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College of Engineering

EFFECT OF PILE CROSS-SECTIONAL SHAPE ON THE BEHAVIOR OF PILE GROUP UNDER CYCLIC LATERAL LOADING

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering/Soil and Foundation Engineering

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Abstract

In general, pile foundations of different cross-sectional area and group configurations are typically employed to support the structural and external loads such as cyclic loads. This cyclic load may transmit laterally or/and vertically to the foundation as centric load, and sometime be eccentric loads.

Therefore, this research is aimed to study the effect of two cross-sectional shape of pile (circular and square), three pile group configurations (square, triangular and rectangular) and three pile spacings (3D, 5D and 7D) (D is the pile diameter) on the pile group behavior under combined loading. To achieve this aim, a laboratory small scale model has been developed and mainly included soil tank and lateral cyclic load apparatus, in addition all tools and materials used for completing the tests. The soil used in this study is sandy soil with a relative density of 70%.

The combined load is one-way lateral cyclic load simultaneously with vertical static load. The axial load is calculated from allowable load capacity for each group (150, 200, 250 N). The frequency of cyclic load was 0.2 Hz and continue to 100 cycles with critical load ratio of 100% from ultimate lateral load. The axial load applied in the center of pile cap. While, the lateral cyclic load act at three points (at the center of pile cap, at 0.25S and 0.5S eccentric distance), where S is spacing between piles.

It can be concluded that in general, the pile cross sectional shape had significant effect on the lateral performance of pile group. Where the groups with pile of square section have lateral displacement less than circular by about 30% in all cyclic load magnitude. As well as, the group configurations and piles spacings also affected the lateral group performance. For all configuration, the spacing of 7D provide larger effect on the lateral resistance. In this case, for groups of (square, triangular and

rectangular arrangement), the lateral displacement reduced to (26%, 42% and 44%) compared to 3D spacing.

It can be seems that when cyclic load applied in an eccentric distance lead to reduce the lateral resistance, especially for piles of close spacings. The increase in the lateral displacement for the maximum eccentric distance reach to 54% and 45% for circular and square pile sections respectively. Additionally, the pile groups twisted with different angles which increase noticeably with increasing of load eccentricity to about 75%, that’s means the pile failed laterally when applied this type of loading.

For the axial displacement, the vertical movement for all pile group models was upward, which was in case of using square pile shape more than using circular shape by 20%. The vertical movement when applied load at 0.5S was about 0.46 and 0.55 from the embedded length of the pile for circular and square pile shape, respectively.

Finally, the maximum bending moment also effected by the point of eccentricity, it increases to 75% at the maximum eccentric distance. As well as, it effected by the pile section, where the square pile section shows bending moment less than that of circular section by about 50%. It also effected by the arrangement and spacings of pile group. The group of four piles has the lowest bending moment, as well as, the spacing of 3D had largest bending moment than 5D and 7D by about 49%. The maximum bending moment occurred at depth of the first quarter of the embedded length of the pile, from the top of soil.

CHAPTER ONE

INTRODUCTION

1.1 General

For a variety of years, pile groups have been often utilized to support construction like dams, waterfront homes, and highway bridges. Group-pile foundations have also been used in inshore and offshore platforms. These constructions are often vulnerable to significant horizontal forces and actions, thus it's important to precisely identify the problems influencing how pile foundations behave. Extreme pile-head rotation and deflection might result from unconservative research, stressing the superstructure and result in foundations that are not profitable **(Sabry 2002)**.

It is frequently necessary to drive the piles in a group at a small spacing because of the geometric restrictions in foundations that put significant lateral loads at risk. When it comes to the location for example inshore constructions, lateral loads are between 10% and 20% of the axial load. However, in the case of offshore structures, this percentage could be more than 30% **(Rao et al. 1998)**. Consequently, a large loss to the engineering structure may result from a level of horizontal displacement generated by lateral force that is greater than what is permitted **(Bartlett and Youd 1995)**. Stresses from nearby piles have an impact on each individual pile's rigidity within the group (shadow effect). This phenomenon is caused by a reaction in the soil, which lowers the group pile's ultimate lateral capacity and causes the soil surrounding the piles to fail **(Ashour et al. 2004)**.

