Ministry of Higher Education
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University of Diyala
College of Engineering

INVESTIGATION OF LATERAL RESISTANCE CAPACITY OF INCLINED HELICAL PILE GROUP IN SANDY SOIL UNDER CYCLIC LOADING

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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بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

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I certify this thesis entitled **"Investigation of Lateral Resistance Capacity of Inclined Helical Pile Group in Sandy Soil under Cyclic Loading"** was prepared by " Ali Hussein Ahmed Mohammad " was made under my supervision in the University of Diyala in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering.

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We certify that we have read the thesis entitled **"Investigation of Lateral Resistance Capacity of Inclined Helical Pile Group in Sandy Soil under Cyclic Loading"**. We have examined the student (**Ali Hussein Ahmed Mohammed**) in its content and what is related to it, and in our opinion, it is adequate as a thesis for the degree of Master of Science in Civil Engineering.

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Dedication

To………

My father, who was the cause of my success

My mother, the sight of my eyes.

My wife, who supported me in the critical time.

My brothers and my sons whose love flows 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.

ALI HUSSEIN AHMED

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ALI HUSSEIN AHMED

Investigation of Lateral Resistance Capacity of Inclined Helical Pile Group in Sandy Soil under Cyclic Loading

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ABSTRACT

Inclined helical piles are one of the types of deep foundations used to resist loads resulting from tension, lateral external loading, and axial compression. Despite significant progress in helical pile manufacturing and application, particularly in wind turbines and power transmission towers, few studies on their side behavior have been conducted.

In this research, the response of inclined helical and ordinary pile groups (2×1), (1×2), and (3-pile) under lateral cyclic load (CLR) study with the various pile inclination angles (5°, 10°, and 15°), the spacing of the piles to the diameter of the helix (S/Dh = 3), pile diameter (10 mm), and various pile embedded lengths to the diameter of the shaft (L/d = 33, and 26) by using single and double helix for inclined helical piles.

All inclined pile group models are embedded inside sandy soil at a relative density of 65% and tested under the impact of a pure two-way symmetrical side periodic load with a natural frequency of 0.2 Hz.

In this work, various parameters have been studied like the impact of configuration, the impact of pile inclination angles, the impact of helix number in the inclined helical pile and compared with the inclined ordinary pile, and the impact of embedded length for the inclined helical pile under the impact of various levels for periodic load proportion and with the use of a cyclic number until 100.

The results show that increasing the pile inclination angle significantly affects lateral resistance. At a 60% cyclic load ratio, increasing the inclination angles of the piles in all groups from (5°) to (10° and 15°) for the same pile embedded length increases lateral resistance by about (11.5-22.5%) and (21-39%), respectively. The side resistance is also affected by the arrangement of identical piles in the group; the inclined pile group (1×2) has a higher lateral resistance than the inclined pile group (2×1), about (28%, 24%, and 8%) for single helix-pile, double helix-pile, and ordinary pile, respectively.

The inclined helical piles showed better performance than inclined ordinary piles during side cyclic load influence, as the inclined ordinary piles gave side deflection larger than the inclined helical piles with a proportion of (11–100) % at various cyclic load ratios, and the double helix-piles showed better performance compared with the single helix-piles during periodic side load impact, as the double helix-piles gave side resistance larger than the single helix-piles by a proportion of (4–23%) at various cyclic load ratios.

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LIST OF SYMBOLS

Symbol	Term
C	Cohesion
Cc	Compression Index
Cu	Undrained Shear Strength
d	Pile Shaft Diameter
Dh	Helix Plate Diameter
L	Embedded length of pile
P	Helix Pitch
S	Spacing between piles
Gs	Specific Gravity
f	Frequency
HZ	Hertz
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
e_{max}	Maximum Void Ratio of Soil
e_{min}	Minimum Void Ratio of Soil
γ	Unit Weight of Soil
Ø	Angle of Internal Friction

LIST OF ABBREVIATION

Abbreviation	Term
USCS	Unified Soil Classification System
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
PLC	Programmable Logic Controller
B.S	British Standards Institution
API	American Petroleum Institute
SSI	Soil-structure interaction

CHAPTER ONE

INTRODUCTION

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1.1 General

The wide use of piles to transfer lateral and vertical loads to the surrounding soil when encountering soils with low bearing capacity through great depths (Wiba and Vineetha, 2014).

For structures subjected to seismic and wind loads like bridge supports, transmission towers, marine platforms, and retaining walls, the main objective of the piles used in these structures is to transfer the lateral loads of the soil. The most important and most common sources of lateral force are earthquakes, traffic movement, water pressure, and wind gusts, which the piles must bear in the structures mentioned above (Alice et al., 2014). Figure (1.1) shows the inclined helical piles used to support anchored sheet pile wall (Deardorff, 2016).

