Republic of Iraq

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

ASSESSMENT OF PILE GROUP UNDER SIMULTANEOUS LATERAL STATIC AND INCLINED CYCLIC 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

Amal Salman Gummar

(B.Sc. Civil Engineering, 2010)

Supervised by

Prof. Dr. Jasim M. Abbas

2022 **1444**

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

﴿أَلَمْ تَعْلَم أَنَّ اللَّهَ لَهُ مُلْك السَّمَوَات وَالْأَرْض وَمَا لَكُمْ

مِنْ دُون اللَّه مِنْ وَلِيّ وَلَا نَصِير﴾

صدق الله العظيم

(البقرة 107)

CERTIFICATION OF THE SUPERVISOR

I certify this thesis entitled "**Assessment of Pile Group under Simultaneous Lateral Static and Inclined Cyclic Loads in Sandy Soil**" is prepared by "Amal Salman Gummar" under my supervision in the civil Engineering Department at University of Diyala at partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

Signature:

Name: Prof. Dr. Jasim M. Abbas

(Supervisor)

Date: / / 2022

COMMITTEE DECISION

We certify that we have read the thesis entitled (**Assessment of Pile Group under Simultaneous Lateral Static and Inclined Cyclic Loads in Sandy Soil**). We have examined the student (**Amal Salman Gumar**) 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. Hussein A. Shaia	(Member) …………………
3- Assis. Prof. Dr. Qasim A. Mahdi	(Member) …………………
4- Prof. Dr. Hassan O. Abbas	(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:

SCIENTIFIC AMENDMENT

I certify this thesis entitled "**Assessment of Pile Group under Simultaneous Lateral Static and Inclined Cyclic Loads in Sandy Soil**" presented by "**Amal Salman Gumar**" has been evaluated scientifically; therefore, it is suitable for debate by examining committee**.**

Signature:-

Name:

Title:

Address:

Date:

LINGUISTIC AMENDMENT

I certify this thesis entitled "**Assessment of Pile Group under Simultaneous Lateral Static and Inclined Cyclic Loads in Sandy Soil**" presented by "**Amal Salman Gumar**" has been corrected linguistically; therefore, it is suitable for debate by examining committee.

Signature:-

Name:

Title:

Address:

Date:

Dedication

To………

The soul that left life but settled in depth of my soul, my martyred brother.

My parents, reason my existence.

My husband, life buddy.

My brothers and sisters, with whom I strengthen myself.

My daughters who inspire me with strength, Lana and Elaan.

My supportive friend.

Our honorable teachers who stood by us.

Everyone who supported me in word or deed

I dedicate this humble work.

AMAL

ACKNOWLEDGEMENTS

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 go 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.

AMAl

ABSTRACT

Assessment of Pile Group under Simultaneous Lateral Static and Inclined Cyclic Loads in Sandy Soil

By

Amal Salman Gummar

Supervised by:

Prof. Dr. Jasim M. Abbas

ABSTRACT

Pile foundations are often subject to more than one load in nature. Among the common loads that the piles are subjected to are static loads and cyclic loads. The two loadings, when simultaneous, cause a serious problems in the bearing capacity of the piles and the surrounding soil. Therefore, the major objective of this study is to assessment the performance of pile group under inclined cyclic loads simultaneous with static lateral loads in sandy soil with a relative density of 70%.

A series of 96 laboratories investigation were conducted to determine the group of pile response when exposed to combined loadings, by measuring the changes in lateral deflection at tip of pile and the bending moment along the pile depth. Numerous factors are investigated and their effect on group of pile performance model (2×2), including: the ratio of spaces between piles (3D, 5D, 7D), influence of inclination angles of cyclic loading (0°, 10°, 20°, 30°), the cyclic load ratio (20%, 40%, 60% and 80%) and the effect of the presence of a static lateral load on the cyclic load. In light of the findings, the presence of the static load with the inclined lateral cyclic load has a positive effect on the deep foundations where the lateral deflection is reduced by an average of 54% for the three spaces. Also the lateral deflection at combined lateral loading decreases with increasing pile spacing, the percentages of reduction in the lateral deflection compare to pure loading are (16%, 73%, 75%) for spacing (3D,

5D, 7D) respectively. It is important to note that the presence of a static horizontal load reduces the maximum bending moments and the number of critical points along the pile. It is significant to mention that the increase in the inclination of the cyclic load reduces the lateral deflection, where the average of decrease in the lateral displacement of the pure and combined loadings about (7%, 26%, 9%) at 10°, (54%, 30%, 12%) at 20° and (183%, 98%, 141%) at 30° for the three spacings (3D, 5D, 7D) respectively compared to the lateral displacement at critical angle (0°) when CLR = 80%.

