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

EXPERIMENTAL AND NUMERICAL SIMULATION FOR SHALLOW AND DEEP FOUNDATIONS IN LAYERED SOIL SUBJECTED TO EARTHQUAKE LOADING

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

Afnan Hussein Ali

(B.Sc. Civil Engineering, 2019)

Supervised by

Prof. Dr. Hassan Obiad Abbas

Prof. Dr. Safa Hussain Abid Awn

September 2022 **IRAQ** **Safar 1444**

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

﴿ٱلرَّحۡمَٰنُ ۝ عَلَّمَ

ٱلۡقُرۡءَانَ ۝ خَلَقَ

ٱلۡإِنسَٰنَ ۝ عَلَّمَهُ ٱلۡبَيَانَ﴾

صدق الله العظيم

سورة الرحمن (الأية 1-4)

CERTIFICATION OF THE SUPERVISOR

We certify this thesis entitled **"Experimental and Numerical Simulation for Shallow and Deep Foundations in Layered Soil Subjected to Earthquake Loading"** was prepared by "**Afnan Hussein Ali**" under our supervision in the Department of Civil Engineering at the University of Diyala in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering - Soil and Foundation Engineering.

Signature: …………………………………..

Name: Prof. Dr. Hassan Obaid Abbas
(Supervisor)

Signature: …………………………………..

Name: Prof. Dr.Safa Hussain Abid Awn

(Co-Supervisor)

Date: / / 2022

COMMITTEE DECISION

We certify that we have read the thesis (**Experimental and Numerical Simulation for Shallow and Deep Foundations in Layered Soil Subjected to Earthquake Loading)**, we have examined the student (**Afnan Hussein Ali**) 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 Master of Science in Civil Engineering - Soil and Foundation Engineering.

.

Examination Committee Signature

1- Prof. Dr. Hassan Obaid Abbas (Supervisor) …………………..

2- Prof. Dr.Safa Hussain Abid Awn (Co-Supervisor)………………

3- Prof. Dr. Jassim Muhammed Abbas (Member) …………………….

4- Asst. Prof. Dr.Qutaiba Gazi Majeed (Member) ……………………

5- Prof. Dr. Bushra Suhail Zbar (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 Abdullah Khadom

Dean of College,of Engineering / University of Diyala

Date: / / 2022

SCIENTIFIC SERTIFICATE

We certify this thesis entitled "**Experimental and Numerical Simulation for Shallow and Deep Foundations in Layered Soil Subjected to Earthquake Loading**" presented by "**Afnan Hussein Ali"** has been evaluated scientifically; therefore, it is suitable for debate by the examining committee**.**

Signature: ………………..

Name:

Title:

Address:

Date: / / 2022

LINGUISTIC CERTIFICATE

We certify this thesis entitled "**Experimental and Numerical Simulation for Shallow and Deep Foundations in Layered Soil Subjected to Earthquake Loading**" presented by "**Afnan Hussein Ali**" has been corrected linguistically; therefore, it is suitable for debate by the examining committee.

Signature: ………………..

Name: Asst. Prof. Ahmed Adel Nouri

Title:

Address:

Date: / / 2022

Dedication

To my model and hero, the pure spring, my tree that does not wither, and the shade that l shelter in at all times….My dear father

To the fount of my affectionateness, the sun of my Wishes, and the flower of my dreams…My dear mother

To those who are for my heart and for my life the best companionship and joy….My sisters and brother

To the soul, who wished to realize this dream of completing a master's degree…My college mate (Leith Essam)

To my friends and everyone, who wishes me success in my life.

I dedicate this humble work.

Afnan Hussein Ali

2022

Acknowledgments

Many thanks and praise are due first and above all to my Creator, Almighty "ALLAH", the Most Beneficent, the Most Gracious, and the Most Merciful, who gave me the ability and the desire to complete this work despite all the hurdles and constraints in the way of its completion.

First, my deepest thanks are presented to my supervisor *Prof. Dr.Hassan Obed Abbas and Prof. Dr. Safa Hussein Abid* for their supervision, advice, insightful criticisms, patient encouragement, and great efforts to explain things clearly aided in writing this thesis in innumerable ways. So, I feel deeply indebted and grateful to them.

I thank all the people who helped me, especially *Asst. Prof. Dr. Waad A. Zakaria,* a faculty member in the Civil Engineering Department-College of Engineering- University of Diyala, for his valuable opinions and efforts throughout the preparation of this research.