Figure (1.1): Inclined Helical Piles used to Support Anchored Sheet Pile Wall (Deardorff, 2016).

1.2 Inclined Helical Pile

In 1936, for the first time, Irish engineer Alexander Mitchell used helical piles or stilts as the foundation for homes. Helical piles are one of the types of deep foundations that are available in different lengths and diameters, they are used to resist forces caused by axial pressure and tensile strength, in addition to lateral loading. Helical piles consist of one or more pieces of inclined, circular iron helical pieces (or flanges) welded to a steel shaft or made to the shaft itself as one piece and can be zinc plated or galvanized to resist corrosion as shown in Figure (1.2). Helical piles are inserted into the soil by a downward torque applied to the pile head, which leads to the pile entering the ground in a downward circular motion (Kristen, 2007).

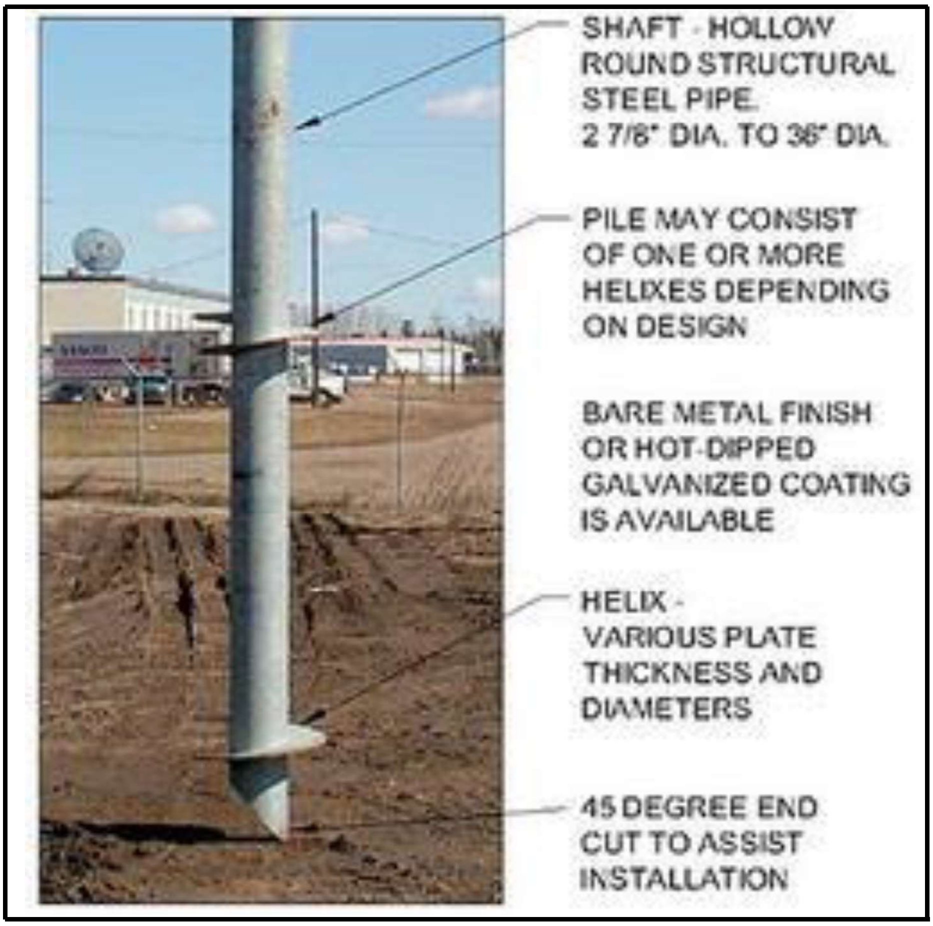

Figure (1.2): Helical Piles Parts (Hussein and Karkush, 2021).

There has been a great development in the field of installing and increasing the axial bearing capacity of helical piles in recent years, as the current used helical piles have an axial bearing capacity of more than 3MN. The process of inserting helical piles with large diameters in special soils such as very hard clays and very dense sand needs a source that provides us with great rotational torque and as a result of the availability of heads with high rotational capacity, which made it easier to enter the helical piles with a diameter of more than 508 mm in stiff soil (Sakr, 2010).

