PERFORMANCE PREDICTION OF PREFABRICATED VERTICAL DRAINS BENEATH EMBANKMENT ON SOFT GROUND BY FINITE ELEMENT ANALYSIS

THANATH GOPALAN

A project report submitted as a partial fulfilment of the
requirement for the award of the degree of
Master of Engineering (Civil-Geotechnics)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JULY 2010

To my loved ones

ACKNOWLEDGEMENT

Firstly, I would like to extend and express my sincere gratitude to my supervisor, Professor Dr Aminaton bt Marto, for her valuable comments and on all occasions having the time to explain and provide relentless advice.

My heartfelt and sincere appreciation is also extended to management and engineers of SSP Geotechnics for providing all the necessary data required for this project.

My gratitude also goes to all my fellow classmates and friends whom have provided assistance in various numerous occasions. It is hoped that they achieve success in all their undertakings.

Without my family's support and encouragement, it would not be possible to have completed my study. My wholehearted appreciation and thankfulness goes to my loved ones.

ABSTRACT

Preloading and prefabricated vertical drain (PVD) is a commonly employed ground improvement technique to expedite consolidation process by means of shortening the drainage path. Advancement in finite element method (FEM) analysis has enabled modeling of PVD in finite element program to acquire settlement magnitudes and time rate of consolidation. Monitoring results in particular settlement data from two adjacent zones were analyzed using Asaoka (1978) method estimating the total settlement and back-calculated coefficient of horizontal consolidation of the soil. Thereon, using the back analyzed coefficient of consolidation, computer program PLAXIS v.8 was used to estimate the total settlement and rate of consolidation by means of finite element method (FEM). Reasonable agreement of settlement curves were obtained between the FEM analysis and actual field settlement of the PVD treated ground. However, in FEM analysis, it was observed that the ultimate settlements predicted were less than those determined by Asaoka method, but the degree of consolidation achieved were higher. The horizontal coefficient of consolidation was determined to be in the range of 1.4 m^2/yr to 2.6 m^2/yr which generally encompasses the conventional design c_h/c_v ratio of 2. Sensitivity study of the soil horizontal permeability to smeared zone permeability, k_h/k_s ratio generally indicates that as the ratio exceeds 4, the predicted settlement is underestimated significantly.

ABSTRAK

Saliran tegak pra-fabrikasi (PVD) berserta pra-bebanan surcaj merupakan suatu kaedah biasa yang digunapakai bagi mempercepatkan proses pengukuhan tanah liat. Kemajuan dalam kod unsur terhingga membolehkan enapan serta masa yang diperlukan bagi enapan diperolehi mengunakan program kod unsur terhingga. Rekod enapan khususnya dari dua zon berhampiran telah dianalisis dengan kaedah Asaoka (1978) untuk meramal enapan maksima serta analisis-kembali nisbah pekali pengukuhan dalam arah mendatar. Program PLAXIS v.8 digunakan untuk meramal enapan maksimum serta kadar pengukuhan tanah lembut dengan kaedah unsur terhingga. Nilai yang diperolehi antara enapan yang direkod di tapak dan yang diramal mengunakan program unsur terhingga adalah berdekatan dan munasabah. Namun demikian, telah diperhati bahawa enapan maksima yang diramal mengunakan kaedah unsur terhingga adalah kurang daripada yang ditentukan menerusi kaedah Asaoka, tetapi darjah pengukuhan tanah yang didapati mengunakan kaedah unsur terhingga adalah lebih tinggi. Nisbah pekali pengukuhan dalam arah mendatar yang diperolehi berada dalam julat 1.4 m^2/tahun ke 2.6 m^2/tahun yang secara lazimnya berada dalam lingkungan biasa c_h/c_v nisbah 2. Kajian parametrik yang dijalankan dengan nisbah k_h/k_s menujukkan bahawa semakin meningkat nisbah k_h/k_s, semakin rendah ramalan enapan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

c_c	-	Compression index
c_r	-	Recompression index
CR	-	Compression ratio
RR	-	Recompression ratio
e	-	Void ratio
P_c	-	Preconsolidation Pressure
c_v	-	Coefficient of vertical consolidation
c_h	-	Coefficient of horizontal consolidation
d_m	-	Equivalent mandrel diameter
d_w	-	Equivalent drain diameter
D_e	-	Diameter of equivalent soil cylinder of vertical drain
H_d	-	Length of drainage path
$F(n)$	-	Vertical drain spacing factor
F_r	-	Well resistance factor for vertical drain
F_s	-	Smear effect factor
q_w	-	Discharge capacity of PVD
k_h	-	Soil horizontal permeability
k_v	-	Soil vertical permeability
k_s	-	Smeared soil permeability
k_{ve}	-	Equivalent vertical permeability
k_{hpl}	-	Horizontal permeability of undisturbed zone in plane strain
U	-	Degree of consolidation
U_v	-	Degree of consolidation in vertical direction
U_h	-	Degree of consolidation in horizontal direction
T_v	-	Dimensionless time factor for vertical consolidation
T_h	-	Dimensionless time factor for radial consolidation