Appreciation and thanks are also extended to the all staff of the College of the Engineering/ University of Diyala and especially the Department of Civil Engineering(Geotechnical Specialization) and Engineering Consulting Bureau for soil investigation reports.

Finally, I would like to express my love and respect for my family; no words can express how grateful I am for their patience and encouragement in the thesis preparation.

Afnan Hussein Ali

2022

Experimental and Numerical Simulation for Shallow and Deep Foundations in Layered Soil Subjected to Earthquake Loading

By

Afnan Hussein Ali

Supervised by:

Prof.D. Hassan O.Abbas

Prof.D. Safa H.Abid Awn

ABSTRACT

Governorate of Diyala (Baqubah City, Iraq) is considered an affected area by seismic activity, and this is due to geological characterization, which is located along the earthquake line that runs between the Arab and Iranian plates. It is critical to investigate two different foundation systems (soil-raft and soil-pile system) on the given soil conditions of Baquba soil properties under real earthquake records. Especially after the Halabja earthquake in 2017, near the Iranian-Iraqi border.

The 3-D seismic behavior of piles and raft foundations is experimentally and numerically investigated in this study using the finite element program PLAXIS3D v20.Twenty models are performed to highlight the vertical settlement, horizontal displacement, bending moment, and pore water pressure under El-Centro, Halabja, and Ali-Gharbi earthquakes. A raft model of a four-storey building was simulated with (18.5x18.5 m) dimensions and different thicknesses (0.8,1,1.2,1.4,and1.6m), and change the raft with a pile foundation with different diameters(0.5,0.7,1m) and length 19m. An experimental model was developed using shaking table to analyze a verification case similar to the domain problem of raft foundation under the Halabja earthquake. It found the numerical analytical results to the experimental results are extremely well matched, in the term that the maximum settlement obtained numerically is more than the experimental work is about 8%.

The results raft foundation showed the vertical settlement decreases as the thickness increases from 0.8m to1.6m, and the percentage of reduction

ranged between 5% at 1.4m to 17% at 1m, (7% to8%) at 1.6m, and (19% to21%) at 1.4m, while the horizontal displacement with the percentage of reduction is about 39.49%, 43%, and 45.17% under the El-Centro, Halabja, and Ali AL-Gharbi earthquakes, respectively. The maximum bending moment distribution at the raft foundation under the different earthquakes appeared the same behavior with the change of thickness and decreases about 87% with an increase the thickness to 1.4m and 85% at 1.6m.

From the pile foundation simulation, it observed the vertical settlement and horizontal displacement similar to the edge, exterior, and interior piles which means the diameter of the pile did not affect the displacements. On the other hand, the percentage difference in the maximum settlement ranged between (0.5-3)% under the Halabja and the Ali Al-Gharbi earthquakes. While the lateral displacement increase with the direction of the earthquake from the right to the left side of the pile-soil system. The maximum bending moment along pile foundations occurred at a depth of 10m of the interior pile has the largest diameter of the group model with a range between (40-59)% more than the corner, and exterior piles for all earthquakes applied. In general, the highest values of the settlement and displacements were under the Halabja earthquake with a percentage increase of (85-89)% and 44% over the El-Centro and Ali Al-Gharbi earthquakes, respectively. while under Ail Al-Gharbi increase of (73-80)% over the El-Centro earthquake.

Finally, In the case of comparison between the overall response of raft and groups pile subjected to the same load and factor safety under the El-Centro earthquake, it is clear the settlement with in the rate of 18% and horizontal displacement with68% for raft foundation more than pile foundation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF NOTATIONS AND SYMBOLS

Symbol	Term
C	Cohesion
C	The damping matrix
C_c	Compression Index
CL	Lean Clay
Cs	Swelling index
Cu	Undrained Shear Strength
C_v	Coefficient of Consolidation
D	pile Diameter
E	Young's modulus
e_{max}	Maximum void ratio of soil
e_{min}	Minimum void ratio of soil
Gs	Specific Gravity
Hz	Unit of frequency
I.P	Plasticity Index
K	The stiffness matrix
L.L	Liquid Limit
M	The mass matrix
Mw	Richter magnitude
Ni	The shape function matrix
O.M.C	Optimum Moisture Content
P.L	Plastic Limit
SM	Slity Sand
SP	Poorly graded Sand
u	The displacement
ú	The Velocity
ű	The acceleration

u_x	Horizontal displacement in x-direction
u_y	Horizontal displacement in y-direction
u_z	Vertical displacement in z-direction
$\underline{v}$	The nodal displacement
Vp	compression wave velocity
Vs	Shear wave velocity
Wc	Water Content
α	The mass-proportional coefficient
β	The stiffness-proportional coefficient
ν	Poisson's ratio
ξ	Damping ratio
ϒd	Dry unit weight
ϒsat	Saturated unit weight
ψ	Dilatancy angle
Φ^{o}	Angle of internal friction

