COMPARISON BETWEEN PREDICTED AND OBSERVED SETTLEMENT OF VERTICAL DRAIN TREATED ROAD EMBANKMENT ON SOFT CLAY

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil-Geotechnics)

Faculty of Civil Engineering
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MAY 2006

To my beloved family

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, academicians and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my project supervisor, Associate Professor Dr. Hajah Aminaton Marto, for encouragement, guidance, critics and motivation. I am also very thankful to my Programme Coordinator, Dr. Nurly Gofar, Director of GCU Consultants Sdn. Bhd., Ir E.G. Balakrishnan, Director of Minconsult Sdn. Bhd., Ir Rose Ganendra, Manager of Geotechnical Division of Minconsult Sdn. Bhd, Dr. M.V.Nagendra and Chief Resident Engineer of Minconsult Sdn. Bhd., Ir. Benedict Indran for their support, guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Last but not least, I am very much grateful and indebted to my mother Puan Hajah Hasnah Ab Rahman, my dad Tuan Haji Ahmad Asif, my wife Puan Rohaya Che Ghani and all my family members, for their support, patience and understanding.

ABSTRACT

Prefabricated Vertical Drain (PVD) with surcharge preloading is one of the most widely used techniques to accelerate the process of consolidation. In practice it is sometime difficult to choose proper design parameters in PVD design. Back-analysis from field records is a good method to verify the design parameters. This study was undertaken to compare the predicted and monitored settlement of a road embankment on soft clay treated with PVD. Back-calculation of the design parameters was performed based on the available monitoring records. Magnitude of settlement was calculated using the classical one-dimensional consolidation theory. The monitored settlement was then evaluated using Asaoka's method. Terzaghi-Hansbo's solution was adopted in predicting the time-rate of consolidation with the application of PVD. The analysis and comparison between field and laboratory (or theoretical) value of the settlement design parameters show that the coefficient of volume compressibility m_{vlab}=1.25m_{vfield}, compression ratio CR_{lab}=1.19CR_{field}, and the ratio of coefficient of horizontal to the vertical consolidation c_h/c_v= 1.6. c_h from piezocone dissipation test was found to be 3 times larger than the back-calculated c_h value. The study also suggests that smear effect is a factor which cannot be ignored in the design of PVD.

ABSTRAK

Saliran tegak pra-fabrikasi (PVD) dan pra-bebanan surcaj merupakan salah satu kaedah yang telah digunapakai secara meluas bagi mempercepatkan proses pengukuhan tanah liat lembut. Secara praktikal, kadangkala adalah sukar untuk memilih parameter-parameter yang sesuai dalam merekabentuk PVD. Analisis-kembali rekod-rekod di tapak merupakan kaedah yang baik untuk mengesahkan parameter-parameter rekabentuk yang digunakan. Kajian ini dilaksanakan untuk membandingkan enapan ramalan dan enapan yang direkodkan di tapak bina sebuah tambak jalan yang dibina di atas tanah liat yang diperbaiki dengan PVD. Analisis-kembali parameter rekabentuk dilaksanakan berdasarkan rekod cerapan enapan di tapak yang sedia ada. Jumlah enapan ramalan dikira menggunakan teori pengukuhan satu-dimensi. Enapan yang dicerap kemudiannya dianalisa menggunakan kaedah Asaoka. Penyelesaian Terzaghi-Hansbo digunapakai dalam meramalkan kadar-masa pengukuhan bilamana PVD digunakan. Analisis dan perbandingan parameter rekabentuk dari ujikaji makmal dan parameter dari analisis-kembali menunjukkan bahawa pekali kebolehmampatan isipadu, m_{vlab}=1.25m_{vfield}, nisbah mampatan CR_{lab}=1.19CR_{field}, dan nisbah pekali pengukuhan dalam arah mendatar terhadap pengukuhan dalam arah menegak c_h/c_v= 1.6. c_h dari ujian lesapan *piezocone* adalah 3 kali lebih tinggi dari c_h yang diperolehi dari analisis-kembali. Kajian ini juga telah menunjukkan bahawa kesan lumuran merupakan faktor yang tidak boleh diabaikan dalam rekabentuk PVD.

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C_c	-	Compression index
C_s	-	Swelling index
C_r	-	Slope on recompression curve
CR	-	Compression ratio
C_α	-	Coefficient of secondary compression
$C_{\alpha\varepsilon}$	-	Secondary compression index
c_v	-	Coefficient of consolidation (vertical drainage)
c_h	-	Coefficient of consolidation (horizontal drainage)
d_m	-	Equivalent mandrel diameter
d_w	-	Equivalent diameter of drain
D_e	-	Diameter of the equivalent soil cylinder (for vertical drain)
e	-	Void ratio
$F(n)$	-	Vertical drain spacing factor
F_r	-	Well resistance factor for vertical drain
F_s	-	Smear factor for soil disturbance
G	-	Shear modulus
H_d	-	Length of drainage path
H_o	-	Initial thickness of compressible layer
I_r	-	Rigidity index
k	-	Coefficient of permeability
m_v	-	Coefficient of volume compressibility
P_c'	-	Preconsolidation pressure
q_w	-	Discharge capacity of vertical drain at an hydraulic gradient of unit
r	-	Radius
RR	-	Recompression ratio
S	-	Drain spacing

S_c	-	Consolidation settlement
S_i	-	Immediate/elastic settlement
S_t	-	Total settlement
S_u	-	Undrained shear strength
t	-	Time
T_v, T_h	-	Dimensionless time factor for vertical, horizontal flow direction
u	-	Pore water pressure
U	-	Degree of consolidation
z, L	-	Distance, length
σ, σ'	-	Applied stress, effective stress
β	-	Slope in Asaoka's plot
Δ	-	Difference
γ	-	Unit weight

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Construction of embankment fill on soft cohesive soils with low permeability will generally induce consolidation settlement to take place. Depending on the thickness of the compressible stratum and its engineering characteristics, consolidation settlement may take a few weeks to years to cease. It is necessary to analyse both the magnitude and time-rate of settlement of the subsoil supporting the embankment so that the settlement in the long run will not influence the serviceability of the embankment.