β	-	Slope in Asaoka's plot
Δ	-	Difference
γ	-	Unit weight of soil
c_u	-	Undrained shear strength
ω	-	Dilatancy angle of soil
ϕ	-	Friction angle of soil
E	-	Young's modulus
υ	-	Poisson's ratio

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

In a land where thick soft compressible layers predominate, it is almost always a concern if a satisfactory level of service can be provided. Commonly, this serviceability criteria is benchmarked to the maximum allowable post construction settlement of the constructed platform. With the rapid increase of population and accompanying demands of developments and infrastructures, rather unfavourably it has resulted in coastal reclamation and construction on low-lying lands, which comprises of compressible soils. The pre-existing subsoil if subjected to external loading for instance an embankment would cause significant magnitude of consolidation settlement to occur over a considerable time frame.

As to resolve this problem and ensure serviceability, precompression or preloading with prefabricated vertical drains are usually selected as the soft ground improvement method attributed to its cost-effective factor. Preloading refers to the process of compressing the underlying soils under an applied vertical stress prior to placement of the final construction load whereas prefabricated vertical drains are artificially created drainage paths that has a sole purpose of shortening the drainage path thereby accelerating the rate of primary consolidation settlement. Principally, the time rate of consolidation are governed by the thickness and intrinsic properties of underlying compressible soil besides the deliberated arrangements and characteristics of the vertical drain.

Hansbo (1981) derived an approximate solution for vertical drain based on the ‘equal strain hypotheses by Baron’s (1948) solution’ by taking both smear and well resistance into consideration. Presently, this analytical approach is the widely used method in the design of vertical drains. Further development to reflect the axisymemetric condition of vertical drain in plane-strain condition to employ a realistic two-dimensional finite element analysis for vertical drains was established by Indraratna and Redana (1997), Lin *et al.* (2000) Chai *et al.* (2001) and others. This method enables a less restrictive and comprehensive analysis to be carried out in comparison to the analytical method.

1.2 Problem Statement

It is irrefutable that numerous projects have been or are being completed by integrating the preloading and prefabricated vertical drain as the soft ground improvement method. The design may be by analytical, finite element analysis or mere empirical, subject to the preference and proficiency of the designers. Whichever method is used, the accuracy of soil investigation works and adequacy of acquired information is of paramount importance in producing an unambiguous design that later matches field measured observations. This is vital in verifying the design approach, especially by the finite element analysis as it is relatively newly developed.

Only a handful of investigation and study on the performance of ground treated by preloading and prefabricated vertical drain using the finite element analysis approach has been documented. As always in scientific endeavour, theories are often subject to peer review and assessment. Hence, the effectiveness in practise of modelling prefabricated vertical drains in soft compressible soils must be evaluated and assessed.

1.3 Objectives of study

It is intended that this study will contribute to the field of Civil-Geotechnical Engineering, particularly in finite element modelling of soft soils improved by means of preloading and prefabricated vertical drains. The objectives of this study are outlined in the following:

1. To predict and compare settlement of embankment over soft ground treated with preloading and Prefabricated Vertical Drains (PVD) obtained by finite element modelling and field instrumentation measurements.

2. To verify the performance of PVD by back analysis determination of the horizontal consolidation coefficient.

3. To determine the effects of undisturbed horizontal permeability and smeared zone permeability ratio on the magnitude and rate of consolidation modelled in FEM analysis.

1.4 Scope and Limitation

The case study is based on a project that involved reclamation works for a development on a piece of soft ground in the coastal area of Pulau Indah, Klang. The instrumentation monitoring data are limited to only the settlement monitoring data. Thus neither the dissipation of excess pore water pressure nor estimation of lateral movement of soil is included in this study.

FEM analyses are carried out using commercial 2D finite element program, PLAXIS *v*8. The soil constitutive models used in this study are limited to Mohr-Coulomb (MC) and Soft Soil (SS) models which are offered by PLAXIS *v*8. Also, this study focuses and utilizes only on the permeability matching procedure proposed by Lin *et al*. (2000) to establish the equivalence between axisymmetric and plane strain conditions prior to FEM modelling.

1.5 Significance of Study

This study presents the prediction performance of a ground improvement work namely prefabricated vertical drains with finite element modelling. It is aimed at verifying and validating the efficacy of prediction by finite element method using appropriate conversion techniques to establish a two dimensional flow which in reality is three dimensional.

Through this study, an appropriate modelling technique can be ascertained, in regard of convenience as well as accuracy of prediction by finite element modelling. Also, the effects of undisturbed horizontal permeability to the smeared zone permeability ratio will be evaluated in regard to the magnitude and time rate of consolidation to gauge its variance effect in consolidation analysis by finite element method.