Cap under Lateral Load

Although lots of researchers contributed towards the study of pile behaviour under lateral load, few works are available in the literature regarding lateral resistance of pile cap (Mokwa, 1999). Neglecting this resistance in design results in excessive estimates of pile group deflections and bending moments under load, and underestimates the foundation stiffness. In many situations, neglecting cap resistance introduces inaccuracies of one hundred percent or more (Mokwa and Duncan, 2003). There is a need for rational procedure to include cap resistance in the analyses to resist lateral loads. In this study an attempt has been made to study the phenomenon using both analytical and experimental methods. In the analytical approach, the finite element analysis is performed and in the experimental approach, model study of pile and pile groups are undertaken.

1.3.2.1. Finite Element Analysis of Lateral Resistance of Pile Cap

Finite element analysis is one of the sophisticated methods for mathematical modelling and thus ensuing high accuracy of the results. *PLAXIS 2D,* a finite element *2D* software has been used for this purpose. The pile-soil model is generated for plain strain condition with 15 node elements. The minimum dimensions of the draw area have to be finalised such that the geometry model will fit the draw area. The soil is modelled by the geometry lines. The plate elements are considered for modelling of pile and cap. Three position of pile cap is considered for this study. The interaction between the soil and the pile is modelled at both sides by means of interfaces. The interfaces allow for the specification of a reduced pile friction compared to the friction in the soil. Interfaces are indicated as dotted lines along the geometry line (Pile). In order to simulate the behaviour of the soil, Mohr-Columb model is considered for investigation of the problem. With the help of standard fixity option of the software, the boundary condition is created. It will generate a full fixity at base of the geometry and roller conditions at the vertical faces (u_x=0, u_y=free).

The mesh generation in finite element analysis is not only difficult task but also critically important to achieve a better and accurate results of the problem. Select 15 node triangular elements as the basic type of element to model soil layers. The mesh generation takes full account of the position of points and lines in the geometry model, so that the exact position of layers, loads and structures is accounted for in the finite element mesh.

The lateral loads corresponding to the different displacement are picked up and transform the findings in to graphical form. The parametric study is performed by varying length of pile, pile diameter, spacing and position of pile cap. Finally calculate the lateral resistance of pile cap from the ratio of the difference of lateral load of piles for which pile caps are not free from the ground surface and are free from the ground surface to the lateral load of piles for which pile caps are free from the ground surface at a particular deflection. And expressed in percentage.

1.3.2.2. Experimental studies of Lateral Resistance of Pile Cap

A laboratory test facility is developed to physically model the lateral load tests on pile groups and pile caps. The sand which is considered as foundation material was tested in the laboratory first. The sand has to be poured in to the test tank carefully from a particular height such that it attains desired relative density of soil. The model pile is prepared such that the piles will be flexible by using the guideline in the literature considering the stiffness factor (Poulos and Davis, 1980). First the pile group is placed such that the pile cap just at the ground surface which is free from ground implies no resistance of pile cap from the soil. Second the pile group has to be placed such that the pile cap came to contact with the soil of the test tank. And the displacement was measured for the corresponding load.

Load-displacement graphs then are plotted. From the graph the lateral resistance of pile cap is evaluated by calculating the ratio of the difference of lateral load of piles for which pile caps are not free from the ground surface and are free from the ground surface to the lateral load of piles for which pile caps are free from the ground surface at a particular deflection. The parametric study is performed by varying materials of pile and pile cap, length of pile, pile diameter, spacing and position of pile cap.

1.3.3. Statistical Analysis on Experimental Data

Regression analysis is performed using two advanced statistical tools namely Super Vector Machine (*SVM*) and *M5P*. The support vector regression (*SVR*) is an adaptation of a recently introduced statistical / machine learning theory based classification paradigm known as, support vector machines (Gunn, 1998; Singh, 2008; Hua *et al.*, 2007).

Model tree technique provides a structural representation of the data and a piecewise linear fit of the class (Quinlan 1992). These have a conventional decision tree structure but use linear functions at the leaves instead of discrete class labels. Like conventional decision tree learners, *M5P* builds a tree by splitting the data based on the values of predictive attributes.

The classification and regression analysis is performed on the experimental data using the *SVM* and *M5P* tools.

1.4. ORGANISATION OF THE THESIS

Chapter 1 introduces the contents of the dissertation.

Chapter 2 consists of a detailed literature review and background. The review is quite broad and critical, pointing out faulty concepts which have been used through the years. The literature systematically reviews the different analytical and experimental methods used for dealing with behaviour of pile group under lateral load including pile cap reaction.

Chapter 3 presents the development of computer code to study behaviour of pile group under lateral load using established approaches.

Chapter 4 discusses some enlightening aspects of finite element analysis of pile cap resistance under lateral load.

Chapter 5 deals with design and construction of laboratory test facility to perform lateral load tests on pile groups. This chapter discusses laboratory tests procedure to observe the performance of pile groups with and without caps embedded in soil.

Chapter 6 deals with the statistical analysis on experimental data using Super Vector Machines (*SVM*) and *M5P*.

Finally chapter 7 consists of conclusion and the future scope of the problem.