UNIVERSITI TEKNOLOGI MARA

MODELLING SOFT SOIL REINFORCED WITH INFILLED CIRCULAR PREFABRICATED VERTICAL DRAIN BY CONSIDERING RADIAL CONSOLIDATION UNDER EQUAL STRAIN APPROACH

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ABSTRACT

Construction on soft clay commonly leads to excessive settlement, low bearing capacity and prolonged consolidation due to its high compressibility, low shear strength and poor drainage characteristics. Conventional Prefabricated Vertical Drains (PVDs) are widely used to accelerate consolidation by shortening the drainage path; however, they provide limited reinforcement and do not significantly reduce the final settlement magnitude. In contrast, stone columns and geotextile encased columns improve stiffness and bearing capacity but have limited drainage capability. To address these limitations, this study investigates an infilled circular Prefabricated Vertical Drain (icPVD) as a dual-function ground improvement system that integrates radial drainage and mechanical reinforcement under equal strain conditions. The study determines the physical and engineering properties of the soil and drain materials, investigates vertical stress distribution and settlement behaviour under time-dependent monotonic loading, verifies the behaviour using PLAXIS 2D numerical modelling, and develops empirical models for predicting the Stress Concentration Ratio (SCR). The research involved laboratory material characterisation, Rowe Cell tests, large-scale consolidometer tests, finite element modelling and multiple linear regression analysis using Minitab. The results show that the icPVD system improved stress redistribution and settlement control compared with untreated soil and geotextile-encased column systems. Under 30 kPa loading, icPVD recorded a settlement of 0.546 mm, corresponding to approximately 65.0% reduction compared with untreated soil. Under staged loading of 60, 120 and 240 kPa, the settlement of icPVD remained 19.8%, 14.2% and 14.9% lower than the GEC system, respectively. The icPVD also exhibited improved stress concentration behaviour, with SCR increasing from 3.2 at 30 kPa to a peak value of 5.2 at 120 kPa, indicating effective load transfer from the surrounding soft soil to the reinforced column. PLAXIS 2D successfully reproduced the observed stress distribution, pore pressure response and settlement behaviour, confirming the reliability of the numerical modelling approach. The developed SCR prediction models achieved high predictive accuracy, with R^2 values ranging from 89.69% to 96.42%; the best PC/PM-based model achieved R^2 = 96.42% and paired t-test p-value = 0.603. Overall, the findings demonstrate that icPVD can enhance soft clay performance through combined drainage, confinement and stiffness improvement, while the empirical SCR model provides a practical tool for predicting stress transfer behaviour in reinforced soft clay under radial consolidation conditions.

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CHAPTER 1
INTRODUCTION

1.1 Background

Soft soils, frequently found in coastal and riverine regions, present significant engineering challenges due to their high compressibility, low shear strength, and poor drainage characteristics. The construction of infrastructure on these deposits often leads to critical issues, including bearing capacity failures (Black et al., 2011; Marto et al., 2013; Nik Ab Aziz et al., 2015) and excessive long-term settlement (Ayadat & Hanna, 2005; Black et al., 2011). As the demand for infrastructure development in these challenging regions increases, the need for robust and efficient ground improvement techniques has become paramount.

To mitigate these issues, various reinforcement and drainage strategies are widely implemented. Prefabricated Vertical Drains (PVDs) are frequently installed to accelerate primary consolidation by shortening the radial drainage path; however, they do not inherently reduce the total magnitude of settlement. Conversely, mechanical inclusions like Stone Columns (SC) are utilised to increase the bearing capacity and stiffness of the foundation. Yet, when installed in extremely soft soils, ordinary stone columns often fail due to excessive lateral bulging. Encasing these columns with geosynthetics to create Encased Stone Columns (ESC) provides the necessary lateral confinement, increases column stiffness, and prevents bulging (Murugesan & Rajagopal, 2006). While ESCs significantly reduce settlement and exhibit higher Stress Concentration Ratios (SCR) compared to unencased columns (Khabbazian et al., 2010), they can still suffer from prolonged consolidation times if internal drainage is not optimized.

To harness the dual benefits of accelerated drainage and mechanical reinforcement, integrated composite systems such as the infilled circular prefabricated vertical drain (icPVD) have emerged. In this system, the drain acts simultaneously as a radial conduit for pore water expulsion and as a confined structural inclusion to transfer applied loads. Unlike conventional prefabricated vertical drains that primarily function