BEARING CAPACITY OF SOFT SOIL REINFORCED BY BOTTOM ASH COLUMNS USING PLAXIS 3D

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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)

School of Civil Engineering
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FEBRUARY 2021

DEDICATION

This thesis is dedicated to my father, for earning an honest living for us and for supporting and encouraging me to believe in myself. It is also dedicated to my mother, the strong and gentle soul who taught me to trust Allah, believe in hard work and that so much could be done with little.

ACKNOWLEDGEMENT

I would like to deeply praise the Almighty ALLAH SWT for giving me the guidance, patience, perseverance and strength for me to get through this experience and also, I would like to take this opportunity to express my sincere gratitude to all those who have contributed in completing this project.

In particular, I wish to express profound gratitude to my research supervisor Assoc. Prof. Dr. Ahmad Safuan A. Rashid, for his encouragement, knowledge, motivation, patience and time in helping me along the preparation of this project. It was a great privilege and honour to work and study under his guidance.

Thanks to my friends especially Yousef Hamdan and Ahmed Mohammad for their continuous support and help.

Last but not the least; I am extremely grateful to my parents for their love, prayers and caring in all aspect of my life and especially for educating and preparing me for my future. Also, I express my thanks to my siblings for their emotional support and encouragement, and finally thanks to all parties and persons who had involved directly or indirectly in the completion of this project.

ABSTRACT

Soft soil is usually a heterogeneous material with very different properties. The main problem of soft soil is expressed in low bearing capacity and deformations under loading (settlement). In certain regions, such issues are daunting for geotechnical engineers. In order to solve this problem, granular columns introduced as a ground improvement technique to increase the load-bearing capacity and decrease settlement by replacing the soft soil with columns group of granular materials such as bottom ash. Bottom ash is a by-product material that might be utilized as a green granular column when altering the natural source materials such as sand or aggregate. This paper studies the ultimate bearing capacity of a foundation on soft soil reinforced by five groups of end-bearing bottom ash columns using a finite-element PLAXIS 3D modelling with three different constitutive soil models. The area replacement ratio of the five groups were 13.1%, 19.6%, 26.2%, 32.7% and 39.3%. In comparison with untreated soil, the ultimate bearing capacity in soft soil increased up to three times with the increment of area replacement ratio. The obtained numerical findings were compared to existing physical modelling results carried out by previous researchers and these results have been validated through this comparison. Based on the results, the Hardening Soil model can well describe the soil behaviour with an accurate estimation for load-bearing capacity when compared to experimental outcomes.

ABSTRAK

Tanah lembut biasanya ialah bahan heterogen yang mempunyai sifat-sifat yang berbeza. Masalah utama tanah lembut adalah keupayaan galasnya yang rendah dan perubahan bentuk yang boleh berlaku ketika pembebanan (enapan). Di sesetengah kawasan, masalah-masalah ini amat sukar buat jurutera geoteknik. Bagi menyelesaikan masalah ini, teknik tiang bahan berbutir telah diperkenalkan untuk meningkatkan keupayaan galas beban dan mengurangkan enapan. Melalui teknik ini, tanah lembut akan digantikan dengan kumpulan tiang bahan berbutir seperti abu dasar. Abu dasar ialah bahan hasil sampingan yang boleh digunakan sebagai tiang bahan berbutir hijau apabila bahan-bahan sumber semulajadi seperti pasir atau agregat diubah. Kertas kajian ini mengkaji keupayaan galas muktamad binaan asas di atas tanah lembut yang diperkukuhkan dengan lima kumpulan tiang abu dasar galas hujung menggunakan model unsur terhingga PLAXIS-3D dengan tiga model tanah konstitutif yang berbeza. Nisbah penggantian luas lima kumpulan tersebut adalah 13.1%, 19.6%, 26.2%, 32.7% dan 39.3%. Berbanding tanah yang tidak dirawat, keupayaan galas muktamad tanah lembut meningkat sebanyak tiga kali ganda bersama peningkatan pada nisbah penggantian luas. Dapatan numerik ini telah dibandingkan dengan model fizikal sedia ada yang terhasil daripada kajian yang telah dijalankan oleh penyelidik-penyelidik terdahulu. Melalui perbandingan yang telah dilakukan, dapatan numerik daripada kajian ini telah disahkan. Berdasarkan hasil kajian ini, model Hardening Soil boleh menghuraikan kelakuan tanah dengan baik, di mana ia telah memberikan anggaran yang tepat untuk keupayaan galas beban apabila dibandingkan dengan hasil eksperimental.

