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

ASSESSMENT OF SETTLEMENT FOR RAFT FOUNDATION UNDER ECCENTRIC LOADING NEARBY SANDY SLOPE USING FINITE ELEMENT METHOD

A Thesis Submitted to the Council of the 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

By

Dina Mozahem Abd

(B.SC. Civil Engineering, 2006)

Supervised by

Prof. Hassan Obaid Abbas, (Ph.D.)

August/2022 A.D. **IRAQ** **Muharram/1444 A.H.**

"بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ (١) الحمد لله رب العالمين
(٢) الرحمن الرحيم (٣) مالك يوم الدين (٤) إياك
نعبد وإياك نستعين (٥) إهدنا الصراط المستقيم (٦)
صراط آلذين أنعمت عليهم غير المغضوب عليهم ولا
الضالين (٧)"

صدق الله العظيم

سورة الفاتحة

Supervisor's Certification

I certify this thesis entitled "**Assessment of Settlement for Raft Foundation under Eccentric Loading nearby Sandy Slope using Finite Element Method"** was prepared by "**Dina Mozahem Abd**" 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 **-** Soil and Foundation Engineering.

Signature:

Name: Prof. Dr. Hassan O. Abbas

Date: / /2022

(Supervisor)

COMMITTEE DECISION

We certify that we have read the thesis entitled (**Assessment of Settlement for Raft Foundation under Eccentric Loading nearby Sandy Slope Using Finite Element Method**), we have examined the student (**Dina Mozahem Abd**) 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 **-** Soil and Foundation Engineering.

Examination Committee		Signature
1- Prof. Dr. Hassan O. Abbas	(Supervisor)	………………
2- Assis. Prof. Dr. Waad A. Zakaria	(Member)	………………
3- Assis. Prof. Dr. Adnan J. Zedan	(Member)	………………
4- Prof. Dr. Jasim M. 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: / / 2022

Scientific Expert Certification

I certify this thesis entitled "**Assessment of Settlement for Raft Foundation under Eccentric Loading nearby Sandy Slope using Finite Element Method**" presented by "**Dina Mozahem Abd**" has been evaluated scientifically; therefore, it is suitable for debate by examining committee.

Signature:

Name:

Title:

Address:

Date: / /2022

Linguistic Expert Certification

I certify this thesis entitled "**Assessment of Settlement for Raft Foundation under Eccentric Loading nearby Sandy Slope using Finite Element Method**" presented by "**Dina Mozahem Abd**" has been corrected linguistically; therefore, it is suitable for debate by examining committee.

Signature:

Name:

Title:

Address:

Date: / /2022

Certificate of Originality

This is to certify, that the research paper entitled "**Assessment of Settlement for Raft Foundation under Eccentric Loading nearby Sandy Slope using Finite Element Method**" submitted by me is an outcome of my independent and original work. I have duly acknowledged all the sources from which the ideas and extracts have been taken. The project is free from any plagiarism and has not be submitted elsewhere for any degree.

Signature:

Name: Dina Mozahem Abd

Date: / /2022

Dedication

I dedicate my thesis to the soul of the most precious person in existence, to the soul of my dear mother, whose prayers accompanied me in her life and even after her death...

Also I dedicate this work to my son Ali and to my daughter Aya, may God prolong their lives, I hope that they will be proud of me and my struggle and my continuing to complete my studies despite the hardships of life and the passage of many years since graduating…

Dina

Acknowledgements

"In the name of Allah, the most beneficent, the most merciful".

First praise be to "Allah" who gave me the strength and health to work and enable me to achieve this research.

I would like to express my sincere thanks to my supervisor Prof. Dr. Hassan Obaid Abbas for his supervisions, precious advices, technical guidance, continuous encouragements, and giving generously of his time when help was needed throughout the preparation of my thesis, I am greatly indebted to him.

I would like to express my sincere thanks for Assist. Prof. Dr. Waad Abd Al Sattar Zakaria, for giving advice generously of his when help was needed, I am greatly indebted to him Appreciation.

My thanks are also extended to all staff of University of Diyala and to all my friends and every person who helped me to complete my thesis.

My thanks and gratitude to my travel companion, my life partner, my dear husband Wael Majdi Musa for his support throughout the study, research period and all my life.

Finally, I would like to express my love and respect to my family, no word can express my gratitude to them.

