Ministry of Higher Education
and Scientific Research
University of Diyala
College of Engineering

PERFORMANCE OF PILE GROUP UNDER INCLINED CYCLIC LOADING 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

Reyah Daher Khorshed

(B.Sc. Civil Engineering, 2001)

Supervised by

Prof. Dr. Jasim M. Abbas

June 2021 **IRAQ** **Dhu Al-Hijjah 1442**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَمَا تَوْفِيقِيَ إِلَّا بِٱللَّهِ عَلَيْهِ تَوَكَّلْتُ

وَإِلَيْهِ أُنِيبُ

صدق الله العظيم

سورة هود(٨٨)

CERTIFICATION OF THE SUPERVISOR

I certify this thesis entitled "**Performance of Pile Group Under Inclined Cyclic Loading in Sandy Soil"** was prepared by "**Reyah Daher Khorshed**" under my supervision in the civil Engineering Department in University of Diyala in partial fulfillment of the requirements for the degree of master of science in civil engineering.

Signature:

Name: Prof. Dr. Jasim M. Abbas

(Supervisor)

Date: / / 2021

COMMITTEE DECISION

We certify that we have read the thesis entitled (**Performance of Pile Group Under Inclined Cyclic Loading in Sandy Soil**). We have examined the student (**Reyah Daher Khorshed**) in its content and what is related with it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

Examination Committee	**Signature**
1- Prof. Dr. Jasim M. Abbas	(Supervisor) ……………….
2- Assis. Prof. Dr. Waad A. Zakaria	(Member) …………………
3- Assis. Prof. Dr. Safa Hussian	(Member) …………………
4- Prof. Dr. Mahdi O. Karkush	(Chairman) ……………….
Prof. Dr. Wissam D.Salman	(Head of Department)…………...

The thesis was ratified at the Council of College of Engineering/ University of Diyala.

Signature…………………………

Name: Prof. Dr. Anees A.Khadom

Dean of College Engineering / University of Diyala

Date:

Dedication

To………

My husband, who was the cause of my success

My mother, the sight of my eyes.

My sisters , who supported me.

My sons whose love flow in my veins.

My friend to help me and supported me

Our honorable teachers who taught and rewarded us their knowledge.

Everyone, who wishes me success in my life,

I dedicate this humble work.

REYAH

Thanks are to Allah for all the things which led me into the light during the critical time.

I would especially like to express my deep appreciation and sincere gratitude to my supervisor, Prof. Dr. Jasim M. Abbas for his supervision and his valuable guidance and assistance throughout conducting this work.

Appreciation and thanks to the Dean and the staff of the College of Engineering, University of Diyala and also the staff of Soil Laboratory and thanks to all my colleagues, for their help.

REYAH

ABSTRACT

Performance of Pile Group Under Inclined Cyclic Loading in Sandy Soil

By

Reyah Daher Khorshed

Supervised by:

Prof. Dr. Jasim M. Abbas

ABSTRACT

Many types of foundation exposed to periodic inclined loads resulting from different sources. These forces in turn affect the foundations of the structures. Therefore, there is a need to intensify laboratory and field studies to assess this issue. To study the effect of inclined cyclic loading on pile group, an experimental program with a small scale model can be used. Thus, this study displays assessment via small-scale models of pile groups embedded in sandy soil with D_r 70% to identify the behavior of this model while exposed to inclined load.

The testing program involved examining the behavior of three models of pile groups with three configurations 2x2, 2x3, and 3x2 were slenderness ratio L/D of 40 with changing different parameters such as a number of loading cycles (1, 5, 25 ,50, 100), the effect of angles of inclination load i.e. (0^o,15^o, 30^o, and 45^o), (CLR) is the rate of cyclic load ratio (20%, 40%, 60%, 80%), at frequency (0.2) H_z and the ratio of the spacing between piles (S/D) 3, 5, and 7.

A new specially devised loading actuator was designed to achieve static and incline cyclic loading. The bending moment along the pile and lateral displacement of pile group head were measured.

It can seem that the piling group's displacement and the bending moment is increased with increasing cycle no.of loading cyclic for all spacing. Additionally, the lateral displacement of the pile group increased significantly when decreased the pile spacing from 7D to 3D.