LIST OF ABBREVIATION

Abbreviation	Term
ASTM	American Society For Testing and Materials
DAQ	Data Acquisition
LVDT	Linear Variation Displacement Transducer
USCS	Unified Soil Classification System

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1Introduction

The phenomenon of earthquakes is considered one of the most dangerous natural disasters that occur without warning and causes damage to any building or structure through settlement, ground cracking, and loss of bearing capacity of soil- foundation system (Sadiq and Albusoda, 2020). The foundation is the lowest part of the structure that comes into direct contact with the soil media and is placed on or beneath the ground surface to transfer all of the loads from the structure to the underlying soil. In addition to the static loads, the foundation must be constructed to withstand the dynamic loads induced by earthquakes.

Generally, the foundations can be divided into two categories, shallow and deep foundations. The first category consists of spread footing, wall footing, combined footing, and raft footing. The second category is piers, cassations, drilled-shaft-foundations, and piles (Aung and Tun, 2012). As a result, foundation engineers must keep abreast of technological advancements in these domains, or be well informed in these fields, to achieve cost-effective and safe designs. There is still a lot of work to be done in developing methodologies to evaluate seismic bearing capacity and earthquake-induced permanent displacements in shallow and deep foundations (Fattah et al., 2016).

1.2 Statement of the Problem

Rapid progress is the means to develop the cities, as a Baqubah area, which calls for construction actions of many modern facilities for different loads in values between the medium to heavy that supported with various types of shallow and deep foundations. Also, the natural soil area that are form weak to medium-soft soil with a high percent of silt extends over large sites in this city, and up to thickness ranging from (0.5m to 18,20,24m) according to the soil investigation for the governorate reports.

The foundations of any building or structure must be designed to withstand all vertical and lateral loads imposed, safely without impairing stability or causing excessive movement to that building. Seismic risk mitigation is one of the most difficult challenges in civil engineering, and geotechnical earthquake engineering can make an important contribution to this challenge. (Kulkarni and Sambre, 2015). Shallow foundations are subjected to lateral forces induced by earthquake movements, which may be dominant in some structures, and buildings with these foundations may overturn under earthquake load. Deep foundation design for dynamic load resistance is primarily based on limiting deflection criteria that take into account the safe operation of the superstructure. As a result, a careful engineering analysis of the behavior of pile foundations under anticipated static and dynamic working loads becomes a critical step in the satisfactory performance of pile foundations (Boominathan and Ayothiraman, 2007).

Tectonically Iraq is located in a relatively active seismic zone at the northeastern boundaries of the Arabian Plate. The Arabian Plate in the southwest is connected to the Iranian in the notheast and Anatolian Plates by the Zagros-Taurus Belts. The annual seismic activity of various strengths is declared in seismic history (Al-Taie and Albusoda, 2019). Especially, active seismic activity was recorded with varying intensities in 2017 and 2018, and with magnitude ranged between 4.0 and 7.3 on the Richter scale, (Al-Taie, 2015) and (Albusoda, 2016). Figure (1.3) depicts some of the damage to several Iraqi structures. As Iraq's seismicity has increased in a general and discernible way from south to north and west to east (Abd Alridha and Mohammed, 2015). The Zagros-Taurus active mountain belt, which is entrapped between two plates, the Arabian and the Iranian, has a relatively extensive zone of compressional deformation on the eastern side of the study region (Jasim, 2013). Since the Baqubah city is located in this geographical area, which made it is sensitive to earthquakes.

In the last few decades, most researchers have undertaken the fundamental characteristics of foundations under dynamic loads, but the study of the behavior of shallow foundations and deep foundations under earthquakes has little been reported. According to the above-mentioned problems, the experimental work and numerical model of the raft-soil system and the pile-soil system will be built in this study with FEM **PLAXIS-3D**, and their dynamic response will be analyzed by inputting Halabjah, Ali-Gharbi, and El-Centro seismic waves.

