THE INFLUENCE OF GEOLOGICAL AND GROUNDWATER CONDITIONS ON THE PILES DRIVING EFFECTS INDUCED AGAINST NEARBY BUILDINGS

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Geotechnics)

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DECEMBER 2018

DEDICATION

This project report is dedicated to my dear father, mother and wife. This dedication is the least thing that I can do in returning your countless favours, and your sacrifice for me.

ACKNOWLEDGEMENT

My deep gratitude goes firstly to my God for supporting me; this generated by my faith of him, and my faith that he can make every impossible possible. Then I would like to thank my parents, my wife and family members for their endless support throughout my ups and downs while attending my university study. Also, I would like to thank my university, Universiti Teknologi Malaysia (UTM), and all my tutors for all what they taught me especially those in Department of Geotechnics/School of Civil Engineering.

All my appreciation, respect, and a lot of thanks goes to my academic supervisor Ap. Dr. Ahmad Safuan Bin A. Rashid, for his continuous support and guidance throughout my master project journey.

Finally, I would like to extend my acknowledgment to the computer laboratory technicians and postgraduate office staff, for their support and advice.

ABSTRACT

Installation of pile foundations by impact hammers produces numerous negative effects in the surrounding environment. For civil and geotechnical engineers, the most important one is the vibrations induced by various piles driving operations. Since many construction works including pile foundations installation usually take place in narrow urban areas, it is of great importance to predict and control the effects that may harm the surrounding structures. Hence, the study of all related aspects to the vibrations generation and propagation is insistently needed. This study has been conducted to investigate the influence of subsurface geology and groundwater conditions in controlling the effects induced by piles driving operations against nearby buildings. 2016 PLAXIS 3D software was used to numerically simulate the process of pilling and the effects reflected on one building located in the near proximity. Six models with similar soil, building, pile properties, soil strata order and with different groundwater and geological conditions have been constructed. In addition, dynamic load with dynamic load-time multiplier has been used to simulate a single acting hammer action on the pile head. Both, displacement and applied force changes have been investigated through one point located in the nearest building column to the pilling operation. After investigation, it has been found that the subsurface geology plays more significant role in controlling the effects of piles driving, compared to the groundwater conditions. However, the depth of pilling and the soil, pile and building properties have the major role. Lastly, by using the force resonance approach it was concluded that; driving piles through saturated soils causes lower values of force resonance compared with dry soils. In addition, driving piles through horizontal layers causes higher force resonance than that in inclined layers, but lower than that in folded (basin-shaped) layers.

ABSTRAK

Penanaman asas cerucuk dengan menggunakan penukul impak menghasilkan pelbagai kesan negatif pada keadaan sekitarnya. Bagi para jurutera awam dan jurutera geoteknik, ciri paling penting yang perlu diambil kira adalah getaran yang terhasil daripada pelbagai operasi penanaman cerucuk. Memandangkan kebanyakan kerja-kerja pembinaan sering berlaku di kawasan bandar yang sempit, termasuklah operasi penanaman asas cerucuk, amatlah penting untuk kita meramal dan mengawal kesan-kesan yang berpotensi merosakkan struktur di sekitarnya. Oleh itu, kajian dari pelbagai aspek yang berkaitan dengan generasi getaran dan penyebaran/sebaran perlu dijalankan. Kajian mengenai penyiasatan pengaruh subpermukaan geologi kawasan dan keadaan air bawah tanah telah dilakukan dalam memastikan pengawalan terhadap kesan-kesan daripada operasi penanaman cerucuk terhadap sturktur berhampiran dapat dilaksanakan. Perisian PLAXIS 3D 2016 telah digunakan bagi mendapatkan stimulasi secara angka dalam proses penanaman cerucuk dan kesannya terhadap sesuatu struktur secara jarak dekat. Enam model telah dihasilkan dengan ciri-ciri sama dari segi jenis tanah, struktur bangunan, cerucuk, siri strata tanah dengan keadaan air bawah tanah dan keadaan geologi yang berbeza. Selain itu, beban dinamik serta dinamik pengganda beban-masa telah digunapakai dalam mensimulasikan tindakan tunggal penukul pada kepala cerucuk. Kedua-dua anjakan dan perubahan daya terpakai ini telah dikaji melalui satu titik lokasi ruangan bangunan berdekatan dengan operasi penanaman cerucuk. Hasil kajian mendapati subpermukaan geologi memainkan peranan lebih penting dalam pengawalan kesan-kesan penanaman cerucuk berbanding perubahan keadaan air bawah tanah. Walau bagaimanapun, aspek lain seperti kedalaman penanaman cerucuk, jenis tanah, ciri-ciri cerucuk dan ciri-ciri bangunan juga tidak kurang penting dalam pengawalan kesan negatif terhadap struktur sekitarnya. Akhir sekali, dengan menggunakan pendekatan daya resonan, kesimpulan yang boleh dibuat ialah; penanaman cerucuk di kawasan tanah tepu akan menyebabkan penghasilan nilai daya resonan yang lebih rendah berbanding di kawasan tanah kering. Manakala penanaman cerucuk pada lapisan mendatar akan menyebabkan penghasilan daya resonan lebih tinggi berbanding pada lapisan condong, dan juga lebih rendah nilainya pada lapisan terlipat (berbentuk-lembangan).