The group 2x2 showed decreasing in lateral resistance about (60%-77%) compared with other groups for all spacing. In addition, the lateral resistance of group 2x3 is less than group 3x2 for all spacing. Also for all models, there is an accumulated in lateral displacement increase by increase CLR and for CLR=60% indicates the Critical Cyclic Load in100 cyclic.

The inclined load would be divided into two components, i.e. axial and horizontal components, the axial component from the inclined load is working as the vertical load on the pile groups, and causing the increase of the stiffness of the piles group and decreasing the lateral deflection about (37%-75%) in the soil in front of the pile and this would be seen when the angle close to the vertical axis(i.e. 45^o).

It is significant to mention that the location of maximum bending moments; this position is usually at the upper portion of the embedded length of the piles for each row which equal 1/4L. Similarly, The pile group model (2x3) showed the behavior of bending moment is less than the model (3x2) by approximately (25%, 16%, 23%, 40%) for angles 0^o, 15^o, 30^o, 45^o respectively.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	Definition
c	Cohesion
Cu	Coefficient of Uniformity
Cc	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
Dr	Relative Density of Soil
Es	Modulus of elasticity of soil
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
Gs	Specific Gravity
H	Lateral Load Applied on The Pile Head
H_Z	Hertz
I	Moment of Inertia
L	Embedded Length of Pile
L/D	Slenderness Ratio of Pile
M	Bending Moment
P	The Soil Pressure Per Unit Length of The Pile

Symbol	Definition
R	Outside Radius of The Pipe
Y	Pile Deflection
γ	Unit Weight of Soil
ε	Measured Strain
Ø	Angle of Internal Friction

LIST OF ABBREVIATION

Abbreviation	Definition
USCS	Unified Soil Classification System
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 General

Foundations of numerous constructions are exposed to inclined cyclic loads similar to in foundations of offshore structures, towers of wind energy converter, transmission towers, etc. In such circumstances, to improve the load-bearing capacities of accepted foundations and to reduce the resulting settlements, piles can be used. Also, in the difficult cases where the lateral and axial movements are produced along the pile with the moments generated by reason of seismic and wind loads, a pile foundation must satisfy the serviceability and safety conditions completely. Generally, the vertical force of the pile is predominant, on the other hand in special cases such as piles carrying wind energy and offshore foundations or conductors, the axial, a normally vertical load is coupled by a horizontal (lateral) load (Goswami, 2017).

1.2 The Cyclic Loading

Several difficulties facing geotechnical engineers are the soil settlement below the foundations of constructions. After the static loading is exposed, the estimate of the settlement is easy, however, this prediction is further complicated when dynamic loading and the cyclic load are subjected. The cyclic load causes accumulated soil compressibility, which increases extremely through an increasing number of cyclic loads. This incessant compression can cause undesirable deformations that can influence the purpose of the constructions (Agaiby, 2015).

The “cyclic” loading is a term that is used generally to describe changeable loads that have repetitive patterns and a degree of uniformity in return period and amplitude as shown in Figure 1.1. Cyclic loads can be in actual fact of environmental source (waves, wind, tide, earthquakes, seasons and ice sheets) or anthropogenic as a result of (blasting operations, traffic, rotating machinery and plant operations). Cyclic bearing capacities of soil should be enough to support the construction and its exterior cyclic loads and retain deformations in satisfactory limits, while keeping an adequate reserve against uncertainty conditions in parameters of soil (Puech, 2013).

