# COMPARISON BETWEEN PREDICTED AND OBSERVED COMPRESSIBILITY CHARACTERISTICS OF TREATED SOIL USING PRECOMPRESSION AND VERTICAL DRAIN

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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

Universiti Teknologi Malaysia

JUNE 2010

To my beloved husband, sons and daughter..

## AKNOWLEDGEMENT

During preparing this thesis, I was in contact with many people, academicians and practitioners. They have contributes towards my understanding and thoughts. I wish to express my sincere appreciations to my supervisor, Associate Professor Dr Kamarudin Ahmad, for encouragement, guidance, critics and motivation. I am also thankful to my program coordinator, Associate Professor Dr Nurly Gofar and Ir Azizan, Resident Engineer of UTHM Development Project, for their support and advice. I would also to express my gratitude to Dr Ir Ramli Nazir for providing me a data which is very important to my thesis. Without his help, the data for the project would not be available for analysis. My appreciation also extends to all my colleagues especially to Thanath, Vicky and Zalina who have provided assistance in all occasions. Their views and opinion are useful indeed. Last but not least, I am very grateful and indebted to my beloved husband Razali Kassim, my beloved mother Pn Halijah Mahmood and my dad En Zukri Majid and all family members for their support, patience and understanding.

# ABSTRACT

Prefabricated vertical drain, PVD with preloading is one of the widely used techniques to accelerate the consolidation process in ground treatment program. Sometimes, it is very difficult to choose proper design parameters during design stage. Therefore, back analysis from field records is a means to verify these design parameters. The purpose of this project is to evaluate the performance of ground improvement by pre-compression and vertical drain implemented for the construction of permanent campus of Universiti Tun Hussein Onn (UTHM), Parit Raja, Batu Pahat, Johor Darul Ta'zim by comparing the settlement design parameters between field and theoretical value. The anticipate magnitudes of settlements were calculated using Terzaghi's one dimensional consolidation theory while the monitored settlements were evaluated using Asoaka's method. The predictions of the total settlements with and without soil treatment had been made for three different zones. The time rate consolidation with the application of PVD was calculated using Hansbo's solution adopting both vertical and radial consolidation effects. The back calculated coefficient of consolidation in horizontal direction, $c_{h(back\text{-}cal)}$ from Asoaka's plot was performed using different time intervals and it was found that the longer time interval produced lower field coefficient of horizontal consolidation. The modified coefficient of horizontal consolidation, $c_{h(modified)}$ value also had been evaluated and it was concluded as $c_{h(modified)} = 0.22\ c_{h\ (lab)}$. This $c_{h(modified)}$ value would contribute to the formation of settlement curve resembling the actual settlement recorded from Asoaka's plot. The $c_{h(back\text{-}cal)}$ value was about 1.04 to 3.59 $m^2$/year. The value evaluated from dissipation test was found to be larger than $c_{h(back\text{-}cal)}$ value indicated that the smear effect was significant. However, this laboratory coefficient of horizontal consolidation, $c_{h(lab)}$ was in good agreement with normal assumption of $c_h = 2c_v$ especially in Zone A while in Zone B and C the ratio was found to be 1 to 1.3. The ratio of $c_{h(back\text{-}cal)}$ over $c_{v(lab)}$ was found to be 0.27 to 0.96. The ratio of $c_{h(modified)}/\ c_{v(lab)}$ was in range 0.27 to 0.88 while the ratio of $c_{v(field)}\ /\ c_{v(lab)}$ value was found to be 0.13 to 0.48. The correlation of coefficient of volume compressibility, $m_{v(field)} = 0.4\ m_{v(lab)}$ in Zones A and C, while the ratio was found to be 0.2 in Zone B. The compression ratio can be concluded as $CR_{(field)} = 0.03\ CR_{(lab)}$ and the compression index, $C_c$ value can be summarized as $C_{c(\mathrm{field})} = 0.03\ C_{c(lab)}$ while the recompression index, $C_r$ was found to be $C_{r\ (field)} = 0.12\ C_{r\ (lab)}$. This study shows that laboratory values were significantly higher than the field values.