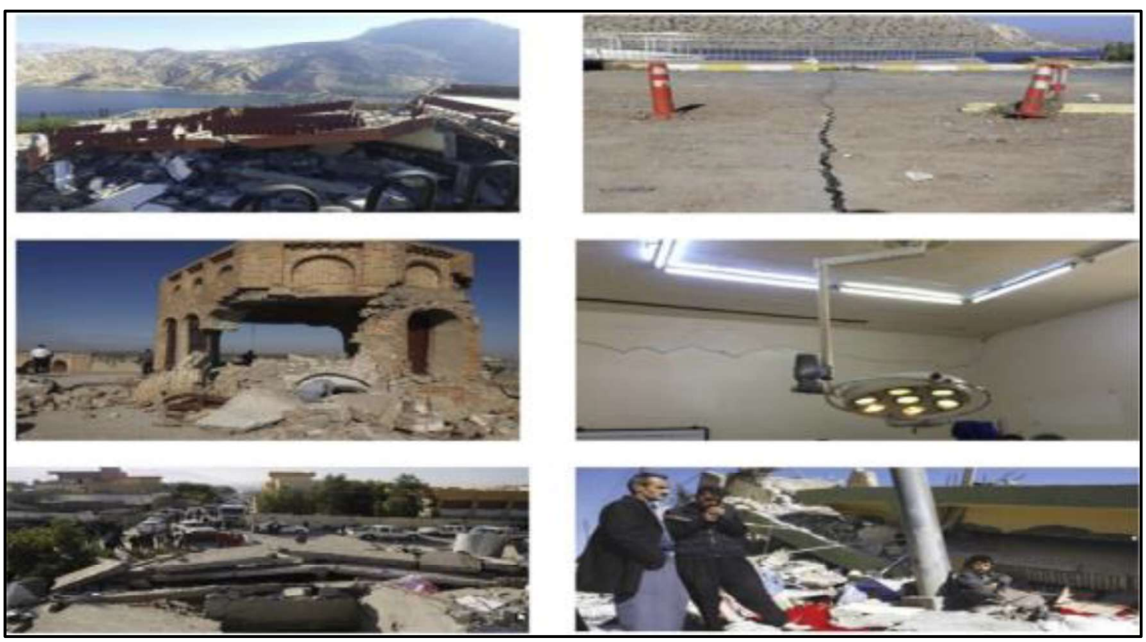

Figure (1.3): Damages to different structures in Iraq due to the Halabja earthquake, 2017 (after Al-Taie and Albusoda, 2019).

1.3 Objectives of the Study

The main objective of this study is to assess the behavior of the shallow (raft foundation) and deep foundation (Pile foundation) under earthquakes excitation including the stronger earthquakes that struck Iraq in late past years, " El-Centro, Halabjah and Ali Al-Gharbi" according to the soil properties of Baqubah city. The simulation was made experimentally using a shaking table model and numerically through a three-dimension finite element approach **(PLAXIS- 3D 2020)**. The objectives of this study can be presented in the following points:

1. Studying the dynamic behavior of raft-soil under seismic loading system experimentally and numerically through settlement.
2. Investigating the influence of thickness on the dynamic behavior of raft foundations under different excitation frequencies.
3. Investigating the influence of pile length on the dynamic behavior of pile foundations under different excitation frequencies.

1.4 Layout of the Study

The research work is presented in five chapters as summarized below:

• **Chapter One:** introduces a general introduction to the type of foundations and the effects of the earthquake. In addition to a general overview of the goals of this study.

• **Chapter Two:** includes a brief description of the earthquakes and seismic waves. Also contains history view of the earthquake in Iraq and the geology of Diyala city. Moreover, a review of the researchers related to the behavior of the shallow and deep foundations under dynamic loadings.

• **Chapter Three:** contains a finite element modeling using **PLAXIS 3D 2020** program and checking the accuracy of this software by comparison with experimental work performed to study the validity of numerical analysis of the soil-raft system under earthquake action.

• **Chapter Four:** investigated the dynamic behavior including the horizontal displacement, vertical settlement, bending moment, and pore pressure for both raft-soil system and pile-soil system built-in layered soils of Baquba city under the influence of the real earthquake acceleration.

• **Chapter Five:** displays a summary of the main conclusions of the current study and covers the recommendations for further research on the related topic.