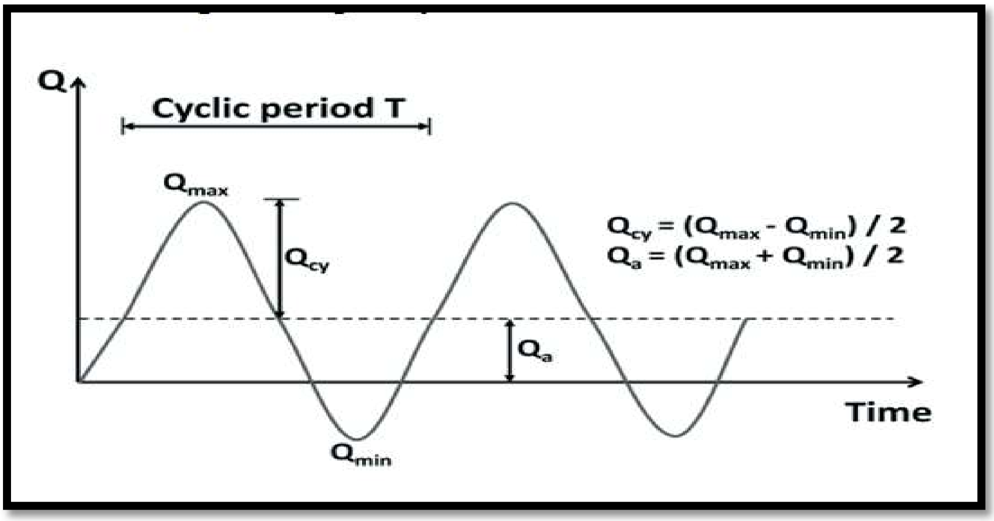


Figure (1.1): Cyclic Loading Definitions. (Puech, 2013)

1.3 Lateral Pile Performance

A lateral force on a pile is meaning a pile foundation that subjected to a load in the horizontal direction or causes a moment. Two factors influence the design of these piles, first is the allowable displacement of the pile and the other is the allowable pile bending moment as shown in Figure 1.2. Thus, the acceptable pile bearing capacity in the horizontal direction is limited at the level that pleases both of the following two criteria at the same time:

(1) The horizontal displacement (y_o).

(2) The maximum bending moment (M_{max}).

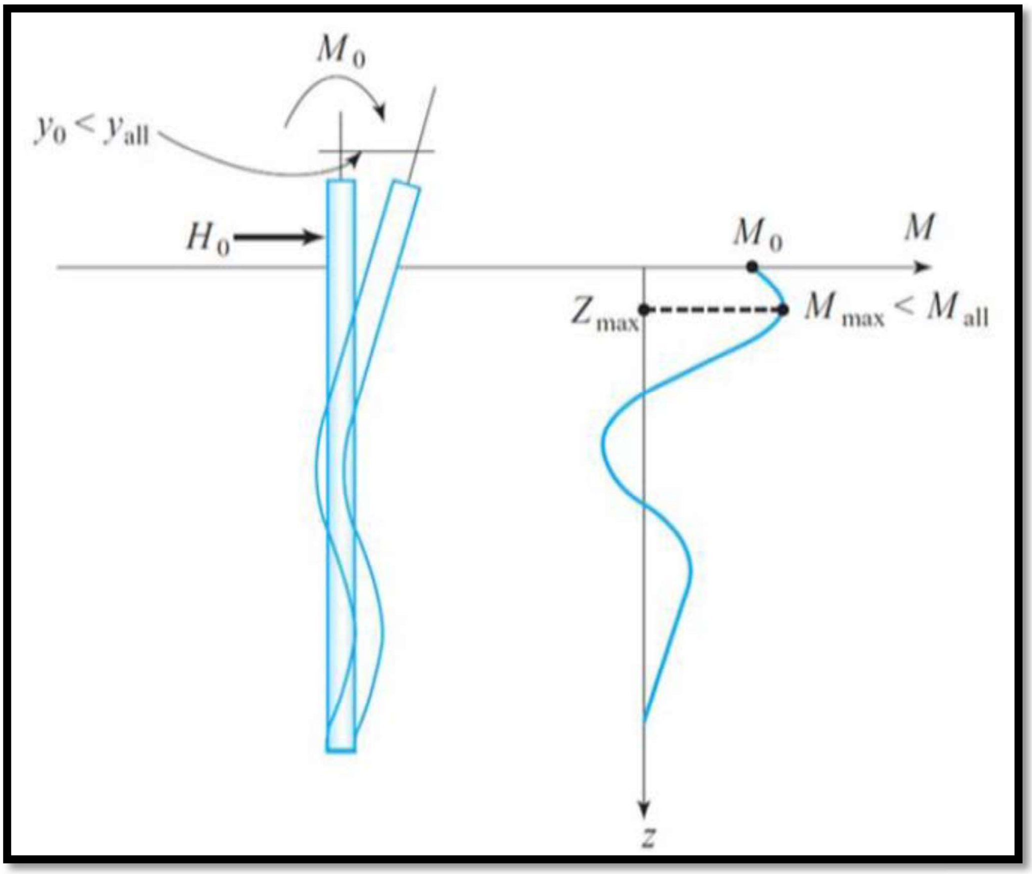


Figure (1.2): Horizontal Displacement and Maximum Bending Moment (Park, 2018).