# ABSTRAK

Saliran tegak pre-fabrikasi, PVD dan pra-bebanan surcaj merupakan salah satu teknik yang digunakan secara meluas untuk mempercepatkan proses pengukuhan tanah liat semasa rawatan tanah. Kadangkala sangat sukar untuk menentukan parameter-parameter yang sesuai semasa peringkat rekabentuk. Oleh itu analisis kembali daripada rekod ditapak digunakan bagi mengesahkan parameter-parameter rekabentuk yang digunakan ini. Tujuan kajian ini dilaksanakan adalah untuk menilai kemajuan tanah yang dibaiki dengan pra-bebanan dan saliran tegak yang dilaksanakan di kampus tetap Universiti Tun Hussein Onn (UTHM), Parit Raja, Batu Pahat, Johor Darul Takzim dengan membandingkan antara parameter rekabentuk teori dan sebenar di tapak. Jumlah enapan ramalan dikira menggunakan teori pengukuhan satu dimensi Terzaghi, manakala jumlah enapan sebenar di tapak dianalisa berdasarkan kaedah Asoaka. Penyelesaian Hansbo digunakan bagi meramal kadar masa pengukuhan bilamana PVD digunakan dengan megambil kira kesan pengukuhan menegak dan mendatar. Analisis kembali nisbah pekali pengukuhan dalam arah mendatar, $c_{h(back\text{-}cal)}$ daripada graf Asoaka di analisa menggunakan jangkamasa yang berbeza dan didapati analisis menggunakan jangkamasa yang panjang akan menghasilkan nilai pekali sebenar ditapak yang lebih rendah. Pekali pengukuhan arah mendatar diperbaiki, $c_{h(modified)}$ juga di analisa dan didapati $c_{h(modified)} = 0.22c_{h(lab)}$. Pekali $c_{h(modified)}$ ini menyumbang kepada lengkung enapan ramalan yang menyamai lengkung enapan sebenar yang direkodkan oleh graf Asoaka. Nisbah pekali pengukuhan dalam arah mendatar, $c_{h(back\text{-}cal)}$ yang diperolehi adalah antara 1.04 hingga 3.59 $m^2$/tahun. Nilai pekali yang diperolehi daripada ujian lesapan *piezocone* didapati lebih besar daripada nilai $c_{h(back\text{-}cal)}$ menunjukkan faktor kesan lumuran adalah penting. Walaubagaimana pun, nilai $c_{h(lab)}$ ini adalah bertepatan dengan kebiasaan anggapan $c_h = 2c_v$ terutamanya di Zon A manakala di Zon B dan C pula nisbahnya adalah antara 1 hingga 1.3. Nisbah $c_{h(back\text{-}cal)}$ kepada $c_{v(lab)}$ didapati antara 0.27 hingga 0.96. Nisbah $c_{h(modified)}/c_{v(lab)}$ adalah antara 0.27 ke 0.88 manakala nilai nisbah $c_{v(field)}/c_{v(lab)}$ yang diperolehi adalah 0.13 hingga 0.48. Pekali kebolehmampatan isipadu adalah $m_{v(field)} = 0.4\ m_{v(lab)}$ di Zon A dan C, manakala di Zon B nisbahnya adalah 0.2. Nisbah mampatan yang diperolehi adalah $CR_{(field)} = 0.03\ CR_{(lab)}$ dan nilai indeks mampatan, $C_c$ adalah $C_{c(field)} = 0.03\ C_{c(lab)}$ manakala indeks ketidakmampatan, $C_r$ adalah $C_{r\ (field)} = 0.12\ C_{r\ (lab)}$. Kajian ini menunjukkan parameter yang diperolehi melalui ujian makmal adalah lebih tinggi daripada nilai sebenar yang diperolehi di tapak.

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# LIST OF SYMBOLS

| | | |
|---|---|---|
| $a$ | - | Width of Strips |
| $a_v$ | - | Coefficient of Compressibility |
| $BH$ | - | Borehole |
| $B$ | - | Width |
| $B,t$ | - | Thickness of Strips |
| $C$ | - | Compressibility coefficient |
| $CPT$ | - | Cone Penetration Test |
| $C_{a\varepsilon}$ | - | Modified of Secondary Compression Index |
| $C_\alpha$ | - | Rate of Secondary Compression |
| $C_c$ | - | Compression Index |
| $c_h$ | - | Coefficient of consolidation in Horizontal Direction |
| $CR$ | - | Compression Ratio |
| $C_r$ | - | Recompression Index |
| $C_u$ | - | Undrained Cohesion of Soil |
| $c_v$ | - | Coefficient of Consolidation in Vertical Direction |
| $d_w$ | - | Equivalent diameter of prefabricated vertical drain |
| $E$ | - | Young Modulus |
| $E_u$ | - | Undrained Modulus |
| $e$ | - | Void ratio |
| $e_0$ | - | Initial void ratio |
| $e_1$ | - | Final void ratio |
| $G$ | - | Shear Modulus |