Dina

Assessment of Settlement for Raft Foundation under Eccentric Loading nearby Sandy Slope using Finite Element Method

By
Dina Mozahem Abd

Supervised by
Prof. Dr. Hassan O. Abbas

Abstract

Communication Towers may be found in areas outside cities, where sloping lands and hills, a self-supporting tower with four legs and a height of 50 meters with raft foundation is the typical tower adopted in this study. The communication tower represents a lightweight structure compared to other structures and at the same time exposed to eccentric load represented by the overturning moment resulting from the wind load, this load depend on the basic wind speed, and the prevailing speeds in Iraq (33, 38, 42, and 44) m/sec are the speeds which adopted to obtain the values of eccentricity. The study examines the behavior of tower foundation near sandy slope under the influence of parameters: eccentricity ratio (e/B) at values (0.08, 0.11, 0.14, and 0.15), relative density (loose, medium, dense), angle of slope at values (20˚ and 30˚) with constant height of the slope (10) m and embedment depth of the foundation (D_f/B) at values (0 and 0.125), using Finite Element Method in Plaxis 3D program, these parameters investigate with two constitutive models: Hardening Soil Model (HSM) and Mohr Coulomb Model (MCM). After finding a method of representing the projected moment on raft foundation by Finite Element Method in Plaxis 3D program, results of angle of rotation for all models of the study are compared with the permissible value of (1/600), one of the most important findings of this study is that the ultimate bearing capacity of the foundation was not reached, and the failure mechanism is the overturning of the structure, and its determinants are differential settlement and angle of rotation of the foundation. The results of soil representation with (HSM) are close to that of (MCM) for both dense and medium-dense soils, while the results of (HSM) exceed significantly (MCM) in loose soils. The results also indicate that the acceptable distance of the tower foundation from the crest of the slope is equal to half the width of the foundation or more ($b/B \geq 0.5$), which cancels out the effect of the slope and the foundation behaves as if it were on flat ground, which is also the recommended distance for the construction of the tower safely and for the two soils dense and medium-dense density, while avoiding the construction of the tower on loose soils, depending on the permissible value of the angle of rotation. Increasing the ratio of the embedment depth for the foundation reduces the maximum settlement below foundation by a rate ranging from (31.18-47.25) %.

Table of Contents

List of Figures

List of Tables

List of Symbols

Symbol	Meaning
e	Eccentricity.
M	Overturning moment.
B	Foundation width.
L	Foundation length.
$q_{max.}$	Maximum pressure in soil under foundation.
$q_{min.}$	Minimum pressure in soil under foundation.
Q	Applied load.
B'	Effective width.
L'	Effective length.
q_u'	Ultimate bearing capacity.
$q_{u(e)}$	Ultimate bearing capacity at eccentricity.
c'	Cohesion.
c_u	Undrained cohesion.
φ'	Angle of internal soil friction.
Ψ	Dilatancy angle.
Dr	Relative density.
R_K	Reduction factor.
D_f	Embedment depth.
Δq_s	Bearing Stress.
$(\Delta q_s)_a$	Allowable Bearing Stress.
$(\Delta q_s)_b$	Bearing Capacity.
$(\Delta q_s)_l$	Bearing Stresses Causing Local shear failure.
$(\Delta q_s)_u$	Ultimate Bearing Capacity.
H	Height of slope.

β	Angle of slope.
b	Distance from the footing to crest of slope.
N_s	Stability number.
V	Poisson's ratio
$E^{'}$	Young's modulus of soil.
I_θ	Influence value.
$tan\,\theta$	Angle of rotation.
q_s	Net safe pressure of raft.
N_{cor}	SPT value with both overburden pressure and energy corrections.
F	Horizontal wind load.
q_z	Velocity pressure.
G_H	Gust response factors.
C_F	Structure force coefficient.
A_E	Effective exposure area of structural component section
K_z	Exposure coefficient.
V_b	Basic wind speed.
E	Solidity Ratio.
A_F	Projected area (m^2) of flat structural components in one face of the section.
A_R	Projected area (m^2) of round structural components in one face of the section.
A_G	Gross area of one tower face (m^2).
D_F	Wind direction factor for (flat component).
D_R	Wind direction factor for (round component).
R_R	Reduction factor for (round component).

i_e	The reduction ratio for the bearing capacity.
W_f	Weight of raft foundation.
P^{ref}	Reference pressure.
R_f	Failure ratio.
q_a	Asymptote value of shear strength.
q_f	An ultimate deviator stress.
K_o	Coefficient of the lateral earth pressure.
K_o^{nc}	Coefficient of the lateral earth pressure for normally consolidated.
γ_{un}	Unsaturated unit weight.
γ_{sat}	Saturated unit weight.
E_{50}^{ref}	Secant stiffness.
E_{oed}^{ref}	Tangent stiffness.
E_{ur}^{ref}	Unloading/ reloading stiffness.
v_{ur}	Poisson's ratio for unloading/ reloading.
m	Power of stress level.
R_{inter}	Interface strength.