In the horizontal direction the allowable pile bearing capacity is limited at the quantity that is suitable for both of the pile inside the group exposed to lateral loading are affected by the presence of in the same way loaded close pile by reason of the interaction of pile–soil-pile, causing to decrease in horizontal load ability of the group piles, Park, (2018). The piles exposed to lateral loads can be separated into short rigid piles in addition to long flexible piles as shown in Figure 1.3.

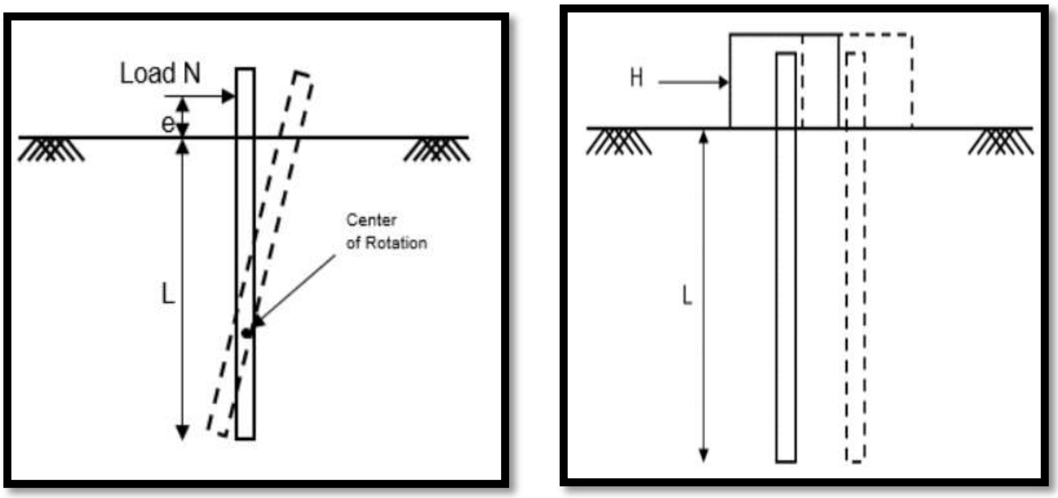
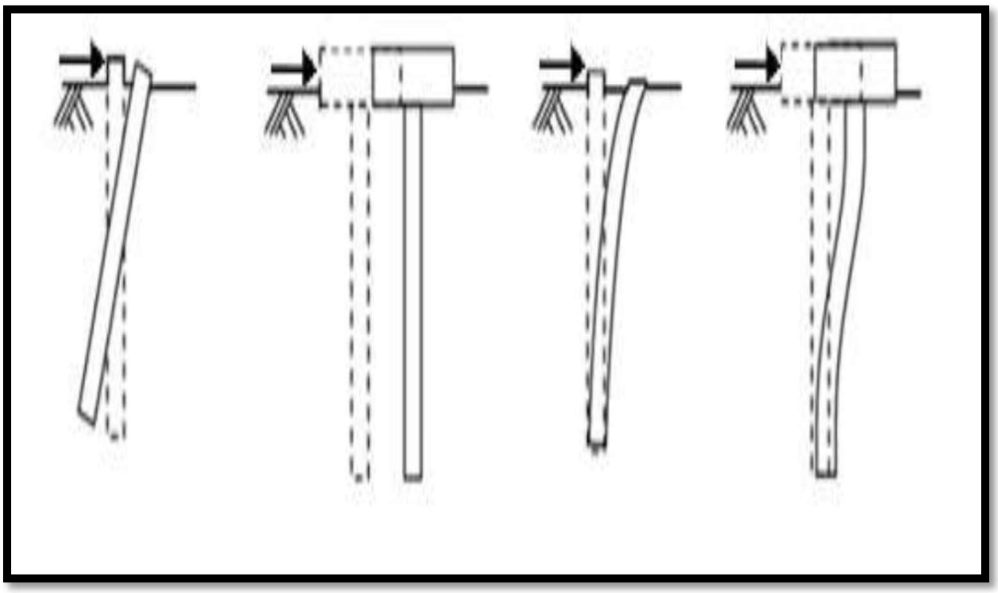