| | | |
|---|---|---|
| $Gs$ | - | Specific Gravity |
| $H$ | - | Thickness of the Compressible Layer |
| $H_d$ | - | Length of Drainage Path |
| $I_p$, $\alpha$ | - | Influence Factor |
| $I_p$ | - | Plasticity Index |
| $I_r$ | - | Rigidity Index |
| $k$ | - | Coefficient of Permeability |
| $k_h$ | - | Horizontal Coefficient of Permeability |
| $k_s$ | - | Permeability of Smeared Zone |
| $k_v$ | - | Vertical Coefficient of Permeability |
| $LL$ | - | Liquid Limit |
| $n$ | - | Ratio of $D/d$ |
| $m_v$ | - | Coefficient of Volume Compressibility |
| $OCR$ | - | Over-Consolidated Ratio |
| $p$ | - | Pressure |
| $PI$ | - | Plastic Index |
| $PVD$ | - | Prefabricated Vertical Drains |
| $q$ | - | Extra surcharge |
| $q_c$ | - | Cone Resistant |
| $q_u$ | - | Unconfined compression Strength |
| $r$ | - | Radius |
| $RR$ | - | Recompression Ratio |
| $s$ | - | Drain Spacing |
| $S_c$ | - | Primary Consolidation Settlement |
| $S_i$ | - | Settlement Reading, Immediate Settlement |
| $S_{i-1}$ | - | Preceding Settlement |
| $S_f$ | - | Final Settlement |
| $S_s$ | - | Secondary Compression Settlement or Creep |
| $SPT\text{-}N$ | - | Value of Standard Penetration Test |
| $s_u$ | - | Undrained shear strength |
| $t$ | - | Time |

| | | |
|---|---|---|
| $t$ | - | Time of consolidation |
| $t_f$ | - | Time of  Interest for Secondary Consolidation |
| $t_p$ | - | Time of The Beginning of Secondary Consolidation |
| $T_h$ | - | Time factor for Horizontal Drainage |
| $T_r$ | - | Time factor for Radial Drainage |
| $T_v$ | - | Time Factor |
| *UTHM* | - | Universiti Teknologi Tun Hussein Onn Malaysia |
| $U$ | - | Degree of Consolidation |
| $U_e$ | - | Excess Pore Water Pressure |
| $U_r$ | - | Average Degree of Consolidation Ratio for Radial Drainage |
| $U_v$ | - | Average Degree of Consolidation Ratio for Vertical Drainage |
| $U_{vr}$ | - | Average Degree of Consolidation Ratio for Combined Vertical and Radial Drainage |
| $v$ | - | Poisson's Ratio |
| $W_L$ | - | Liquid Limit |
| $W_n$ | - | Natural Water Content |
| $z$ | - | Depth |
| $\alpha$ | - | Constant Which Depends on The Spacing Ratio of The Vertical Drain |
| $\Delta e$ | - | Change in Void Ratio |
| $\Delta p$ | - | Change in Stress |
| $\Delta\sigma'$ | - | Change in Effective Stress |
| $\sigma'_0$ | - | Initial Effective Stress or Existing Overburden Pressure |
| $\sigma_c'$ | - | Pre-consolidation Pressure |
| $\gamma_w$ | - | Water Unit Weight |

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# CHAPTER 1

# INRODUCTION

## 1.1 Background

Soft ground deposits are widespread and cover many coastal regions of the world, such as Japan, Eastern Canada, Norway, Sweden and other Scandinavian countries, India and the South East Asian countries. In Malaysia, soft soil deposits are widespread all over the country and mostly found in the coastal area. Further extensive development activities are apace in many lowland areas to promote human activities such as agriculture, industry, housing, infrastructure facilities and so on. With the decrease in suitable land for construction, the next choice available is to expand the development in the geotechnical challenging environment such as wetlands or soft soil area and highlands.