LIST 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_{max}	Maximum Void Ratio of Soil
e_{min}	Minimum Void Ratio of Soil
f	Frequency
Gs	Specific Gravity
Hz	Hertz
I	Moment of Inertia
L	Embedded Length of Pile
L/D	Slenderness Ratio of Pile
M	Bending Moment
r	Outside Radius of pile
H	Horizontal Load
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

There is rapid progress in all aspects of life, so there must be an inevitable development in engineering constructions, which leads to major challenges that require an increase in the safety factor. Here comes the role of the civil engineer, who is often more careful in his dealings with the lateral load from the vertical load. The vertical load's time and value are known, while the lateral load may be unexpected and random.

As for the piles, which are the ideal foundation for solving the problem of distribution and transfer engineering structure loads through weak, compressible soils or water into solid or less compressive soils or perhaps rocks. Piles may be exposed to different loads, vertical and horizontal, or between them, which is the inclined load, according to the condition and position of the structures (Cheng & Jack, 2008).

1.2 The Static and Cyclic Loads on Pile

In geotechnical engineering, the loads imposed on the soil and on geotechnical installations are divided into a static load and a dynamic load, and this behavior varies under each load. Static loads accumulate very little dynamically, even to the point of negligence while cyclic load produces compressibility's of the piling soil, which grows exponentially with increasing number of cyclic loads (Reilly and Brown 1991). Geotechnical engineering is concerned with cyclic loading because of its decisive effects in terms of design and safety for engineering facilities in general and marine facilities in particular, since the loads whose value and frequency are uniform to a high degree are cyclic loads (Agaiby et al. 2015). The most sources of cyclic loading are depicted in Figure 1.1.

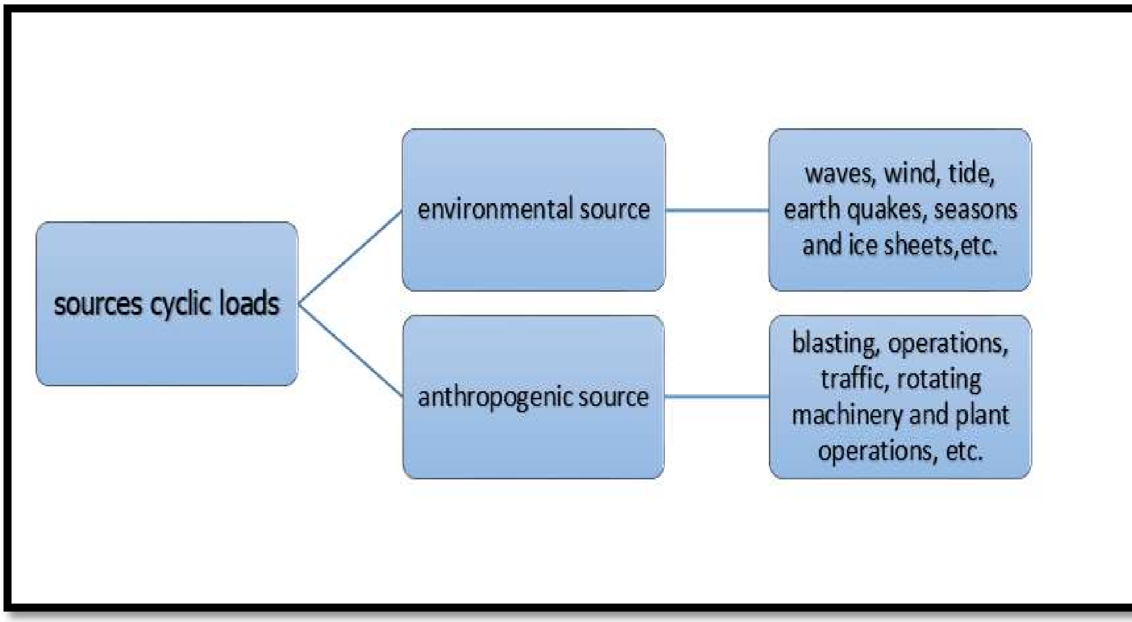

Figure (1.1): Cyclic Sources of Load (Puech, 2013).

1.3 Lateral Performance of Pile Foundations

Lateral loading piles are instilled usually vertically, but the load mandatory on them is laterally or may be inclined. These piles, in turn, adverse those loads by crowding the negative pressure in surrounding soil.

While the factors that affect the degree of distributions of soil reactions are:

1. Soil stiffness around the pile.
2. Pile stiffness inside the soil.
3. Restricting ends of piles.

Lateral-loaded piles are divided in terms of length into: long pile called (flexible pile) and short pile called (rigid pile), lateral displacement, shear and bending moment of the piles occurs, whether it is elastic or rigid when subjected to lateral loading as shown below in Figure 1.2. It can be seen that in the long pile distributions the shear and bending moment vanish with depth in contrast to the short pile which continues until its end (Matlock and Reese, 1960).