In regards to the piles, it provides the perfect base for resolving the distribution and transmission of engineering structural loads via water or weak, compressible soils into solid, less compressible soils, or possibly rocks. In accordance with the state and placement of the structures, piles may be subjected to a variety of loads, including static, centric and eccentric cyclic loads and vertical and horizontal loads. If the foundations are not sufficiently designed to withstand such loads, maybe lead disastrous effect.

Based on the eccentricity of the loads and/or the asymmetric geometry of the superstructures, significant eccentric lateral loads could be transmitted to the foundations of the structures. Actually, there is evidence that tall buildings have suffered remarkable permanent deformations due to eccentric loads from strong winds **(Vickery 1979)**.

1.2 Cyclic Loading

The loads exerted on the soil and foundations are classified as static and dynamic loads in geotechnical engineering, and each load has a different behavior. While cyclic loads cause the piling soil's compressibility to increase exponentially with the amount of cycle loads, static loads accrue very little dynamically, particularly to the point of ignorance **(Reilly and Brown 1991)**.

As seen in Figure (1.1), the term "cyclic" loading is commonly used to characterize variable loads with repeating patterns and a certain level of regularity in return period and amplitude, the sources of cyclic loading that occur most frequently shown in Figure (1.2) **(Puech 2013)**. Depending upon the direction of orientation of the loads applied to piles, the nature of the cyclic lateral loading can be categorized primarily as one-way or two-way, depending on whether the maximum and the minimum loads were oriented in the same or opposing directions.

One of the challenges that geotechnical engineers face is the settlement of soil beneath building foundations. Estimating the settlement is straightforward while the static loading is known; however, when the cyclic and dynamic loads are taken into consideration, this prediction becomes much more difficult. As the number of cycle loads increases, the accumulated soil compressibility rises dramatically due to the cyclic load. This constant compression may result in unexpected deformations that affect the buildings' planned operates **(Agaiby 2015)**. Geotechnical engineering is concerned with cyclic loading due to its decisive implications on design and safety for engineering facilities in general and marine facilities in particular.

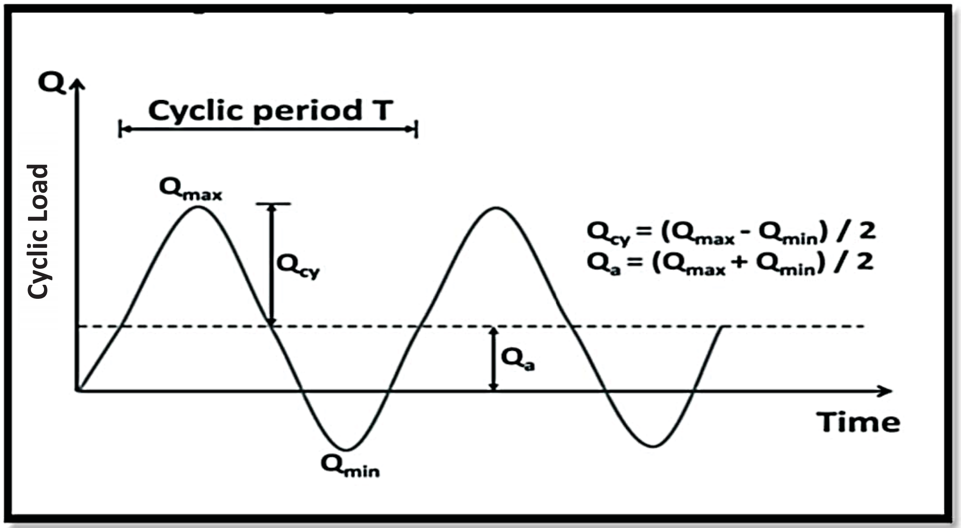

Figure (1.1): Definition of Cyclic Loading **(Puech 2013)**.

