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BEHAVIOR OF PILE SUBJECTED TO AXIAL AND CYCLIC LATERAL LOADS IN SANDY SOIL

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

by

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَيَسْأَلُونَكَ عَنِ الرُّوحِ ۖ قُلِ الرُّوحُ مِنْ أَمْرِ رَبِّي وَمَا أُوتِيتُمْ مِنَ الْعِلْمِ إِلَّا قَلِيلًا ﴿٨٥﴾

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Dedication

To …

My father, who was the cause of my success

My mother, the sight of my eyes.

My wife, who supported me.

My sisters and sons whose love flow in my veins.

Our honorable teachers who taught and rewarded us their knowledge.

Everyone, who wishes me success in my life,

I dedicate this humble work.

MUQDAD

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MUQDAD

ABSTRACT

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ABSTRACT

Offshore foundations are often subjected to huge environmental cyclic lateral loads due to ocean waves, current and wind, which could exceed their capacity, in addition to its fundamental function to transmit the vertical loads of self-weight of structures into the deep soil strata. The repetitive nature of such loading with the presence of vertical loads produces a gradual alteration in the head displacement and bearing capacity of the piles. This sometimes may produce catastrophic consequences. A cumulative displacement and bending moment lead to a problems in the pile foundations represented by serviceability problem due to the extra displacement of the piles and failure structurally when the bending moment value reach to the point of yield. In order to investigate the influence of combined loading on the pile-soil interaction performance, a cyclic loading system has been developed. Through this multi-purpose system, lateral sinusoidal loading could be applied on the head of an instrumented model pile with strain gauges at various amplitudes and frequencies under stress-controlled mode.

A series of 72 laboratory tests are performed to investigate the single pile response when subjected to combined loads, by illustrating the variation of horizontal and vertical displacements as well as bending moment along the pile depth. Moreover, numbers of parameters are studied, including: cross section shape of the pile

(circular and square), slenderness ratio L/D (25 and 40), magnitude and frequency (0.067, 0.1 and 0.2 Hz) of the cyclic load. All tests are achieved in dry sand with one relative density (R.D.) 70% (i.e. dense). One hundred cycles are used in each test to represent repetitive of environmental loading on offshore structures during the storm wave.

Results obtained from the experimental tests under the combined load confirm that the lateral displacement and bending moment along pile decrease with increasing the vertical load level, the rate of reduction reach to 73 % and 46 % for displacement and maximum bending moment after 100 cycles respectively. Exactly the contrary, but it may cause problem with respect to allowable settlement. For piles under the influence of combined loads regardless vertical load level, the displacements (vertical and lateral) and bending moment increase with increasing the magnitude of cyclic load ratio (CLR), the difference in the rate of increase reaches to 82%. Although the square and circular pile sections had nearly the same outside dimensions, the square pile provides lateral deflection that is 12 to 42 % lower than a circular pile for the same amount of cyclic load. Besides, there is an observable influence of slenderness ratio (L/D) and frequency on the values of displacements (lateral and vertical) and bending moment. Most of these values under the effect of the pure cyclic load are higher than those observed in combined loads for all frequencies (i.e. 0.067, 0.1 and 0.2 Hz). Furthermore, the increasing in the number of cycles under the influence of high cyclic lateral loads and frequency (i.e. 0.2 Hz.) has a greater influence on the behavour of the pile compared on low cyclic lateral loads and frequencies (i.e. 0.067 and 0.1 Hz).