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LIST OF ABBREVIATIONS

FEM	-	Finite Element Method
HS	-	Hardening Soil model
LL	-	Liquid Limit
MC	-	Mohr Coulomb Model
PI	-	Plasticity Index
PL	-	Plastic Limit
SL	-	Shrinkage Limit
SS	-	Soft Soil Model
USCS	-	Unified Soil Classification System

LIST OF SYMBOLS

A_r	-	Area replacement ratio
c	-	Cohesion
C_c	-	Compression index
C_s	-	Swelling index
c_u	-	Undrained shear strength
E	-	Modulus of elasticity
e	-	Void ratio
G_s	-	Specific gravity
k	-	Coefficient of permeability
kN	-	Kilo newton
kPa	-	Kilo pascal
m/s	-	Metre per second
mm	-	Millimetre
N	-	Poisson's ratio
q_u	-	Ultimate bearing capacity
w	-	moisture content
ϕ	-	Internal friction angle
ψ	-	Dilatancy angle
k^*	-	Modified swelling index
λ^*	-	Modified compression index
γ_{dry}	-	Dry unit weight
γ_{sat}	-	Saturated unit weight

CHAPTER 1

INTRODUCTION

1.1 Background of the problem:

The development of urbanisation is taking place intensively through Malaysia as the population rate is rising. However, due to the shortage of construction sites; construction is executed on land of weak ground conditions nowadays, especially the soft soil sites. This soft soil normally has a low bearing capacity due to the low permeability beside the high compressibility which will affect the stability of the building that will be carried out on this type of soil (Marto et al., 2016).

In order to avoid these difficulties of construction on the soft soils, ground treatment using variety types of methods is necessary. Among these different methods of soil improvement, the granular column technique is an effective, economic and sustainable method to enhance and strengthen the soft soils. In order to achieve enhanced strength. This technique requires replacing 10-35 percent of the in-situ soil with granular materials which are compacted in cylindrical holes under light to moderately loaded structures (Killeen, 2012). As a result, the bearing capacity of soil will be improved due to the high stiffness properties of the granular material which leads to reduce the total settlement of the soil in site.

Malaysia has been creating an excessive amount of coal ash in both forms of bottom ash and fly ash through the production of electricity using a coal-fired power plant (Feuerborn, 2005). Increasing the waste amount in coal-burning methods such as bottom ash has become a major issue as same as other types of waste. Huge quantities of bottom ash are created to produce high amounts of electricity annually. As a consequence, to dispose of this bottom ash, a wide landfill area must be supplied, and for sustainability aspects, this has become a significant challenge for our environment (Muhardi et al., 2010)

However, the new trend in the world nowadays is to use sustainable methods in the construction sector, such as using by-products or waste materials rather than natural materials like sand, stone, gravel, timber and others, and since bottom ash has the same characteristics as granular aggregates, that makes it suitable for this task.

In general, the characteristics of bottom ash particles are coarse, porous, glassy, granular and in terms of colour they are greyish which is almost comparable to the natural sand characteristics. Goutam and Ventappa, (2008) found that bottom ash is able to give maximum unit weight with a range of 11.87 kN/m^3 to 18 kN/m^3 when compacted, with an optimum moisture content ranging from 12 % to 34 %. According to Travedi and Singh (2004), a medium degree of permeability with a coefficient of permeability value up to 9.6 x 10^{-4} m/s has been shown by the bottom ash, while at maximum compaction, Abdul Talib (2010) reported that bottom ash may have an angle of friction up to 40 °.

The choosing of ground improvement method is crucial to maintain the safety and the lower cost of construction. Therefore, one of the most common techniques in today's world to get control of the high compressibility and weak bearing capacity in soft soil is the stone column. Stone column is an efficient method that helps to lower the settlement and fasten the pore water pressure dissipation which in turn enhances the bearing capacity of soft cohesive soil. According to (Kumar and Stewart, 2003; Muhardi et al., 2010), the characteristics of bottom ash are nearly the same as sand. Consequently, this material has the ability to be used as an alternative in stone column. The usage of stone column with a replacement material of bottom ash will lead to cost-effective project and reduce the land consumption for bottom ash disposal.