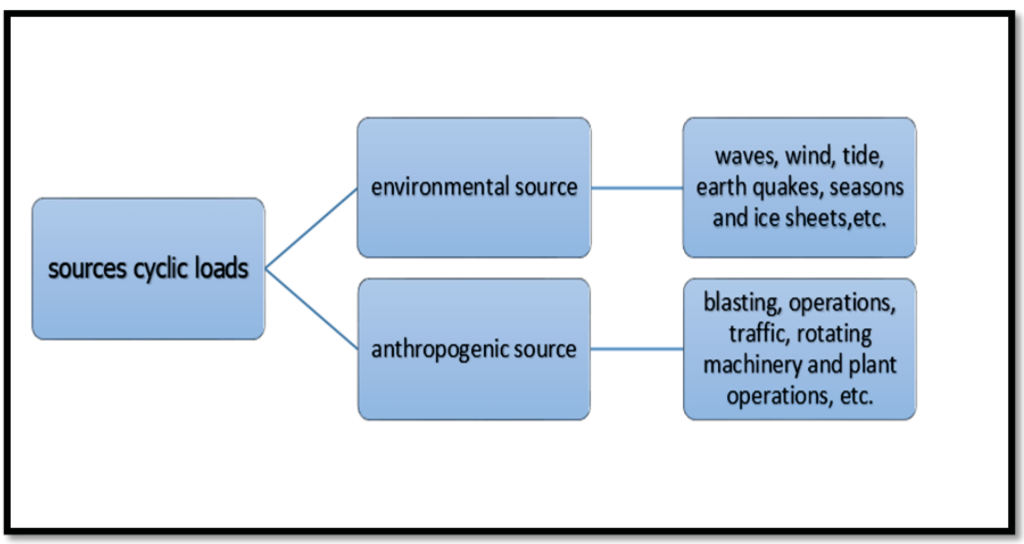

Figure (1.2): Sources of Cyclic Load **(Puech 2013)**.

1.3 Problem Statement

In nature, pile foundations are rarely subjected to a single load; instead, they are frequently chosen for deep foundations when the other foundations are insufficient. Multiple loads may act simultaneously on piles, and they may also act in separate directions at the center of the foundation or may affect as eccentric loads on these foundations. An eccentric lateral load would be transmitted to foundations of the constructions, due to the eccentricity of the loads, torsion will develop, which will produce complicated structural responses.

Many studies have examined the lateral force placed on piles; these studies focused on static loads, centric cyclic loads and other forms of loads. Therefore, this study will be thorough and complimentary to the previous research. As it simulates the reality where two different loads are applied in same time, one of them is vertical static and the other is lateral cyclic load at different eccentric distances. It is applied to group of piles with different spacing, configurations and two cross sections of piles. These variables provide precise information regarding the influence of piles cross sections, group configuration, pile group spacing, number of cycles, and load eccentricity on the pile group performance and the dangerous of these loads on the foundation of structures, and thus a safe design that increases the life and efficiency of the structure.

1.4 Importance of the Study

The lateral load capacity of piles plays a crucial role in the design and analysis of pile foundations for massive projects (offshore and inshore structure). Even though trustworthy performances have been developed to estimate the lateral capability of piles under static loads, there are a few little details that engineers should be aware of while designing a group of pile foundation under dynamic loads. Therefore, study the effect cross-sectional shape of piles, piles group configurations and spacing of pile group under the effect of centric and eccentric lateral cyclic load is very important to increase the database of the performance of pile foundations in geotechnical engineering requirements, increase the safety of buildings and reduce the cost and human losses.

1.5 Objectives of the Study

Implementation of eccentric lateral cyclic loads on group of piles having different cross-sectional areas and configurations is a complex case, so this research investigated the following:

1- Investigate the effect of cross-sectional shape of piles and configuration of group of piles on the performance of pile groups under combined load (vertical static and lateral cyclic load).
2- Study the influence of load eccentricity and the response of pile group under eccentric lateral cyclic load.
3- Identifying the effect of the pile's interaction with soil and the spacing between piles on the resistance of the lateral pile under different loading conditions.

1.6 Thesis Layout

The general format of the current study is as follows:

Chapter one:- Presents the study's objectives and a succinct overview of piles subjected to both static and combined cyclic lateral loading.

Chapter two:- A summary of published research on the lateral cyclically loading (centric and eccentric) and static loading of pile foundations is given in this chapter. The research includes field studies, theoretical and experimental studies, and a variety of analytical approaches.

Chapter three:- Uses a counting-down technique to show the procedures and practical methodology before presenting the piles and soil classification.

Additionally, a detailed description of the traditional models of pile-soil manufacture was given by the method used to evaluate the dynamic response of the group of piles when implanted in dry sandy soil.

Chapter four:- The results of a realistic system model are discussed and presented. Group of pile interactions under centric and eccentric cyclic loading with static vertical loading are analyzed by this model. The framework used to a pile group model illustrates the influence of the eccentricity, spacing between piles, group configuration and piles cross section on the dynamic response of the pile group.

Chapter five: - Presents recommendations and findings derived from the research's test results.