RESPONSE OF PILE GROUP SUBJECTED TO VERTICAL AND LATERAL LOADING – THREE DIMENSIONAL NUMERICAL STUDY

By

Amira Fouad Ismail Mohamed

A Thesis Submitted to the

Faculty of Engineering at Cairo University

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Response of pile group subjected to vertical and lateral loading – three dimensional numerical study

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Pile, Laterally loaded pile, Numerical analysis, Soil, P-y curve

Summary:

The pile–soil interaction is sophisticated problem when it solved in a coupled analysis (single analysis). So, the traditional methods for analysis of piles depend on sub-grade reaction between soil and pile do not account the combination between the vertical and lateral loads. Therefore, based on FEM, the computer program **PLAXIS 3D Foundation** was used to undertake numerical studies on the behavior of single pile and Pile group. The influence of pile group size, pile length, load eccentricity and soil type on the lateral response of piles and pile group as well as group efficiency had been studied. Furthermore, relied on the numerical analysis the relation between soil reaction and soil displacement (p-y curves) was also presented in this study for six types of soil.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbol	Description	Units
L	Length of the pile	(m)
D	Pile Diameter	(m)
L/D	Embedded length to diameter ratio	(–)
c	Cohesion	(KN/m^2)
ϕ	Angle of Internal Friction	(º)
I_C	Consistency index	(–)
S	Spacing between piles	(m)
S/D	Spacing to diameter ratio	(–)
E_{50}	Secant stiffness	(KN/m^2)
E_{oed}	Oedometer stiffness	(KN/m^2)
E_{ur}	Unloading reloading stiffness	(KN/m^2)
ψ	The dilatancy angle	(º)
νo	Low initial value of poisson`s ratio	(–)
Ri	Interface reduction factor	(–)
E	Young's Modulus (Stiffness)	(KN/m^2)
Krc	The relative stiffness factor	(–)
E_P	Modulus of elasticity of the pile	(KN/m^2)
I_P	Moment of inertia of the pile	(m^4)
E_S	Secant modulus of soil	(KN/m^2)
b	Pile cap width	(m)
e	displacement between head of the pile and the ground level (eccentricity)	(m)
d	Pile cap thickness	(m)
α	A ratio of ultimate vertical load carried by the group	(–)
Pult	The ultimate lateral load capacity	(ton)
η	The ratio between the group capacity and the theoretical capacity	(–)
vult	The ultimate vertical load	(ton)
p	Soil reaction	(ton /m)
y	Soil displacement	(mm)
M	The bending moment	(KN.m)
σ	The corresponding average stress	(KN/m^2)
k	The pile modulus	(m^3)
z	depth	(m)

Abstract

In designing high rise buildings, engineers commonly used piles to transfer mainly vertical loads. However, lateral loads (wind load, earthquake loads,…) should be considered in designing piles. Therefore, in actual case, combined action of vertical and horizontal loads can occur in many situations for pile. So, the study of combined load behavior of soil is important. However, the pile–soil interaction is sophisticated problem when it solved in a coupled analysis (single analysis). So, the traditional methods for analysis of piles depended on sub-grade reaction between soil and pile do not account for the relation between the vertical and lateral loads. So, the computer program is used in this study to analyze single pile and Pile group subjected to lateral load with and without vertical load.

The current research is adopted **PLAXIS 3D Foundation** to undertake numerical studies on the behavior of single pile and Pile group. In the current finite element model, the pile was treated as a linear elastic material and the soil was treated as non-linear materials using hyperbolic relationship between stress and strain by means of harding soil model. The response of the piles subjected to laterally loaded are studied. The response of piles are studied under the effects of length of pile, group size, pile load eccentricity and soil type are presented in this research. In this analysis the response of pile group subjected to combined of lateral load and vertical loads are studied. The vertical load were applied first as a ratio of group capacity then the lateral load is increased gradually on pile and, it will be described this point later.

Furthermore, the response of pile group is studied under the effect of pile length where as the pile length represents as short pile and long pile. Also, this research focus on the group efficiency.

