IMPROVEMENT

GROUND IMRPOVEMENT ON LAND RECLAMATION PROJECT-PREFABRICATED VERTICAL DRAIN WITH PRE-LOADING

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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
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2020

DEDICATION

Dedicated to my beloved family, beloved Lin and friends that always support and encourage me during the tough path. Thank you so much.

ACKNOWLEDGEMENT

I would like to thank everyone who had contributed to the successful completion of this project. First at all, I would like to express my sincere gratitude to my company Benalec Holdings Berhad especially my Chief Operating Officer Ir. Yap Lee Chor for his professional and invaluable technical advice regarding the technology and method of construction for land reclamation and ground improvement project. I'm able to gain a lot of knowledge of geotechnical engineering in this company.

I would also like to express my appreciation to my supervisor, Dr. Siti Norafida Binti Jusoh for her invaluable advice, guidance and enormous patience throughout the development of the project.

Lastly, I would like to express my gratitude to my loving parent, my beloved Lin and friends who had helped and given me encouragement. Thank you for those who always physically and psychological supporting, motivating, directing and coaching me.

ABSTRACT

The presence of soft marine clay deposits makes the land reclamation become a great challenge in the field of geotechnical engineering due to the nature of high compressibility, excessive settlement characteristic and low shear strength. Ground improvement works in the ongoing Tanjung Piai Maritime Industrial Park (TPMIP) reclamation project comprise the installation of prefabricated vertical drains (PVDs) with preloading and subsequent placement of sand surcharge to improve and accelerate the consolidation of the underlying compressible soils. Therefore, the desired degree of consolidation have to be achieved or ascertained prior to the surcharge removal in such ground improvement projects. The ultimate settlement can be predicted by both empirical analysis (Terzaghi's theory of one-dimensional consolidation) and numerical analysis (Finite Element Modelling), and subsequently compared with the field settlement monitoring results (Asaoka Method). The predicted magnitude of ultimate settlement obtained from empirical analysis is 2141 mm whereas ultimate settlement obtained from numerical analysis is 2298 mm showing that 2% and 8.5% respectively higher than ultimate settlement predicted from Asaoka's plot. The results obtained from both empirical analysis and numerical analysis approach reflects that consolidation settlement calculation showing a good agreement on both methods. However, it was expected that the different rate of consolidation settlement is inevitable due to certain constraint in applying the soil parameters which obtained from the ground investigation works. Therefore, the actual monitoring results should reflect the actual soft ground condition and the designer can deploy theoretical calculation in consolidation settlement analysis for future works.

ABSTRAK

Kehadiran tanah liat marin yang lembut membuatkan aktiviti penambakan menjadi satu cabaran yang besar di dalam bidang kejuruteraan geoteknik kerana sifat pemampatannya yang tinggi, ciri-ciri pemendapan yang tinggi dan kekuatan ricih yang rendah. Kerja-kerja penambahbaikan tanah di projek penambakan Tanjung Piai Maritime Industrial Park (TPMIP) yang kini sedang berjalan telah merangkumi pemasangan “Prefabricated Vertical Drains (PVDs)” iaitu dengan pra pengisian dan penempatan surcaj pasir untuk meningkatkan dan mempercepatkan pembentukan tanah yang mampat. Oleh yang demikian, tahap pembentukan tanah yang diinginkan boleh dicapai atau dikenalpasti berdasarkan pembuangan surcaj di dalam projek pembaikan tanah tersebut. Kadar pemendapan tanah yang tertinggi dapat diramalkan menerusi dua jenis analisis iaitu analisis empirikal (Teori Terzaghi mengenai pembentukan satu dimensi) dan analisis numerikal (Pemodelan Finite Elemen), dan kemudiannya hasil analisis itu dibandingkan dengan hasil pemantauan pemendapan kawasan projek (Kaedah Asaoka). Ramalan kadar tertinggi pemendapan tanah yang diperoleh dari analisis empirik adalah 2141 mm manakala kadar pemendapan tanah tertinggi yang diperoleh dari analisis numerikal adalah 2298 mm yang menunjukkan 2% dan 8.5% lebih tinggi daripada kadar tertinggi pemendapan tanah yang diramalkan dari plot Asaoka. Keputusan yang diperoleh dari analisis empirikal dan analisis numerikal menunjukkan bahawa pengiraan kadar tertinggi pemendapan tanah antara kedua-duanya mempunyai persamaan yang rapat. Namun, kadar pemendapan tanah dijangka akan berbeza disebabkan oleh batasan tertentu dalam penggunaan parameter tanah yang telah diperolehi dari hasil penyelidikan kerja tanah. Kesimpulannya, keputusan pemantauan pemendapan tanah yang terhasil seharusnya mencerminkan realiti sebenar keadaan tanah di kawasan tersebut dan pereka/juru perunding boleh menggunakan pengiraan teori tersebut bagi analisis pembentukan pemendapan tanah pada masa akan datang.