List of Abbreviations

Abbreviation	Meaning
FEM	Finite Element Method.
FOS	Factor of safety.
HSM	Hardening Soil Model.
IQ 301	Iraqi specifications, 2014.
MCM	Mohr Coulomb Model.
RFM	Reduction factor method.
SPT	Standard Penetration Test.
TEA/EIA Standard	Structural Standards For Steel Antenna Towers And Antenna Supporting Structures, 1996.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

The construction of structures is usually not only on the flat ground, most of the time there is an urgent need to construct one or another structure near a slope, usually the structure is subjected to centric loads, and at other times it is subjected to eccentric loads, eccentricity is the result of vertical or/and inclined load that affect at a distance from the center of gravity of the foundation of the structure and this aspect is mentioned by most of the previous studies, also the eccentricity is the result of the effect of moment, at this case how will the moment effect on the behavior of the foundation, especially if this foundation is near a slope.

Among the structures affected by the moment are the tall structures such as communication towers, these structures are characterized by their height, light weight and exposure to wind load and overturning moment below to that load, there are many codes to estimate wind load, all of them depend on the basic wind speed, terrain topology, exposure area and height of the structures. There are several types of communication tower: Monopole, Guyed and Self-Supporting with three or four legs. Self-Supporting (with 4–legs) Communication Tower constructed on raft foundation or other types of foundation according of the bearing of soil, dead load of tower and its installation columns rather light do not resist the effect of wind load, so that the raft foundation with its weight will resist the overturning moment beside the important duty of raft to reduce the differential settlement.

1.2 The Importance of Study

Recently, communications have become an important and complementary part of the details of the present day, which led to the increase of communication towers to cover most areas of the world, including slope areas. The nature of the land on which the tower built may not be flat, but rather tilted, as in agricultural land and hills outside cities, and to ensure the quality of communications, the towers must be fixed and stable.

This study is interested in knowing the behavior of tower foundation near sandy slope soil as it has a slope, and subjected to eccentric load resulting from the moment. It also highlights the differential settlement under the base and the angle of rotation, the tower is used as a model for the study is a 50m-height self-supporting communication tower with four legs, and the foundation is a raft foundation, not a separate.

Among the most important things that the study comes up with is to arrive at an acceptable way to deal with the simulation of moments in Finite Element Method used in the approved engineering program and the other thing is to reach the determinants of failure for the high structures that are light in weight and subject to eccentric loads.

1.3 The Statement of the Problem

The foundations of high structures subjected to eccentric loads that come from the overturning moment resulting from lateral loads such as wind force and earthquakes. Usually, solid structures resist these eccentric loads through their rather large weights, as in the case of concrete towers, but in the case of towers with metal structures, such as communication towers, all of the above details are applied to them except for one thing, which is their light weight compared to solid towers.

Rigid foundation of tower can increase in weight to resist overturning moment and reduce differential settlement and angle of rotation of the foundation around its base. The acceptable values of the differential settlement and the angle of rotation depend on the type of high structure and its uses.

Towers under study do not built inside cities and flat lands only; the need requires their presence outside the cities and near inclined lands. Here, the effect of the slope will be with the effect of the eccentric load on the tower foundation. That requires obtaining the safe distance of the tower foundation from the crest of the slope with different angles of slope and for different cases of density of soil, Figure (1.1) shows a simple sketch of the problem of the study.

The study using the Finite Element Method (FEM) by choosing two constitutive models to represent the behavior of the soil, this is done after verifying the two models with laboratory results for a previous study of bearing capacity of shallow foundation near slope. The most appropriate mathematical model will be reached with the problems of eccentricity and slope regions. The study includes knowing the optimum conditions for establishing a communication tower foundation near a sandy slope in terms of variables (eccentricity which tower foundation is exposed, relative density, angle of slope, distance of the tower foundation from the crest of slope, and embedment depth of foundation). The nature of the towers is being high structures exposed to wind forces greatly, which causes overturning of the foundation around its base, leading to the eccentricity of the loading. The pressure distribution under the base is irregular (it is increasing) and this leads to differential settlement which causing angle of rotation.