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LIST OF SYMBOLS

Symbol	Symbol Meaning
c	Cohesion
C_u	Coefficient of uniformity
C_c	Coefficient of Curvature
D	Pile diameter
D_{50}	Mean size of soil particles
D_{10}	Effective size at 10% passing
D_{30}	Grain size at 30% passing
D_{60}	Grain size at 60% passing
D_r	Relative density of soil
E_s	Soil Modulus
EI	Stiffness of pile section
E	Modulus of elasticity
e	Eccentricity of load
$e_{max.}$	Maximum void ratio of soil
$e_{min.}$	Minimum void ratio of soil
f	frequency
G_s	Specific gravity
H	Lateral load applied on the pile head
Hz	Hertz
I	Moment of inertia
K_h	Coefficient of horizontal subgrade reaction
K_p	Passive earth pressure coefficient
L	Length of pile
L/D	Slenderness ratio of pile
M	Bending moment
n_h	Coefficient of soil modulus variation
p	The soil pressure per unit length of the pile
p_n	Net ultimate frontal normal soil resistance (force/length)
p_t	Lateral load applied at or above ground level
p_u	Ultimate lateral resistance of pile
P_x	Axial load
$Q_{all.}$	allowable vertical load
$Q_{ult.}$	ultimate vertical load
r	Outside radius of the pipe
S	Net ultimate lateral shear drag (force/length)
V	Vertical load
x	Segment length of the pile
y_g	Deflection at ground level
y	Pile deflection
z	Section modulus of the pile section

η	Shape factor (0.8 for circular; 1.0 for square)
ξ	Shape factor for shear (1.0 for circular; 2.0 for square)
γ	Unit weight of soil
γ_d	Initial dry unit weight of soil
ε	Measured strain
Ø	Angle of internal friction

LIST OF ABBREVIATIONS

Abbreviation	Meaning
API	American Petroleum Institute
ASTM	American Society For Testing and Materials
CLR	Ratio of magnitude of cyclic lateral load to static ultimate lateral capacity of the pile
LVDT	Linear Variation Displacement Transducer
SSI	Soil-structure interaction
PLC	Programmable Logic Controller

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Pile foundations are used for the purpose of distributing extremely heavy structural or skeletal load through a weaker undersoil or subsoil. Pile foundations (Poulos and Davis, 1980) also buffer the lateral loads that develop due to various natural phenomena like strong waves, tectonic activities, and movement of the soil. Piles are generally made up of wood, steel, and concrete and are subjected to either lateral, axial, or a combined load of axial and lateral loads along side with their moments. The biggest concern of interaction of soil structure is determining how the soil will behave under a laterally loaded pile.

1.2 Problem Statement

The laterally loaded piles have a number of uses as foundations of structures such as offshore platforms, bridges, high-rise buildings, transmission towers, wind farms. As these structures become higher and structure masses increase, more accurate and reliable calculations are necessary. In addition, many areas in the world experience several destructive storms, earthquake, and other seismic activities that have a cyclic nature, and it is in these areas that extra attention needs to be paid to the significance of a strong pile foundation and the role plays in supporting constructions.

Even though static loading is an essential consideration while designing pile foundations, it is the dynamic loading that presents the greatest challenge because of the supplementary forces on pile foundation excreted by dynamic loading, which bring additional complexity to the soil-structure interaction problem. Hence, Arta

(1992) posited that due importance needs to be given to the designing of vertical piles with regards to lateral loading. This type of loading induces progressive degradation of the foundation capacity associated with increased pile head lateral displacement and lead to higher bending moments than static loading, which at the end may lead to a tight structure, is likely to create service problems (Karthigeyan et al. 2006).

Figure (1.1) illustrates some types of lateral loading on pile foundations. These lateral loads may be grouped in the following forms: - static, transient, cyclic and others (Arta, 1992). Lateral static types of loading include earth pressure and drag from stream flow. Transient loading includes earthquakes, ship berthing, vehicle braking, impact and wind. Cyclic loading includes earthquakes and wave loading. The last group of lateral loading includes consolidation of soil, and effects of shrinkage, creep and thermal change. Often, a foundation will carry predominantly vertical loads, with only light horizontal loads, (e.g., a building with wind loading), while jetties and mooring dolphins may be exposed solely to horizontal loads. In spite of the presence of practical methods that have been developed for predicting the lateral response of single piles under static loads, dynamic loading is the main motivation for scientists and research originations because of the complex nature of the additional exerted forces including axial and lateral loads. The design of vertical piles to carry lateral loads should give consideration to (Arta, 1992):