One of the most important uses of helical piles in civil engineering applications in recent years is: pier supports, bridges, commercial and residential buildings, damaged and historical buildings foundations, wind turbines foundations, machine foundations, transmission towers, and marinas (Türedi, and Örnek, 2020).To obtain a large bearing capacity, helical piles are used as a group and this makes the use of these piles popular in the construction of wind turbines and high-rise and medium-rise commercial buildings, an example where three screw piles give a bearing capacity ranging from 75 to 600 tons (Perko, 2009). During the design, the distances between the piles is an important and crucial element, so when designing the helical pile group, the need to use the least spacing between the piles must be taken into account to avoid weakening the performance of the group because the close distances between the piles reduce its performance, efficiency and carrying capacity (Perko, 2009).

If the soil surrounding the piles has little resistance compared to the horizontal forces transferred to the foundations, or we need to provide additional rigidity to the entire structure, then it is necessary to take into account the use of inclined piles in the foundation, and inclined piles usually provide more solid resistance to horizontal loads compared to vertical piles (AASHTO, 2010). Depending on the direction of loading, there are two types of inclined piles, the pile that is pushed towards the loading is the negative inclined or reverse inclined pile, while for the scattered pile in the direction of loading it is positive or the front pile as shown in Figure (1.3). Due to the high resistance provided by inclined piles to cope with lateral loads resulting from the impact of ships and water waves, etc., inclined piles are widely used in marine structures (Pathak, 2011).

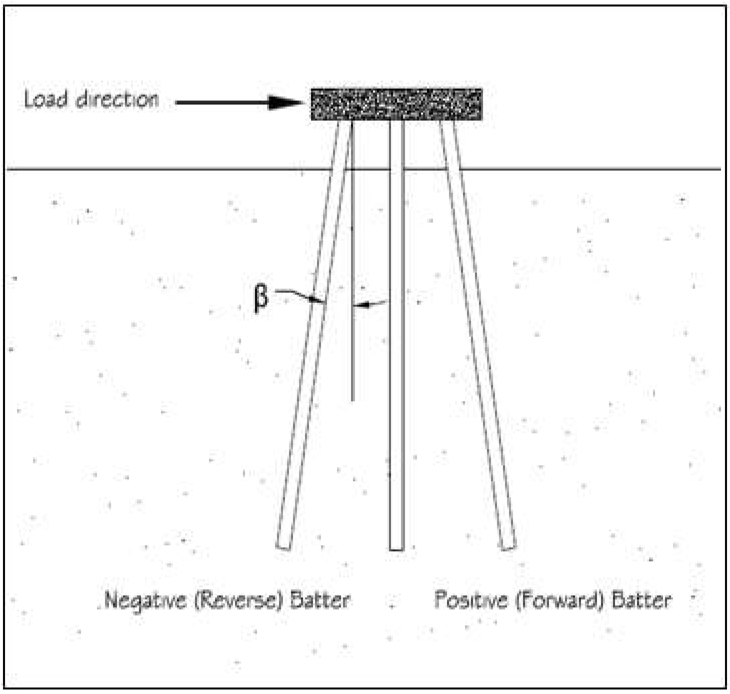

Figure (1.3): Inclined Piles Categorization (Pathak, 2011).

1.3 Helical Pile Advantages

Among the most important features of the helical piles are the following (Deardorff, 2016):

1. Installing a turnkey system is simple and quick.
2. Loading immediately.
3. Small installation tools.
4. Pre-designed system.
5. Easily field adjustable.
6. Correlation of torque with capacity.
7. Installable in any climate conditions.

8. Solve to:
   - Sites with limited access.
   - Water table levels are high.
   - Soils with a weak surface.
9. Environmentally friendly.
10. No vibration.
11. No concrete.
12. There are no leftovers to remove.

1.4 Aims of the Study

As a result of the high development of inclined piles, their large areas of use, and a little knowledge of inclined helical pile group behavior, this study aims to investigate inclined helical pile group behavior under the influence of periodic lateral loads in sandy soil. The study aims to understand the effect of the following on the lateral resistance of the inclined helical pile group under cyclic lateral loading:

1. The pile inclination angles and the pile group configurations.
2. The cyclic lateral load ratios and the cycle number.
3. The pile embedded lengths and the helix number and compared with an ordinary pile.

1.5 Outline of the Thesis

The main content of this study consists of five chapters:

Chapter One: explains and gives a clear idea of the inclined helical piles and their uses, the magnitude, and influence of the side periodic load on the piles' group, and the main aim of this study.

Chapter Two: shows a review of past theoretical and laboratory studies, with some field studies regarding the side behavior of inclined helical piles.

Chapter Three: shows the details of the experimental part of the study, which includes (soil type, piling model, piling cover, test container, method of piling installation, raining device, and periodic side load generation device).

Chapter Four: presents the results of the different configurations of inclined helical pile groups under the influence of pure lateral cyclic load and is discussed in this study.

Chapter Five: presents the conclusions drawn from this study, with the main important recommendations for future studies.