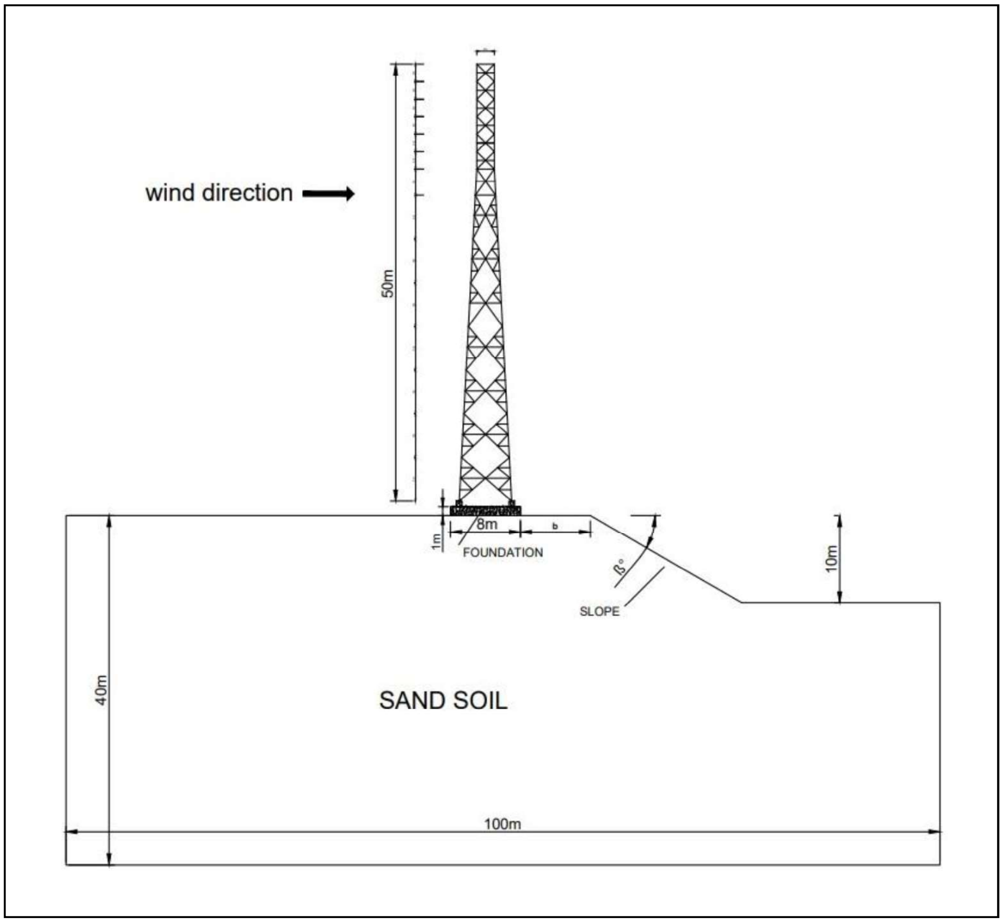

Figure (1.1): Sketch of the problem of the study.

1.4 The Objectives of the Study

This study aims to evaluate the effect of overturning moment on raft foundation of communication tower near slope regions. Ultimate Bearing capacity will be reached or not, especially since the weights of these towers are rather low and there is no increase in the intensity of the vertical loading resistance to overturning moment. The objectives are focused on behavior of communication tower foundation (maximum settlement, differential settlement and the angle of rotation of the foundation) under eccentric loading caused by moment; are divided to investigate the following:

1- Effect of parameters:

- Eccentricity caused by basic wind speed in Iraq.
- Angle of slope.
- Relative density of sand soil.
- Acceptable distance from crest of slope.
- Embedment depth of foundation.

2- Effect of constitutive model.

3- Results with allowable limitation.

1.5 Thesis Outlines

After this chapter which including introduction of thesis, there are four other chapters, as follow:

Chapter two presents literature review of the study which includes introduction of bearing capacity of foundation near a slope, introduction of eccentric load and its effect on bearing capacity, differential settlement under the base and the angle of rotation, introduction of communication tower; its types, forces affecting on communication tower, and factors affected on wind load.

Chapter three discusses primary features of finite element program and numerical modeling which used to simulate the study, also it presents verification of bearing capacity of shallow foundation near a slope by applying laboratory results of literature study in program and comparing the laboratory results with numerical one, also it includes the parametric study with models of raft foundation.

Chapter four presents the results and discussions of parameters (constitutive model, eccentricity caused by moment due to wind load, relative density of sandy soil, angle of slope, distance of the foundation from crest of slope, and embedment depth), as well as examining the results with allowable limitation.

Chapter five presents conclusions and recommendations for further studies.

References of thesis listed after the five chapters of it.