i. Bending strength and stiffness of the piles

ii. Pile group geometry

iii. Resistance of the soil

iv. Induced axial loads

v. Lateral deflection

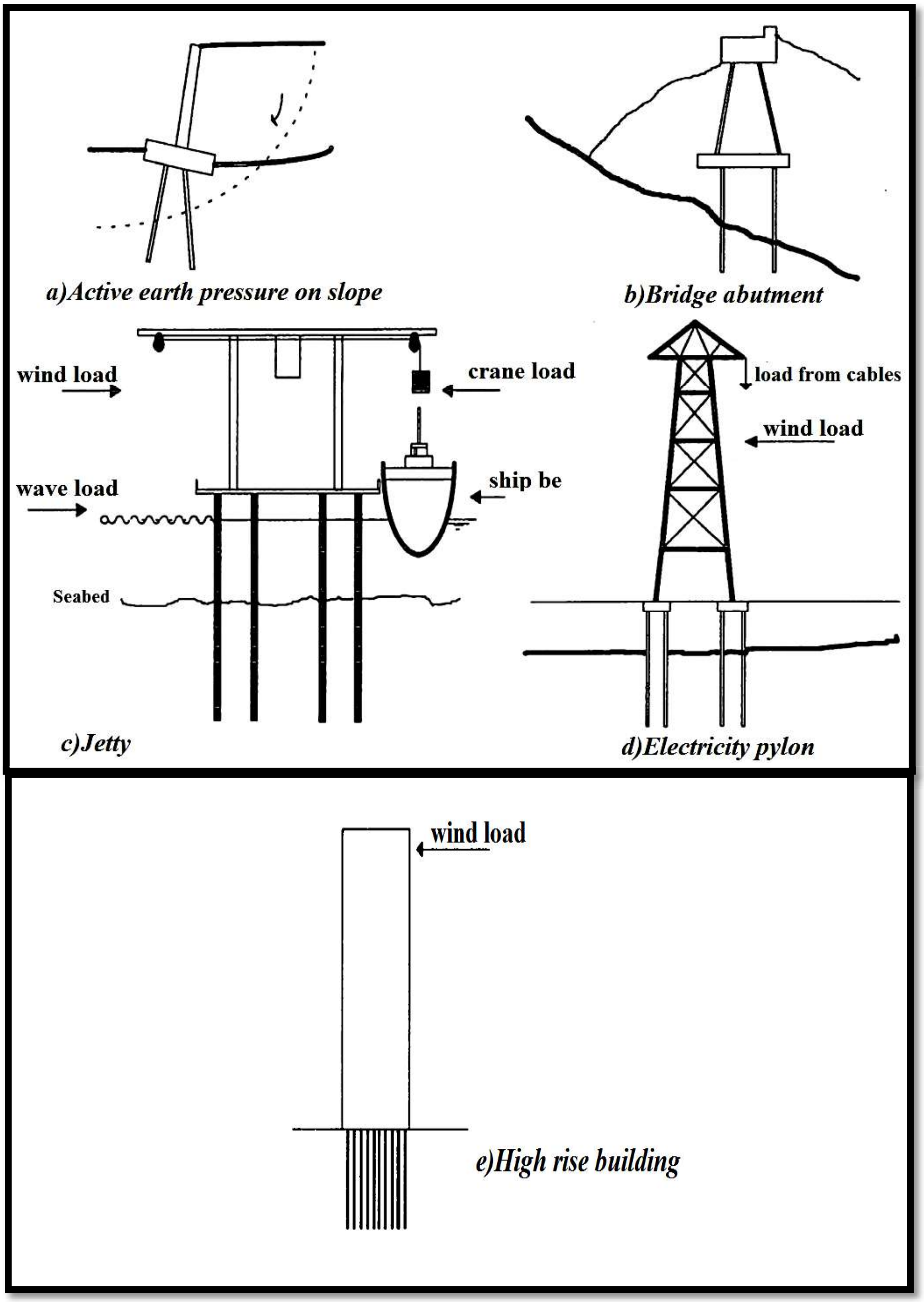

Figure 1.1: Typical lateral loads on structures cited by (After Arta, 1992)