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LIST OF ABBREVIATIONS

FOS	-	Factor of safety
M 1	-	Model 1: horizontal layers with shallow groundwater table
M 2	-	Model 2: horizontal layers with deep groundwater table
M 3	-	Model 3: folded layers (basin shaped) with shallow groundwater table
M 4	-	Model 4: folded layers (basin shaped) with deep groundwater table
M 5	-	Model 5: inclined layers with deep groundwater table
M 6	-	Model 6: inclined layers with deep groundwater table
P wave	-	Compression or longitudinal waves
S wave	-	Shear or transverse waves

LIST OF SYMBOLS

γ	-	Unit weight
A_p	-	Area of pile tip
A_s	-	Pile perimeter area
$A_{S,C,W}$	-	Cross-sectional area of steel, concrete, or wood respectively
C'	-	Cohesion
D	-	Pile diameter
F_{cd} , F_{qd} , $F_{\gamma d}$	-	Bearing capacity depth factors
F_{ci} , F_{qi} , $F_{\gamma i}$	-	Bearing capacity load inclination factors
F_{cs} , F_{qs} , $F_{\gamma s}$	-	Bearing capacity shape factors
f_s	-	Unit friction or skin resistance
$f_{S,C,W}$	-	Allowable stress of steel, concrete, or wood respectively
N_c , N_q , N_γ	-	Bearing capacity factors
N_c^* , N_q^*	-	Bearing capacity factors that include necessary shape and depth factors
q'	-	Effective vertical stress at the level of the pile tip
Q_{all}	-	Allowable load carrying capacity
Q_p	-	Load carrying capacity of the pile point
q_p	-	Unit point resistance
Q_s	-	Load carrying capacity of the pile skin (frictional resistance)
Q_u	-	Ultimate load carrying capacity
q_u	-	Ultimate bearing capacity

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CHAPTER 1

INTRODUCTION

1.1 Overview

As a result of urbanization, dramatic increase in population and the limitation of cities areas that are covered with facilities and infrastructures, as well as the management and planning of cities to be spread out about an inner center or multi-center. The need to build large buildings in height and area is increasing continuously. Hence, the need of strong foundations to carry the large loads imposed by these buildings is necessary.

Throughout the last hundred years, large number of cities around the world transformed from just small rural cities to enormous and crowded ones. Among the transformation process, many construction works including roads, large buildings, skyscrapers, as well as bridges have been done. As this transformation is a long-term process, the construction works have been done in sequences, means that, construction of new buildings has commenced nearby other old ones. In fact, construction of new building in between other existed buildings takes place daily, at least once a day around the world.

1.2 Background

Nowadays, most buildings around the world are founded using pile foundation systems, especially tall buildings and skyscrapers, this is due to the piles high ability to carry and transfer large loads to the base and surrounding soil and rock, compared to shallow foundation systems (Liu & Evett, 1992). Throughout the history, piles were used to support important buildings, in Russia, Roman Empire, Egypt, and others. Wooden and stone piles have been driven before construction of the main building to achieve the stability state. In the 18th century, many investigation works were carried out to evaluate the effect of using wooden piles in construction, and their role in structures stability. After that, the usage of driven wooden piles became highly recommended by civil engineers in America and Europe (Ulitskii, 1995).

In addition to noise, pile driving process produces many undesirable effects on soil, and surrounding buildings and structures, these effects depend on the pile driving method, the properties of subsurface materials and geological situation, the pile properties itself, and the parameters of the driving machine (Woods, 1997). As pile foundations are being driven into the ground by a dynamic load, vibrations will be produced and transferred starting from the machine, going through the pile and then transmitted to the soil and other subsurface structures, these vibrations are the main source of destruction to the surrounding environment. More specifically, the induced vibrations will cause a displacement and excess of pore water pressure in clayey soils near the pile, and apply additional axial loads on in-place piles due to the soil vertical movement, this will lead to develop a new set of bending moments acting on in-place piles as well (Poulos, 1994).

