# SETTLEMENT ASSESSMENT OF SOFT SOIL REINFORCED BY PARTIALLY PENETRATED BY SOIL CEMENT COLUMN

NUR AZLIN BINTI BAHARUDIN

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Faculty of Engineering
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## DEDICATION

***Especially dedicated to:***

**My Parents**

Mr. Baharudin Bin Md. Yassin and Madam Nurain Ong Abdullah

*For their support and love*

**My Family members**

Nur Zalikha Binti Baharudin & Nur Liyana Binti Baharudin

*For their encouragement*

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# ABSTRACT

Soil cement column technique is one of a widely used technique in ground improvement over the past 50 years. The technique involve process of soft soil replacement with mixed materials in order to increase the bearing capacity and reduce the settlement. A preliminary chart of both bearing capacity and settlement of soft soil improved by floating soil cement column were developed in this study. A series of numerical modelling were performed by PLAXIS 3D with different area improvement ratio, $ap$ and column height, $H_c$. Three (3) improvement area ratio $(a_p)$ of 20.7%, 31.0% and 41.0% and two (2) height of column were implemented which 50 mm and 100mm that is correspond to improvement depth ratio (ß) of 0.25 and 0.5. Another important parameter are cohesion ratio, $K_c$ and K. For analysis, two loading condition were applied on untreated and treated soils. The first load condition to identify ultimate bearing capacity or failure process. Firstly, condition of determined the ultimate bearing capacity. After that, the settlement analysis was performed by the used of working load of two third of ultimate load. The second load condition was conducted under design load to identify settlement and failure pattern. Then, a settlement charts were developed to predict the settlement of model treated with soil cement column. The 3D numerical results showed that the bearing capacity of soft soil increase with an increment of improvement area ratio ($a_p$), depth improvement ratio (ß) and cohesion ratio ($K_c$).As well as the settlement that reduced as the improvement area ratio ($a_p$), depth improvement ratio (ß) and cohesion ratio ($K_c$) increased. A non-dimensional analysis was also developed to fully understanding the behavior of soft soil improved by floating soil cement column.

**ABSTRAK**

Teknik tiang campuran tanah dan simen merupakan salah satu teknik pembaikan tanah yang paling banyak diaplikasikan sejak 50 tahun yang lalu. Teknik ini melibatkan penggantian tanah lembut dengan bahan-bahan campuran tanah dan simen bagi meningkatkan keupayaan galas dan mengurangkan enapan. Kajian in melibatkan penghasilan beberapa carta awalan bagi keupayaan galas dan carta enapan bagi tanah lembut menggunakan perisian asas *PLAXIS 3D* dengan nisbah penggantian luas dan panjang tiang yang berbeza. Tiga (3) nisbah penggantian luas iaitu 20.7%, 31% dan 41% dan dua (2) panjang tiang yang berbeza iaitu 50 mm dan 100 mm. Panjang tiang 50mm dan 100mm mewakili nisbah penggantian kedalaman 0.25 dan 0.5. Parameter penting yang terlibat dalam kajian ini adalah nisbah kejeleketan dan nilai tiada dimensi. Dua keadaan beban dikenakan ke atas tanah lembut yang tidak melalui pembaikan dan tanah lembut yang telah melalui pembaikan. Keadaan beban yang pertama adalah bagi mengenalpasti keupayaan galas tertinggi dan proses kegagalan bagi tanah lembut tersebut. Kemudian, analisis bagi enapan dijalankan dengan menggunakan dua per tiga daripada keupayaan galas tertinggi. Keadaan beban yang kedua dijalankan menggunakan beban tersebut bagi mengenalpasti enapan dan bentuk konsolidasi. Seterusnya, sebuah carta enapan dibentuk bagi mendapatkan jumlah enapan bagi tanah lembut yang tidak melalui pembaikan dan tanah lembut yang telah melalui pembaikan. Analisis berangka tiga dimensi menunjukkan bahawa peningkatan nisbah penggantian luas, nisbah penggantian kedalaman dan nisbah kejeleketan meningkatkan keupayaan galas bagi tanah lembut. Selain itu, analisis ini juga menunjukkan pengurangan enapan jika nisbah penggantian luas, nisbah penggantian kedalaman dan nisbah kejeleketan meningkat. Satu analisis berkaitan dimensi dijalankan bagi meningkatkan pemahaman tentang sifat tanah lembut ditambah baik melalui proses teknik tiang campuran tanah dan simen.