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LIST OF ABBREVIATIONS

PVD	-	Prefabricated Vertical Drain
TPMIP	-	Tanjung Piai Maritime Industrial Park
FEM	-	Finite Element Modelling
FEA	-	Finite Element Analysis
PWP	-	Pore Water Pressure
SI	-	Soil Investigation
SPT	-	Standard Penetration Test
CPT	-	Cone Penetration Test
BH	-	Borehole
CD	-	Chart Datum
FV Test	-	Field Vane Shear Test
UU Test	-	Unconsolidated Undrained Triaxial Compression Test
UCT	-	Unconfined Compression Test
SP	-	Settlement Plate

LIST OF SYMBOLS

σ_o'	-	Initial effective stress
$\Delta\sigma'$	-	Stress increment
H	-	Thickness of the compressible layer
H_d	-	Length of drainage
T_v	-	Time factor
C_v	-	Coefficient of consolidation
U	-	Degree of consolidation
U_h	-	Average degrees of consolidation in horizontal directions
U_v	-	Average degrees of consolidation in vertical directions
F	-	Factor influencing the consolidation
$F(n)$	-	Drain spacing factor
F_s	-	Smear factor
F_r	-	Well resistance factor
r	-	Radial
t	-	Time
c_h	-	Horizontal coefficient of consolidation
D_e	-	Soil cylinder equivalent diameter
d_w	-	Drain equivalent diameter
n	-	Ratio of spacing
b_w	-	Half width of the drains
b_s	-	Half width of smear zone
a	-	Width of the PVD
b	-	Thickness/width
u_o	-	Initial pore pressure
u	-	Pore pressure at time *t* (average values)
T_{hp}	-	Time factor in plane-strain
Khp	-	Undisturbed horizontal permeability
$K'hp$	-	Corresponding smear zone
q_z	-	The equivalent plane-strain discharge capacity
q_w	-	Drain discharge capacity

r_e	-	The radius of the influence zone
r_w	-	The equivalent radius of the vertical drain
r_s	-	The smear effect radius
k_h	-	Horizontal permeability of the undisturbed soil
k_s	-	Horizontal permeability of the soil within the smear zone
k_{hpl}	-	Horizontal permeability of undisturbed zone in a plane-strain unit cell
k_{hax}	-	Horizontal permeability of undisturbed zone in axisymmetric unit cell
k_{sax}	-	Horizontal permeability of smear zone in the axisymmetric unit cell
n_i	-	Influence ratio
s	-	Smear ratio
R	-	Well resistance factor
L	-	Discharge length
Cc	-	Compression index
Cr	-	Compression ratio
RR	-	Recompression ratio
Pc	-	Pre-consolidation pressure
β*1*	-	Slope in Asaoka's plot
φ	-	Friction angle of soil
c	-	Cohesion of soil
E	-	Young Modulus of soil
ψ	-	Angle dilatancy of soil
ν	-	Poisson's ratio
λ*	-	Modified compression index
κ*	-	Modified swelling index

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In the past two decades, there has been an increasing number of coastal land reclamation projects for residential, commercial, industrial and tourism development in many of the more developed coastal areas of Malaysia (Shahrizaila and Hiew, 1997). Most of the proposed coastal reclamation works are located along the west coast of Peninsular Malaysia where the sub soils consist of very soft marine clay. In general, the presence of soft marine clay deposits makes the land reclamation become a great challenge in the field of geotechnical engineering. Many engineering problems in the form of slope instability, bearing capacity failure or excessive settlement could occur either during or after the construction phase due to low shear strength and high compressibility of this soil (Mohamad et al, 2016).

The combination of prefabricated vertical drain (PVDs) with preloading ground improvement technique was successfully applied in this project to improve the underlying compressible soils. The project comprises the installation of prefabricated vertical drains and the subsequent placement of surcharge to accelerate the consolidation of the underlying marine clay. This methods have the great potential benefits in improving soft soil deposit by accelerating the consolidation process and had been used worldwide for highway, airport and so on (Lo et al.,2008; Liu and Chu, 2009; Saowapakpiboon et al.,2011; Artidteang et al., 2011; Indraratna et al., 2011).