Besides to, in order to verify the reliability of **PLAXIS 3D Foundation**. The response of the numerical model, used in this study compared with the results obtained by the centrifuge test carried by Chandrasekaran and Dodagoudar (2010).
Furthermore, relied on the numerical analysis the relation between soil reaction and soil displacement (p-y curves) was also presented in this study for six types of soil.

Chapter 1: Introduction

The main components of the pile foundation are the pile cap and piles. And, after selecting materials for the pile foundation to make sure of durability, the designer begins with the components of loading on the single pile or the group. Piles are considering long and slender members which transmit the load to deeper soil or rock of high bearing capacity avoiding shallow soil of low bearing capacity. There are many factors which the pile foundation depended on them, such as, material and geometry of the pile. The main different types of materials used for piles are wood, steel and concrete. The piles are driven, drilled or jacked in the ground according to the type of soil in site and the construction method available, and then are connected to pile caps. In the current research it is studied single pile subjected to lateral loads only and Pile group subjected to lateral load with and without vertical load.

Load piles may be needed when used to support long structures that are subject to wind, wave or earthquake loads. Sometimes piles are exposed to lateral load, for example piles used in offshore structures, such as pavement, harbor, high rise building and tower which exposed to lateral load by wind and earthquake loads. Linear solutions of the differential equation for single piles are available, even in some codes of practice, but are of limited value. So, it is important to know the lateral load to resist capacity of pile foundation. The various forces which act on the laterally loaded pile such as wind load, ship impact, swing and sway of ship, ship morning, and force acting railway on bridge, soil flow and earthquake load.

Although, the structures designed on the principle of the pile had a better performance than those that do not base the pile. However, failure of the group may occur either by failure of the individual piles or as failure of the overall block of soil. The supporting capacity of a group of vertically loaded piles in many cases are considerably less than the sum of the capacities, the individual piles comprising the group. So, the failure of the single pile is happen faster than the failure of the Pile group. This is because the zone of soil or rock which is stressed by the entire group extends to a much greater width and depth than the zone beneath the single pile, This point will described later in this research.

According to the investigation and researches it was found building and bridges subjected to damage which can be summarized as follows[1]:

(1) Detachment between pile cap and pile head due to shear and bending failures in pile head. It can be found in the Hyogoken - Nanbu earthquake. As shown in figs. (1.1 , 1.2) **[1]**.

(2) Girder falling due to the movement of pier supported by pile foundation. Such damage pattern can be found in Tangshan earthquake as shown in figure 1.3**[2]**.

Figure 1.1 and 1.2: Detachment failures between pile head and pile cap, Higashi bridge, Hyogoken - Nanbu earthquake [1].