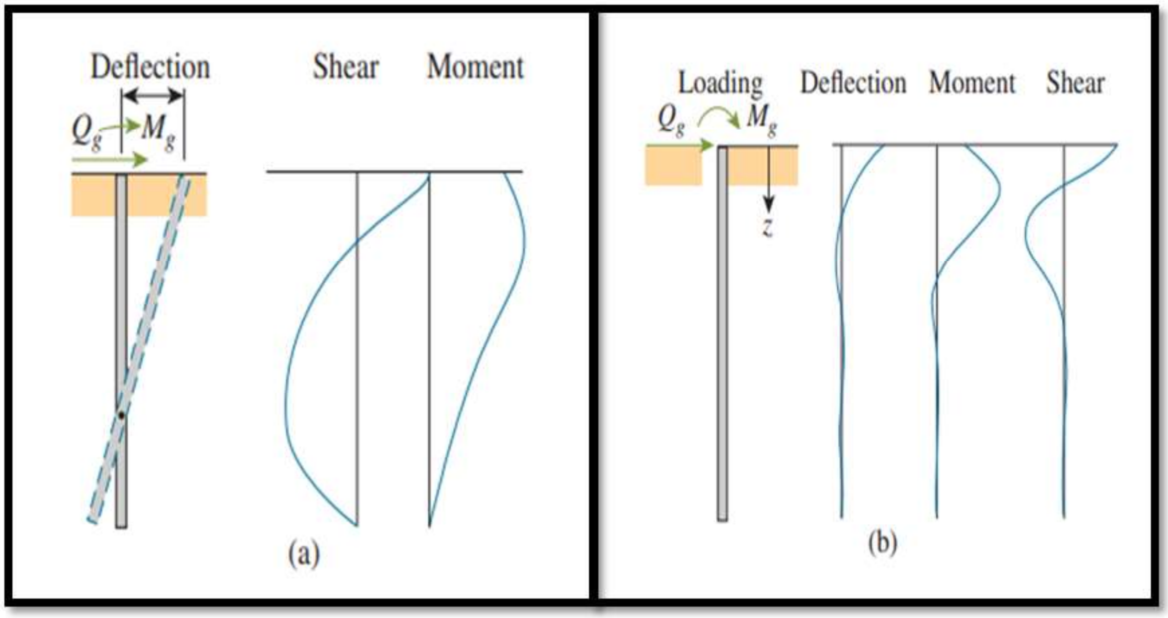

Figure (1.2): Nature of Pile Deflection, Moment, and Shear Force Variation for (a) Rigid Pile & (b) Flexible Pile, (Matlock and Reese, 1960).

The permissible pile displacement and the permissible pile bending moment are the two elements that have an impact on the design of these piles according to Figure 1.3. As a result, the maximum permitted pile bearing capacity in the lateral direction is set at a level that concurrently satisfies the two criteria listed below:

- The displacement horizontally (y_o).
- Maximum bending-moment (M max).

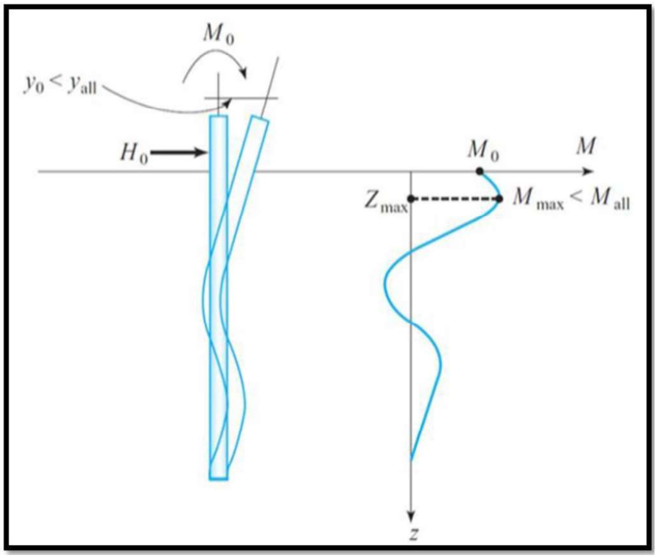

Figure (1.3): Maximum Bending Moment and Horizontal Displacement (Park, 2018).

It is not necessary for all piles to fail together in pile group, failure may occur in part, but affect the entire structure. This is happen in the Japanese earthquake in 1995, where one pile failed and caused the structure to tilt, as shown in Figure (1.4) (Bhattacharya et. al., 2012).

