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EXPERIMENTAL STUDY FOR LATERAL CYCLIC RESPONSE OF PILED-RAFT FOUNDATION IN MULTI-LAYER SOIL

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

BY

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بسم الله الرحمن الرحيم

وَمَا تَوۡفِيقِيٓ إِلَّا بِٱللَّهِۚ عَلَيۡهِ تَوَكَّلۡتُ
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Dedication

To………

My father, who was the cause of my success

My mother, the sight of my eyes.

My husband, who supported me.

My brothers and my 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.

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ABSTRACT

Experimental Study for Lateral Cyclic Response of Piled-Raft Foundation in Multi-Layer Soil

By

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ABSTRACT

In piled raft foundation, the load-sharing system between the raft and piles are occurring to transfer the load coming from the superstructure to the soil. This foundation is usually supporting bridge piers, offshore platforms, marine structures and others that are required to resist not only static loading, but also lateral cyclic loading that developed from different sources of loadings such as wind and seismic loads. Therefore, this complex system in layered soil with different load combination needs more laboratory and numerical studies to improve the knowledge regarding the performance of such a problem.

This study offers an experimental study which is carried out to investigate the behaviour of laterally loaded pile raft models with three configurations (1×2, 2×1, and 2×2) where slenderness ratio is 40. Furthermore, three layers soil are used with different percentage of saturation. In addition, many other parameters are selected; such as spacing between piles 3D, 5D, and 7D (D is a diameter of pile) and cross-sectional shape of the pile (i.e. square and circle). To simulate the loading to be as much close as possible to the real cases, different loading conditions are used such as number of cycles, level of the cyclic load ratio (CLR) and influence of axial load.

The results of the study indicated that deflection and bending moment profiles behaviour increase with an increasing number of cycles for all spacing of piled raft foundation models. Correspondingly, in case of pure lateral cyclic load (without vertical loads) where spacing to diameter ratio is 3, the results illustrated that at the critical cyclic load level CLR=60% for 100 cycles, the lateral deflection is about 42%, 31%, and 44% more than at CLR= 40% of piled raft models (1×2), (2×1) and (2×2) respectively.

Furthermore, it found that the presence of vertical loads has reduced the lateral displacement and bending moment profiles in all cases. For circular pile shape group, the reduction in lateral displacement at 100 cycles was approximately 19%, 14% and 44% for models 1×2 , 2×1 and 2×2 respectively, whereas for square shape, the percentage of the reduction were about 26%, 36%, and 34% respectively. The results also indicated that the increase in the lateral resistance in the group of square piles compared to a circular pile under pure lateral loading conditions within the group 1 × 2, 2 × 1 and 2 × 2 were about 16%, 20% and 23% respectively.

The results demonstrated that lateral deflection and bending moment values of this model in saturated clay soil were less than in partially saturated clay soil and closer to the dry soil of about (35% and 13%) respectively.

Finally, this study illustrated that maximum bending moment for trailing row was less than the leading row for circular piled raft models 1×2, 2×1, and 2×2 by about 16%, 17%, and 7% respectively, whereas the results for square model were about 22%, 13%, and 9% respectively.

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Symbol	Term
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	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
Gs	Specific gravity
H	Lateral load applied on the pile head
HZ	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
V	Vertical load
$Q_{all.}$	Allowable vertical load
$Q_{ult.}$	Ultimate vertical load
r	Outside radius of the pipe

y	Pile deflection
γ	Unit weight of soil
γd	Initial dry unit weight of soil
ε	Measured strain
Ø	Angle of internal friction
Qb	End bearing (base) resistance of pile
Qs	Skin friction (shaft) resistance of pile
qb	Ultimate bearing capacity at pile base
qs	Ultimate skin friction of pile shaft
Ab	Area of pile base
As	Perimeter area of the pile shaft
q'	Effective vertical stress at pile base
Nq	Bearing capacity factor for pile foundation
σ_{av}	Average vertical effective stress in a given layer
K	Lateral earth pressure coefficient
δ	Angle of soil-pile friction (in degree)
R	Radius of curvature of the meniscus
T_c	Surface tension of water
U_w	Pore water pressure
U_a	Air pressure

LIST OF ABBREVIATION

Abbreviation	Term
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

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INTRODUCTION

1.1 Introduction

Day after day, the demand for ample infrastructure increases due to the growing population. To accommodate this increasing, it is required to construct high-rise buildings, express highways, and bridges, etc. Making these skyscrapers require stable and economical foundations to be built because very high self-weight, wind loads and seismic loads come through the structure and subsequently increasing load on the foundation. Many traditional foundations are available, for example shallow foundation, raft foundation, and pile, but using one of these foundations is not suitable and economical for such high-rise buildings that have a tremendous load to be carried by the substructure. In such condition, the pile-raft foundation can be considered the best solution for these structures (Kumar and Kumar, 2018).