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| | | |
|---|---|---|
| $a_p$ | - | Improvement area ratio |
| B, $d_1$ | - | Width of footing |
| $c_{ua}$ | - | Average undrained shear strength of improved ground |
| $c_{uao}$ | - | Average undrained shear strength of improved ground on the top |
| $c_{uc}$ | - | Undrained shear strength of soil cement column |
| $c_{us}$ | - | Undrained shear strength of surrounding soil |
| $c_{usb}$ | - | Undrained shear strength of the native soil at the bottom of the improvement area |
| $c_{uso}$ | - | Undrained shear strength of the native soil at the top of the improvement area |
| $D$ | - | Depth of improvement area |
| $K_c$ | - | Relative cohesion ratio of the column to the soft soil |
| $L$, $d_2$ | - | Length of the footing |
| $N$ | - | Number of measurements (sample) |
| $N_c$ | - | Bearing capacity factor |
| $q_{ult}$ | - | Ultimate bearing capacity |
| $z$ | - | Depth below the soil surface |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Malaysia is working towards achieving a high-income status by 2020. This involves development of the economic structure. Construction industry is one of factors contribute to the development. There are several studies have shown the significant impact of construction industry to the national economic development (Myers, 2013). The heavy and civil engineering construction include the construction of road systems, railways, sewers, bridges and tunnel. The availability of stable soil in Malaysia is one of the main problem for any construction especially in the urban area. The demand for engineering profession especially in geotechnical engineering is increasing to overcome the problem. The common study before any construction are soil properties, cost effective and environmental aspects.

The soft soil has become a threat to the construction industry due to the incapability of the soil to sustain huge load and lead to failure. Construction foundations need to be on stable and strong soil. The usual issues involve in this type of soil are unsatisfactory bearing capacity, extra post construction settlement, instability on soil removal and embankment forming. In geotechnical engineering, the adequate soil engineering characteristics play a major role. Engineer's responsibility is to make sure sufficient properties of the soil by solve the mechanical and chemical problem of local soil. There are variety of methods such as displacement, replacement, reinforcement and stabilization are the approaches practiced to enhance the properties of soft soils. (Shahin *et al.*, 2011). The common practice in Malaysia for soil improvement are surface reinforcement, sand or stone column, preloading, prefabricated vertical drain, piles and chemical stabilization.

Generally, numerical analysis is related to mathematics and computer science that creates, analyse and implement algorithms for solving problems of continuous mathematics (Atkinson). Scientific computing and computational science has develop during 1980s and 1990s as parallel to the growth in the importance of using computer to carry out numerical procedure to solve problems. Numerical analysis is believed as a reliable method and excited field that offers the tools for solving geotechnical challenges according to Riahi (2009). Finite element analysis may be conducted to study the elastic settlement behaviour of foundation (Michael *et al*., 2014). Finite element can be carried out by using PLAXIS for the settlement analysis. The development of charts can be used to aid prediction in construction design.

## 1.2 Problem Statement

The rapid development of Malaysia with strong economic performance has led to massive infrastructure development (Zainorabidin & Wijeyesekera,2007). Roads, housing, drainage are considered as the infrastructure construction. These developments are delayed by a limited suitable land for engineering construction which is area with adverse ground condition such as soft soil and problematic soils. Generally, soft soil in Malaysia can be categorized in quaternary sediments consist of alluvial deposits and organic peat soil (Kaniraj & Joseph, 2006). Soft soils can be characterized as a soil with low strength, highly compressible and low permeability (Mohamad, *et al*., 2015) (Mohammed Al-Bared & Marto, 2017), (Ozdemir, 2016). There are many problems may occur during or after the construction phase such as slope instability, bearing capacity failure or excessive settlement due to low shear strength and high compressibility of the soil. Due to restricted usage of land used had forced for ground improvement such as preloading, preloading associated with vertical drains, reinforcement by columns or deep mixing technique. Deep mixing technique was introduced as new alternative to improve soft soils which are combination of low weight percentage of lime, cement or combination of both which is mixed in depth by specific equipment (Boussida, 2009).

Previous works on bearing capacity has been done related to deep mixing (DM) in the area of soil improvement include laboratory work, full-scale field test and analytical and numerical analysis. All prior research had focused on determination on ultimate bearing capacity of soft clay under vertical load. The behaviour of fully and partially penetrated columns with different improvement area $(a_p)$ and soil cement undrained shear strength$(c_{uc})$ has not been focused in previous study. Moreover, there are limited study on preliminary assessment technique for the feasibility of DM construction for a particular site. Therefore, this study aim to establish settlement design charts for soil reinforced by DM method using partially penetrated soil-cement columns.

## 1.3 Aim and Objectives

The aim of this study is to evaluate the preliminary assessment and establish he design charts settlement of partially penetrated soil cement column by considering several practical guidelines of DM construction. The following objectives are set to achieve the aim of the study:

i. To evaluate the effect of improvement area ratio $(a_p)$, improvement depth ratio (β) and cohesion ratio $(K_c)$ on bearing capacity and settlement of soft soil.
ii. To establish the preliminary design charts for settlement prediction of partially penetrated soil cement column of soft soil.

## 1.4 Scope of Study

In order to establish settlement design chart, numerical simulation will be perform using finite element analysis in PLAXIS 3D. Series of analyses will be completed from previous studies as a comparison template to validate the implementation of the finite element analysis.

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