Muir Wood et al. (2000) reported that using granular material columns has two benefits; firstly, these columns perform as piles that withstand the load by end bearing and skin resistance due to the high stiffness and friction angle and strength compared to soft clay. Secondly, the granular material such as bottom ash possesses higher permeability in comparison with clay which will accelerate the consolidation process and increase strength. However, in laboratory tests, Moradi et al. (2018) reported a number of design criteria influence the performance of stone column such as area replacement ratios Ar, (ratio of column area, Ac, with area of soil, As), the spacing between columns, material's stiffness, and penetration ratio height Hr, (ratio of column height, Hc, to soil height, Hs). Hu (1995) observed different performance on load-bearing between a single isolated column and a group of stone columns. Besides, he revealed the importance of the area replacement ratio on the performance of foundation reinforced with stone column and proposed that a replacement value of more than 25% has a significant impact on bearing capacity enhancement of treated soil.

1.2 Problem Statement

Kaolin clay is normally constituting a problem or difficulty to deal with due to low bearing capacity and high compressibility. Granular column or stone column is a technique which has become very common because it is both efficient and economic. Many researchers have conducted experimental and numerical studies on the performance of stone columns (Remadna et al., 2020; Thakur et al., 2020; Tabchouche et al., 2017; Castro, 2014; Killeen, 2012; Shahu and Reddy, 2011; McCabe, 2009; McKelvey, 2004; Saha et al., 2000; Hughes and Wither, 1974), while few only have tried the use of bottom ash as replacement materials in stone columns (Moradi et al., 2019, Moradi et al., 2018, Hasan et al., 2018, Hasan et al., 2017, Marto et al., 2016, Marto et al., 2014). Furthermore, none has analyzed the bearing capacity enhancement of soft soil with bottom ash columns reinforcement using different soil models in numerical modelling.

Using substitute materials for granular columns is important to save the natural non-renewable resources. Moreover, bottom ash production in large quantities has resulted in environmental problems in terms of providing more space for waste disposal and raise the expenses to acquire this area consequently. Despite, bottom ash characteristics displayed the possibility of being used as a replacement material in granular columns for soft clay reinforcement. The bearing capacity of kaolin clay could be improved and the consolidation could be accelerated due to the high angle of friction and permeability coefficient respectively. In case of using these by-products material (bottom ash) to improve the soft soil, the construction cost of the project might be decreased. Besides, it can help to achieve a sustainable construction environment (Hasan, 2013). However, the simulation and numerical analysis are useful to validate the experimental results, understand and obtain the effects of different parameters on the behavior of bottom ash columns in soft soil.

1.3 Research Objectives

This study is conducted with the aim to determine the effectiveness of bottom ash column installation in kaolin clay by using PLAXIS 3D. The aim can be achieved by following the next objectives:

i. To analyze the influence of area replacement ratio upon the bearing capacity of kaolin clay reinforced by groups of bottom ash columns.

ii. To compare the bearing capacity results obtained with different soil models.

iii. To validate the accuracy of the bearing capacity experimental result with numerical modelling.

1.4 Research Scope

This research focused on the kaolin clay performance strengthen with end-bearing bottom ash columns beneath a rigid footing using numerical analysis. A series of three-dimensional finite element models were carried out. Part of the models was conducted on unreinforced kaolin clay, while the rest performed on kaolin with different bottom ash columns groups.

The physical and mechanical parameters for both the kaolin clay and the bottom ash columns are obtained from experimental testing conducted by Moradi et al. (2018). Moreover, the influence of area replacement ratio is investigated by using different ratios (13.1%, 19.6%, 26.2%, 32.7%, 39.3%).

PLAXIS 3D Foundation is a finite element software that is used for geotechnical engineering purposes and was utilized for this research. Mohr-Coulomb, Hardening soil and Soft soil models were used to simulate the ground model while Mohr-Coulomb model was used for bottom ash columns.

1.5 Research Outline

Chapter 1: This chapter describes the general background of the problem, including the problem statement, the research objectives and the research scope.

Chapter 2: This chapter comprised a brief description of the stone column technique and the finite element analysis, also a historical and relevant literature research works on the same field are reviewed in this chapter.

Chapter 3: This chapter presented the research methodology in general and the data collection method. It covered a discussion of the Finite Element Modelling used in this study, and the calculation steps that will be used.

Chapter 4: This chapter discusses and analyzes the modelling results in comparison with the previous experimental findings on the subject matter of soft clay reinforced with end-bearing bottom ash columns.

Chapter 5: This chapter summarises the study results obtained from numerical modelling tests that were discussed in the previous chapter, and the recommendation for future research.

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