Figure (1.3) : Lateral Pile Response, a) Short Pile (head free), b) Short Pile (head fixed) (Park, 2018).

When the piles are loading in a horizontally direction they can rotate, translate and bend by reason of the transverse nature of load, Rigid piles (short) will not bend deeply would relatively rotate or transform. but, flexible piles (long) will have a bending performance for the reason that of applied load as shown in Figure 1.4(Fleming et al. 1992, Salgado 2008).



(a) Rotation (b) Translation (c) Rotation (d) Translation

Figure (1.4) : Failure Modes of Lateral Load Pile (Salgado 2008).

1.4 Statement of the Problem

Generally, pile foundations are worked to support several structures build upon soft clay or loose sand soils where shallow foundations would undergo dangerous settlements or the bearing capacity is very low. Piles are mostly suggested to resist only vertical loads. But, several constructions for example offshore structures, high-rise buildings, earth retaining walls are exposed to lateral or horizontal pressure influenced by wind load, wave load, movement of traffic, earthquake, etc. In some cases, they possibly will be exposed to incline cyclic loading conditions moreover these force source lateral and vertical movements besides rotation of pile cap. A large number of researchers who had investigated the influence of the various parameters influencing the behavior of laterally cyclic load on pile groups and other investigated experimental studies on the behavior of single pile subjected to inclined static compressive loads. But there are very limited researcher study the influence of the angle of inclination to the cyclic loading. Therefore this work presented to understand the effect of angle of inclination to the cyclic loading using different angles that applying on pile groups representing wind load, wave, and seismic load in the natural.

1.5 The Importance of Study

To designed and examine the pile foundations for highway structures and high-rise buildings are very essential and be influenced by the lateral pile's load capacity. Although durable performances have been changed for statement the lateral ability under static loads of piles, there are limited facts to lead engineers in the design of group pile foundation under dynamic load. Hence, the study of the performance of pile groups under incline cyclic load is significant to complement the database of the behavior of pile foundations in geotechnical engineering requests, increase the protection of structures and decrease the cost besides human damages.

1.6 Objectives of the Study

The main work focused on several points :

1- To study the lateral displacement and maximum bending moment of pile groups under inclined cyclic loading for the different angles of inclination.

2- Investigation of the effects of piles spacing and pile-soil-pile interaction on the lateral resistance of pile groups.

3- To study the effect of the number of cycles of inclined loading with different cyclic load ratios on the lateral movements for pile group models.

1.7 Thesis Layout

The thesis scope has been dividing into five chapters and appendices. A short concise of each chapter and explained in the following passages:

Chapter one: This chapter shows a general definition of piles group foundation exposed to cyclic loading, the objectives of the study, and the scope of this.

Chapter two: This chapter showing reviews existing literature, involving each experimental and theoretical researches along with field studies and several of the analytical procedures to analysis the lateral cyclic loading of piles foundations.

Chapter three: shows the experimental of work and methodology, counting off a display of the soil classification and group piles.

Furthermore showing a complete explanation of the standard models of pile-soil manufacture with the technique that operated to analyze the dynamic response group of the pile when embedded in dry sandy soil.

Chapter four: Introduces the results of the experimental work and their discussion. Analyses the reactions of the group pile model under inclined cyclic loading. The applied system on the group pile model has similarly displayed the influences of the angle of inclination and configuration on the dynamic response of pile groups.

Chapter five: Gives the conclusions achieved after test outcomes of the research; also the recommendations for viewpoint.

Lastly, additional results for the various parameters reviewed and description of investigational work by drawings are shown in Appendixes A and B.