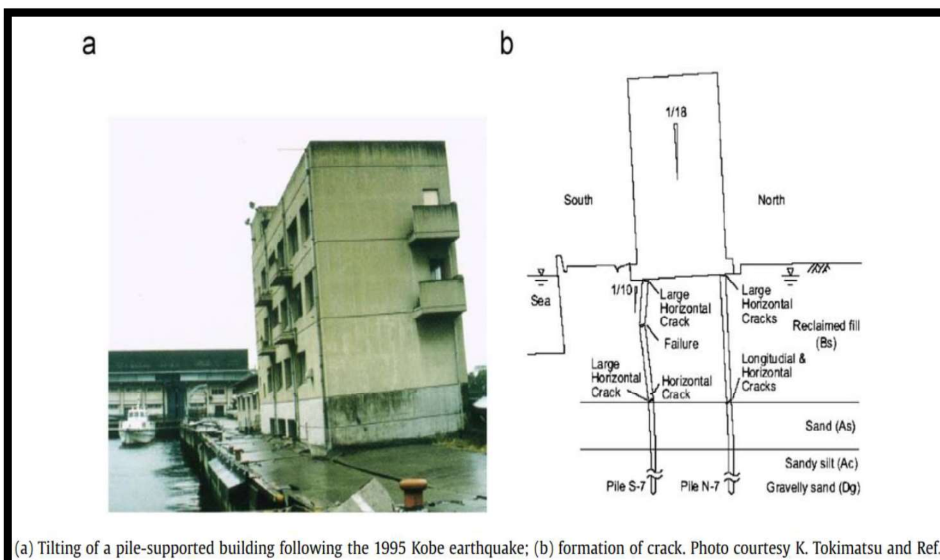

Figure (1.4): Structure Inclination Due to the Failure of Pile (Bhattacharya et. al., 2012).

1.4 Statement of the Problem

Usually the choice made on the deep foundations when the other of the foundations do not suffice, pile foundation seldom subject to a single load, in the nature. Piles may be affected by more than one load at the same time, and may be in different directions. Numerous researches have looked into the lateral load subjected on piles, some of them are in the static loads and the other in the cyclic loads and a few of them in the inclined loads, so this study will be comprehensive and complementary to the preceded it, as it simulates the reality where two different laterally loads are applied in same time, one of them is static and the other is cyclic inclined with multiple angles. It is applied laterally to group of pile with different spacing, and different loading ratios. These variables give clear details about the effect of simultaneous loads and determine the dangerous of these loads on the foundations, and thus a safe design that increases the life and efficiency of the structure.

1.5 Significant of Study

In general, any place in the world is threatened by earthquakes, storms, winds, seismic activities (which have a cyclical nature) and result strong waves may follow it soil movement and its consequences: settlement, shrinkage, expansion and creep. Despite of numerous studies on understanding behavior for deep foundations subject to combined loads but nevertheless there is a poverty of information about the behavior of these foundations under influence of two combined loads both of them are lateral and occurring simultaneously (first is the static load and the other is the inclined cyclic load). There will be an urgent need for more empirical studies in this regard that confirm and add to the conclusions of previous studies, and this is what the current study is looking at which will contribute to adding or confirming a step in the path of geotechnical engineering.

1.6 Research Aims

Implementation of two different lateral loads at the same time on group of pile is a complex case, so this study investigates the following:

1. Investigation the influence of static lateral load on the lateral cyclic capacity and bending moment of piles for different angles of inclination of cyclic load.
2. Study the effect of number inclined cycles loading on the lateral movements of the pile group under different ratios of combined load.
3. Determine the critical ratios of the loads that cause the highest values of lateral displacement and maximum bending moments
4. Identifying the best spacing of piles in-group under pure and combined loading.

1.7 Layout of Thesis

The current study's out line includes: five chapters:

Chapter one: The aims of study and a brief description of piles subjected to combine cyclic and static lateral loading are presented.

Chapter two: This chapter provides an overview of the literature that has been published on the lateral cyclically loading and static loading of pile foundations, including experimental and theoretical research, field studies, and a range of analytical methodologies.

Chapter three: Demonstrates the practical methodology and steps via counting down to presentation of the soil categorization and the piles. Furthermore, the technique used to assess the dynamic response of the group of pile when implanted in dry sandy soil provided a thorough explanation of the conventional models of pile-soil manufacturing.

Chapter four: The outcomes of a realistic system model are presented, as well as the discussions around them. Under inclined cyclic loading with static lateral loading, this model analyzes group of pile interactions. The effects of the angle of inclination and spacing between one pile and another within the same group on dynamic response of the pile groups are illustrated using the framework applied upon model of pile group.

Chapter five: Provides conclusions reached as a result of the research's test results, as well as recommendations.