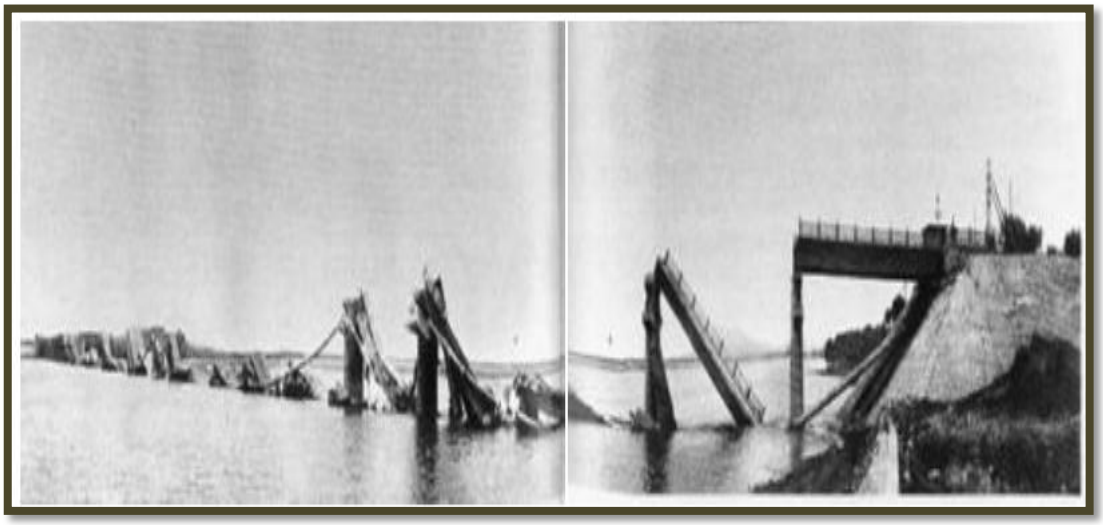

Figure 1.3: Girder falling, Luanhe bridge, Tangshan earthquake [2].

The behavior (elastic and consolidation settlements) of the pile group in all cases are greater than of single pile carrying the same working load. This is because the zone of soil or rock which is stressed by the entire group, **fig.1.4b** extends to a much greater width and depth than the zone beneath the single pile as shown **in fig.1.4a**. In addition to, the traditional methods for analysis of piles do not account for the relation between the vertical and lateral loads.Therefore, the use of a nonlinear three dimensional finite technique for analyzing this problem is necessary. In this research the common package **PLAXIS 3D Foundation** is used, which is considering as a 3D pile–soil modeling tool to undertake studies on the stiffness of a group piles. In the field of geotechnical engineering **PLAXIS 3D Foundation** is consider also as a finite element package intended for three - dimensional analysis of deformation and stability. Therefore, **PLAXIS 3D Foundation** using robust and theoretically sound computational procedures to deal with various aspects of complex geotechnical structures and construction processes.

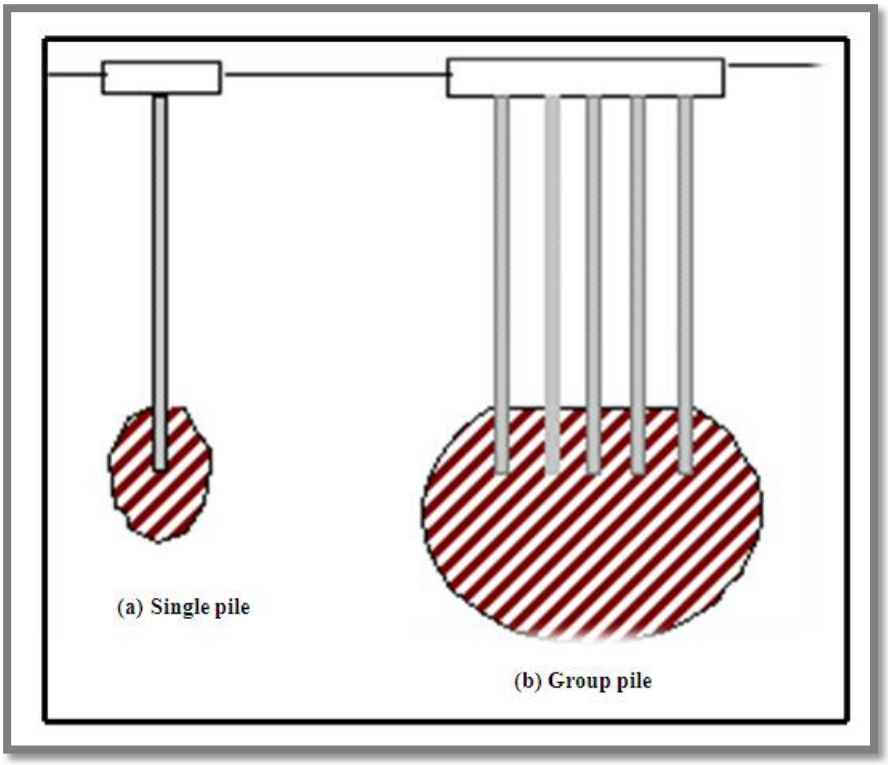

Figure 1.4: Comparison of stressed zone beneath single pile and pile