Large number of researches, analysis, and field measurements were conducted, up to these days, in order to achieve a comprehensive understanding about all pile installation related aspects, starting from creation of general guidelines for the appropriate selection of suitable piles and driving systems and their parameters, to the effects assessment and mitigation of their environmental impact. Among these studies, the study of vibrations induced and their nature, and the parameters that control the propagation of these waves, in addition to studying the pile-soil interactions (Pestana et al, 2002). In general, the studies are directed to obtain a full control of all variables in the pile foundations design and installation. Although, it is difficult, but if the full control is gained, this will lead to fully stable buildings to be built and remain.

Pile foundations installation is an expensive process and time consuming, particularly if it is to be done just for investigation purposes. At the same time, there is a persistent need to develop preventive procedures and solutions against the problems induced by pile driving process. One approach is to simulate the problems numerically, for this case, the first attempt was done by using wave equation analysis in one-dimensional scale, this method was conducted to the pile driving problem for the first time by (Smith, 1962). However, due to the simple way of modelling, the use of one-dimensional modelling has not and will not give satisfactorily accurate results. Instead of that, more reliable and realistic results can be obtained if the overall situation is to be modelled by using a three-dimensional modelling (Mabsout & Tassoulas, 1994).

Finite element method is one of the most useful methods that is used to model the process of pile driving numerically. This is due to its high capability to examine the mechanisms that take place during installation of piles (Henke & Grabe, 2009). Many aspects have been investigated successfully with the aid of finite element modelling, such as; the changes in void ratio and stresses that occur in the soil around the driven pile, as a function of pile diameter, by (Henke & Hügel, 2007), as well as their dependency on the method of installation, by (Henke & Grabe, 2006; Mahutka et al, 2006).

1.3 Problem Statement

As mentioned previously, piles setup process induces vibrations, which transferred through the driven piles to the surrounding environment. Undoubtedly, all subsurface properties have their effect on the way that vibrations propagate, and how much area the induced waves will cover before losing their destructive effects. For civil and geotechnical engineers, the main problem regarding this matter, is to drive pile foundations in a critical environment, this includes, driving piles near to an existing building or any structure, or near to slope edge. Whatever the situation, pile installation will displace, compress, or heave the soil in the area around, which may affect the surrounding medium. The walls of the nearby buildings may become cracked, the soil under the building may settle, and the slope may fail or become unstable. In spite of the large number of researches that have been carried out to investigate the problem, there is a lack of understanding until now. This is due to the large number of variables that control the situation, as well as the uncontrollability of some of these variables, especially the natural ones. In addition to the sophisticated mechanisms of these kinds of problems. Whereas almost all of these researches were concerned to examine the influence of driving machine variables, and soil engineering properties, the concern to study the geological conditions influence was less, and inadequate.

It is important for the real-life practice to produce an effect optimization guideline and detailed procedure, in order to be used for risk mitigation, and effect minimization, during the pile foundations installation process. This approach of solution needs a deep understanding of the mechanisms that govern the situation, and the way that various parameters influence the vibrations propagation, both natural and machine parameters.

1.4 Aims and Objectives

This study is conducted to determine how such a building can be affected, if a pile is to be driven close to it, under different subsurface conditions. These conditions include a combination of different geological soil structures with different groundwater conditions. This study is carried out by using numerical modelling to simulate the overall situation and obtain results. Thus, the objectives that are anticipated to be achieved are:

(a) To obtain quantitative results (displacement and force) about how the subsurface soil structures and the groundwater conditions will change the effects induced by pile driving process on a nearby structure.

(b) To estimate the preferable subsurface conditions, at which the pile driving effects are at minimum.

1.5 The Scope

In this study, pile driving process is simulated using 2016 PLAXIS 3D software, which uses a finite element method to model real-life geotechnical phenomena numerically. Six models with different subsurface conditions are constructed. The components of the structure and the driven pile are remaining equal in the six models; this gives a chance to investigate the influence of subsurface conditions on the effects that a nearby building may experience due to pile driving process. The model contains eight-story building, with a pile driven away from it. It also contains a multi-layer soil with different conditions as following:

(a) Horizontal multi-layer soil with shallow groundwater table.

(b) Horizontal multi-layer soil with very deep groundwater table.

(c) Folded multi-layer soil (basin shaped) with shallow groundwater table.

(d) Folded multi-layer soil (basin shaped) with very deep groundwater table.

(e) Inclined multi-layer soil with very deep groundwater table and the inclination is toward the building, with ground level to be horizontal.

(f) Inclined multi-layer soil with very deep groundwater table and the inclination is against the building, with ground level to be horizontal.

1.6 Hypothesis of the Study

The numerical models that are being done during this study, will help to understand how the effects of the driving process on a nearby structure will differ, in accordance to subsurface conditions changes, means the subsurface soil structures and the groundwater conditions. Therefore, it is anticipated to enhance the present knowledge about pile driving practices.

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