The geotechnical design criteria for road embankment as specified by the Public Works Department (JKR) in the Arahan Teknik Jalan 20/98 require:

i. Total post construction settlement < 250mm

ii. Differential settlement < 37.5mm

In order to ensure that the above criteria can be met and the construction of road embankment can be completed within the time frame specified, it is sometimes necessary that the ground to be treated or improved.

Prefabricated Vertical Drains (PVD), or sometimes referred to as band or wick drains, have been widely used in Malaysia as a means to accelerate primary consolidation settlement. PVD is also installed in order to gain rapid strength increase to improve the stability of structures on weak clay subsoil.

Bergado *et al.* (1996) defined PVD as any prefabricated material or product consisting of synthetic filter jacket surrounding a plastic core having the following characteristics: a) ability to permit porewater in the soil to seep into the drain; b) a means by which the collected porewater can be transmitted along the length of the drain. The filter jacket prevents the surrounding soil from entering the central core but allows free entry of excess pore water to the core. The plastic core supports the filter jacket and provides longitudinal flow paths along the drain even at large lateral earth pressures.

Yee (2000) reported that the ease, rapidity and economy of the drain installation coupled with cheap readily available vertical drain material have made this method in combination with surcharging a much more useful and cost-effective ground improvement technique. PVD is normally combined with surcharge preloading method in order to minimise or even eliminate the compressibility of weak ground prior to placement or construction of any structure on top of the ground or the completed formation.

In this method, pore water pressure is squeezed out during the consolidation of the clay due to the hydraulic gradients created by the preloading. Pore water can flow a lot faster in the lateral direction toward the drain and then flow freely along the drains vertically towards the permeable drainage layers. PVD reduces the length of the drainage paths and hence reducing the time to complete consolidation process.

Although the design procedure of vertical drains is relatively simple, there are other considerations that need to be taken into account in the design and construction process. The design and the performance of PVDs should also be verified by field instrumentation records.

1.2 Statement of the Problem

The test for some of the design parameters are not normally being carried out during Subsurface Investigation (SI) stage, unless special provisions are made. With the inadequate data, some of the design parameters are usually being assumed based on published literatures and from experience. If inappropriate assumptions are made, Site Engineers will often face a problem that the actual recorded settlement behaviour with the application of PVD improvement method differs from the predicted or theoretical values.

A lot of data from road and development projects adopting PVD for improvement of subsoil condition can be used to back-calculate the settlement parameters and for other analysis purposes. These data which includes subsurface investigation and instrumentation monitoring reports coupled with literature review are very useful for analysing and investigating the main factors influencing PVD behaviour and to verify the design parameters.

A road project in Kampar, Perak has adopted PVD with preloading as one of the ground improvement method for the construction of the road embankment. Part of the road alignment traverse through ex-mining pond area. Site investigation works carried out during the preliminary stage reveals that subsoil at the pond area consists of soft clay of varying thickness. Upon completion of the pond filling work, PVDs were installed in order to expedite the consolidation of the soft clay material underneath. Dynamic Compaction was carried out upon completion of the PVD work to ensure that the sand material for the pond filling work is able to achieve the required density. Series of instrumentation program were installed in order to monitor the performance of the PVD treated road embankment.

1.3 Objectives of the Study

The objectives of this study are listed below:

i. To predict the magnitude and time-rate of settlement by adopting Terzaghi's consolidation theory and Hansbo's solution for PVD consolidation.

ii. To determine the back-calculated design parameters, such as the compression ratio, $CR = C_c/1+e_0$, the coefficient of volume compressibility, m_v and the coefficient of horizontal consolidation, c_h.
iii. To determine the correlation between back-calculated c_h and c_h obtained from piezocone (CPTU) dissipation test.
iv. To analyse the dissipation of excess pore water pressure from piezometer record.

1.4 Scope and Limitation of the Study

This is a case study based on actual road project at Kampar, Perak. The subsoil condition, loading type, method of construction, instrumentation system and the PVD being studied are specific to this project. 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.

Evaluation of the performance was carried out based on the available monitoring records and by other site records. Back analysis of settlement data from field monitoring was carried out by adopting Asaoka's (1978) method.

Limited Subsurface Investigation (SI) data and instrumentation records were available in order to make better interpretation and generalisation. Laboratory facility was not available to carry out any testing for verification or for other purpose.

Calculation being carried out using hand calculation and for more rigorous analysis *Microsoft Excel* spreadsheet program was used. FEM analysis was not adopted due to difficulty in the selection of the appropriate soil parameters.

The effect of the Dynamic Compaction works on the installed PVD, movement trends of each layer underneath the ground and the lateral displacement of the embankment are not possible to be evaluated in this study due to the absence of the relevant instrumentation for monitoring purpose.

1.5 Significant of the Study

The back-calculated design parameters and other relationships suggested in this study will be of particular value and will give some indications on parameters to be adopted when predicting the settlement of PVD treated embankment in similar site situation. Factors influencing the performance of the PVD treated embankment and the monitoring records discussed in the study will give guidance on appropriate design and installation methodology for PVD.