1.3 Importance of the Study

When soil-pile foundations undergo a dynamic load analysis, the most essential facts of foundation design are revealed by the interaction between the neighbouring soil and the foundation pile. The manner in which piles respond to dynamic and static loading has been highlighted by numerous studies, however the author believes not much has been said with regards to lateral loading and needs to be studied in detail to arrive at an appropriate conclusion. Nevertheless, this uncertainty regarding the dynamic reaction of pile foundation is despite of the numerous studies that have been conducted over the past three decades and several more empirical studies will be needed to ascertain the influence of the characteristics of the soil pile. Several studies also need to be conducted in the domain of single pile structures in sandy soil to authenticate the theoretical results. However, a very few information is available of dynamic response that was observed on pile foundations. This is mainly due to the large number of variables in both soil and piles that lead to significant difficulties in conducting the tests. However, conducting a full scale testing is rather expensive and requires many time and great efforts, especially for single pile.

Even though full scale testing is the most suitable and beneficial type of testing to investigate the behavior of laterally loaded single pile but it is so expensive compared with other test. While small-scale testing gives similar behavior to full-scale model to some extent. Therefore, small scale testing model in the laboratory is still applicable and reliable within certain limit, by applying a similar field conditions as close as possible to those in the full scale testing model. In this research, tests are conducted on small-scale single piles models embedded within dry sand in the laboratory, which will reflect the behavior of full-scale single pile. The initial part of this research involves the modification of the experimental set up for a single pile model by including the development of a fully reversible cyclic loading actuator.

1.4 Aim of Study

The main aim of the current study is to develop an experimental small-scale single pile model to carry out the investigation of the influence of lateral static and cyclic loading on the response of the pile in sandy soil including:

i. Checking the influence of combined loads on the lateral resistance of piles under cyclic loading.
ii. Establishing the relationship between both of lateral and vertical displacements and number of cycles under different combined loads for pile models by cyclic loading tests.
iii. Assessing the influence of magnitude and frequencies of cyclic loading on the lateral resistance of piles under combined loading.
iv. Investigating the variation of bending moment distribution along pile shaft under combined loading.
v. Assessing the effect of slenderness ratio (L/D) and cross-sectional shape on response of pile models under combined loading.

1.4 The Study Layout

The framework of this study has been segregated into two appendixes, preceded by five individual chapters. The major characteristics of the chapters is listed in the following paragraphs:

Chapter one introduces the concepts pertaining to application of lateral and axial cyclic loading to piles, the issues arising in foundation structures due to lateral loading, and the main aim of this research.

Chapter two reviews extant literature, comprising of both empirical and conceptual works along with field studies and sums up the analytical methods to study the lateral loading of foundations piles.

Chapter three introduces the experimental setup and approach, comprising of a representation of the soil system and the piles. It also presents an elaborate account of the representative models of pile-soil structure along with the procedure used to analyse the dynamic reaction of a single pile when placed in dry sand.

Chapter four The results of the experimental models and their discussion are introduced in this chapter. Studies the reactions of a single pile prototype under axial and cyclic loads. The experiments on the pile model are also conducted to verify the effects of cross section shape, slenderness ratio and frequency of cyclic load on the dynamic response of piles.

Chapter five presents a conclusive picture of the outcome with regards to the empirical analysis of this study, along with suggestions for upcoming studies and researches.

Finally, additional results for the different parameters discussed and description of experimental work by photos are presented in appendixes A and B.