Significant progress in the design of vertical drains for accelerating consolidation of foundation soils has been made in the past two decades through theoretical analysis, laboratory and field performance observations (Hansbo et al. 1981, Holtz et al. 1991, Bergado 1996 and Chai 1999). The Terzaghi's theory of one-dimensional consolidation is commonly adopted to predict the magnitude of ground settlement. However, the stress-strain relationship of the soil is very complicated to analyse where the soil is anisotropic, heterogeneous and non-elastic, therefore Finite Element Modelling (FEM) is necessary to be used for the multi-dimensional analysis (Saputro et al, 2018). Besides that, observation method like Asaoka's method (1978) was implemented for the prediction of ultimate settlement based on the monitoring data. The accuracy of the field data and laboratory test result is one of the major parameter inputs to reflect the real condition of the site which play an important role in design and back analysis with the field monitoring results. In this study, the ground settlement was predicted by both empirical method and finite element method. Subsequently, the settlement results which modelled by using PLAXIS 2D finite element modelling (FEM) were compared with field settlement results which is predicted by Asaoka's method.

1.2 Problem of Statement

Tanjung Piai Maritime Industrial Park (TPMIP) project consists of approximately 3,485 acres of land reclaimed located on low-lying swampy coastal land near the southern tip of west coast Peninsular Malaysia as shown in Figure 1.1. This land reclamation project required area that are currently submerged to be raised to levels permanently above the sea level. The site is underlain by superficial deposits of recent to sub-recent age alluvium (Geological Survey of Malaysia, 1973). The upper soil stratum comprising very soft to soft marine clays and up to about 25 m thick. A detailed of soil investigation and laboratory tests were carried up in order to obtain the soil parameters for detailed engineering design of the proposed land reclamation project.

Prefabricated vertical drain (PVDs) with preloading and subsequently surcharge method was chosen as a ground improvement method in an attempt to accelerate the excess pore water pressure in saturated soft clay prone to excessive settlement. The adopted design is based on well-established empirical relationships for soft ground engineering and Plaxis 2D finite element modelling. A series of instrumentation tools such as settlements plates, surface markers, inclinometers and piezometers were installed in order to monitor the performance of ground improvement work as well as to validate the efficiency of the prefabricated vertical drain system and the degree of consolidation.

This study presented the geotechnical aspects of the design of the ground improvement method, an evaluation of the ground improvement works through field monitoring, and findings from the field monitoring regarding consolidation with prefabricated vertical drains. Ultimate settlements were predicted by the field settlement results Asaoka's method and finite element method Plaxis 2D. Settlement monitoring data were then continuously reviewed and compared with the predicted settlement to validate the efficiency of the prefabricated vertical drain (PVDs) and the rate of consolidation.

Figure 1.1 Tanjung Piai Maritime Industrial Park (TPMIP)

1.3 Objectives of Study

1. To study and interpret the geotechnical data obtained from the soil investigation report.
2. To predict the rate of settlement over the soft ground with the preloading and Prefabricated Vertical Drain (PVD) based on empirical analysis.
3. To validate the efficiency of the prefabricated vertical drain (PVDs) by using numerical modelling of PLAXIS 2D in terms consolidation rate and settlement.
4. To compare the predicted ultimate settlement of the reclaimed land with PVD installation between Finite Element Modelling (FEM) and field settlement monitoring data.

1.4 Scope and Limitation of the Study

This study will focus on the analysis of the soft ground behaviour with the installation of Prefabricated Vertical Drain (PVDs) in term of the consolidation settlement by carrying out the empirical analysis to verify the developed numerical modelling. The laboratory test data are analysed in detail based on the soil investigation report. Relevant parameters were obtained and interpreted with respect to the case study. The scopes of the study are listed as below:

i. The scope of the analysis and discussion are limited to the settlement criteria. Other design criteria such as bearing capacity and slope stability are not being discussed in detail.

ii. Factors of influencing the vertical drain efficiency such as smear effect and well resistance will be briefly mentioned in the part of the literature review, however, it were not concluded into the scope of this study.

iii. Other instrumentation results such as inclinometers and piezometers are not discussed in this study.

iv. The time required for 90% consolidation between finite element analysis and field instrumentation monitoring is compared.

1.5 Significant of Study

In this study, empirical analysis and finite element analysis will estimate and predict the settlement of the PVD treated reclaimed land. Accuracy of the settlement estimation of finite element method will be verified and validated with the completed field data and precise assumptions on soil condition in the field. The comparison between the finite element analysis and field settlement monitoring data would enable the prediction of the time rate settlement for the projects in future.

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