In general, raft is designed as rigid for resisting high moment and differential settlement, which is a result of the intensity of load and relative stiffness of raft and soil. In the case of conventional foundation design, it must be ensured that the building load will be supported by either the raft or the piles with sufficient safety to avoid failure of the load-bearing capacity and loss of overall stability. In piled raft foundation, the contributions of the raft, as well as piles, are taken into account to check the ultimate load-bearing capacity and the suitability for use of the overall system (Singh and Singh, 2011a).

Piled raft foundation consists of three load-bearing elements: piles, raft and subsoil. According to their stiffness, the raft distributes the total load transferred from the structure as contact pressure below the raft and load over each of the piles. In piled raft foundation, the contributions of the raft and piles are taken into consideration to verify the ultimate bearing capacity and the serviceability of the overall system (Singh and Singh, 2011b). The principal benefit of using piled raft foundation is a reduction in the total number of piles due to perhaps only 60-75% of the total structural load carried by the piles and a portion of the load is carried by the raft (Randolph, 1994)

Piled raft foundations are among the most commonly used support structures for offshore projects(Ghalesari et al., 2015), which are often subjected to significant cyclic lateral loads caused by wave actions. Cyclic lateral loads that effected on pile structures can be caused by wind, waves, earth pressure, and water pressure. Furthermore, construction processes and mechanical compaction cyclically load the soil.

The behaviour of a vertical pile that is subjected to repetitive lateral loads affected by several variables such as geometrical and structural properties of the pile, characteristics of the lateral load (e.g. rate of cyclic load ratio), the properties of soil in which the pile is embedded and the change in soil properties as the pile is loaded repetitively (Long and Vanneste, 1994).

The rate of lateral loads in the site of onshore structures is approximately 10-20% of the axial load whereas for offshore structures this rate can reach at about 30% (Rao et al., 1998). Therefore, the amount of horizontal displacement generated by lateral force over the allowable can cause damage to engineering structure (Bartlett and Youd, 1995). Therefore, it is important to consider a lateral force when designing structures that are subject to cyclic loading to meet safety requirements.

1.2 Statement of the Problem

Designing deep foundations to withstand seismic loading is a reality. Seismic loading of structures and foundations reaches its most critical state as a cyclic lateral force. The response of soils and foundations to repetitive lateral forces is highly complex, relegating most design methods to be based upon overly conservative rules-of-thumb (Moss et al., 1998).Plate (1.1) show the failure of pile foundation due to lateral loads by action of several resources.

Unsaturated soil is the most common material encountered in the field of geotechnical engineering. Yet, mechanics of partially saturated soil lags far behind that of saturated soil. A partially saturated soil is a complex multi-phase system consisting of air, water and solid material whose response is a function of the stress state, moisture condition and other internal variables present within the soil. The difficulties of the experimental and theoretical operations delayed the development of understanding the behaviour of partially saturated soils.

Depending on the soil conditions and intensity of loading, piled raft foundations are the most prevalent kind of deep foundations used to support high rise building which are often designed to resist the dead load with adequate safety factor during their life. However, piled raft foundations are subjected to significant axial and lateral cyclic loads, these are generated by several sources. This is particularly true for the piled raft system of offshore structures, which are subjected to rocking motions caused by wave actions, as well as onshore structures, which in turn, makes the structure in danger.

The studies examining the effect of cyclic loading on the piled raft foundation in multi-layered with partially saturated soil are limited and there is need for improvement and an increasing number of researchers begins the working on improving and understanding the mechanical behaviour of such complex system. The work that is presented in this thesis will help to understand the effects of various parameters on the overall performance of the piled-raft foundation through experimental work using small models tested under two-way cyclic lateral loading.

Plate (1.1): Failure of pile foundation due to lateral loads

1.3 Objectives of the Study

Cyclic lateral loading is one aspect of the problem that offshore foundations and other applications have encountered and adds to the complexity of these structures (Brown et al., 1988).

The main work focused on several points:

1. Identifying of the response of piled rafts embedded in multi-layered soil and their variation of properties with changing the degree of saturation for clay layer under two-way cyclic loading.

2. Investigation of the influence of the axial load, number of cycles as well as cyclic load ratio (CLR) on the lateral resistance of the pile-raft system under

pure lateral and combined loading conditions by evaluating the variation of the lateral displacement and the bending moment along the pile shaft.

3. Assessing the effect of cross-sectional shape and spacing between the piles in the group on the response of piled raft models under pure lateral and combined cyclic loading conditions.

4. Evaluating the best pattern under pure lateral and combined loading conditions which meets increased lateral resistance.

1.4 Thesis Outline

The skeleton of the present thesis is divided into five chapters:

Chapter One: gives a brief description of the piled raft problem under cyclic loading and describes the objectives of the study.

Chapter Two: presents a brief review of previous experimental researches as well as field investigations on pile raft foundations to investigate the vertical and cyclic lateral loading of such foundations.

Chapter Three: is devoted to offering the experimental setup used for modeling the piled raft system under cyclic loading in the laboratory, the properties of the soils used in this work, and their classification, besides the testing techniques and program.

***Chapter Four*:** presents the results of the study. Load-displacement curves represent the behaviour of different configurations of piled raft models and their lateral resistance.

Chapter Five: summarizes the most important conclusions of experimental research as well as recommendations for future work.