Generally, soft soils exhibit low strength and high compressibility. Many are sensitive, in the sense that their strength is reduced by mechanical disturbance. For example, foundation failure is likely in structure constructed in soft soil and surface loading beyond yield stress levels due to embankments and shallow foundation inevitably results in large settlements. This is because, these soils respond in a spectacular manner to stress changes, that geotechnical engineer has an obligation to examine to what extend the soft soils can be analyzed within the frame work of development in soil mechanics. The soft soils conditions need to be improved to avoid the excessive settlement and to ensure the stability and safety of the built infrastructure and other facilities.

Nowadays, many ground improvement methods have been proposed and implemented on soft soils to improve the bearing capacity and minimize the settlement. In geotechnical engineering, ground improvement means the increase on soil shear strength, the reduction of soil compressibility and the reduction of soil permeability [1]. Precompression by preloading is one method to improve the bearing capacity and reduce the settlement. It is most effective and economical compare to other methods such as mechanical and chemical stabilization, soil reinforcement such as using granular piles and stone column.

Preloading is usually combined with vertical drain to speed up the consolidation process, hence, reduce the post construction settlement. Prefabricated vertical drain (PVD), or sometime referred to band or wick drains have been widely used in Malaysia as a means to accelerate the consolidation settlement.

## 1.2 Problem statement

Generally, the site investigation is performed to obtain information of the physical properties of soil within a site to design earthwork and foundations for the proposed structures. Such investigation will include surface and subsurface exploration to enable soil sampling and laboratory tests of the soil samples retrieved.

The test on some soil design parameters are not normally being carried out during SI stage, unless special provisions are made. Some design parameters are usually being assumed based on published literature, report and experiences during the designing stage in the absence of adequate data. Inaccurate assumptions would result in problems that the actual settlement differs from the predicted or designed values.

The precompression or preloading and prefabricated vertical drains (PVD) have been used successfully as a ground improvement method for soft soil. The performance of this ground improvement method can be evaluated by comparing the design parameters of the subsoil before and after stabilization work.

## 1.3 Objectives of the study

The aim of this study is to see the difference between predicted or designed parameters from actual condition on site through the analysis of the data that being collected from instrumentations and monitoring program. In order to achieve the aim of the project, the study consists of the following objectives;

i) To predict the magnitude of settlement by adopting the Terzaghi's consolidation theory and time required based on Hansbo's solution for PVD consolidation.

ii) To determine field coefficient horizontal consolidation, $c_h$ value based on settlement data by adopting Asoaka's method.

iii) To determine the correlation of compressibility characteristics by comparing the magnitudes of predicted settlement and monitoring settlement.

## 1.4 Scope and limitation of the study

This is a case study based on a development project in Parit Raja, Batu Pahat, Johor Darul Takzim. The subsoil condition, loading type, method of construction, monitoring and instrumentation system, soil improvement method and PVD are being discussed in this research. The scope of the analysis will be limited to settlement criteria.

Analysis would be based on the available limited Site Investigation and instrumentations monitoring records. Series of instrumentation program such as settlement plates, pieozometers, inclinometers and extensonometers were installed to monitor the performance of the treated ground. 24 locations of Settlement plate instruments was installed to monitor the settlement of the embankment in whole development site, however, only 9 sets of settlement data in Zone A, B and C will be used for analysis in this particular study. Calculation being carried out using manual calculation and for more complicated analysis, *Microsoft Excel* spreadsheet program will be used.

The back analysis of the settlement data from the field data would be carried out by adopting the Asoaka's method. The effect of vertical drain in speeding up the consolidation process was evaluated based on the both effects of horizontal and vertical conditions. However, some consolidation parameters and data were assumed to be fixed for calculation purpose due to the inter-dependency between the parameters used, which were initial void ratio, $e_0$, permeability of smeared zone coefficient, $k_s$, horizontal coefficient of permeability, $k_h$ and vertical coefficient of permeability, $k_v$. The ratio of $k_h/k_s$ was taken as 2 as recommended by Zhou *et al* [1].

Type of prefabricated vertical drain, PVD used for this project is Nylex Flodrain and the PVD specification as attached in Appendix A. The PVD was installed in close spacing with distance 1.5 meter for Zone B and 1.0 meter for Zone A and Zone C in triangular configuration and 16 meters in length for each point.