SETTLEMENT ANALYSIS OF PREFABRICATED VERTICAL DRAIN BY
FINITE ELEMENT ANALYSIS FOR TREATED ROAD EMBANKMENT

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Dedicated to my beloved family (Zuraihan, Mohamad Raiyan Haikal & Nur Rania Zistina), mother, father, lecturers and friends.

Thanks for everything.

May Allah bless all of you.
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Prefabricated vertical drains with incorporated with preloading has been used widely as a ground improvement technique in geotechnical engineering. Prefabricated vertical drains would be essential to speed up the settlement of subsoil in embankment and soft ground construction. The prediction in the embankment settlement is a critically important issue for serviceability of road, especially the pre-construction settlement. In this study, Finite Element Analysis was done for analysing viability of PVD modelling in subsoil using Plaxis 2D 2016 software. Asaoka’s method were used to analyse the field monitoring data that was gathered at a location of an embankments. This method is used to determine ultimate settlement and back calculated coefficient for the horizontal consolidation at a certain location of the embankments. The settlement prediction and the actual measurement at a case study in terms of time to reach 90% consolidation were compared with the field instrumentation results in order to verify the design approach used. Subsequently, the effect of smear disturbance was considered in the parametric study. Various equivalent diameter of influence zone of the PVD are simulated in the modelling of embankment to study the effect of consolidation degree to the drain spacing. Based on the performed analysis, the installation of PVD is proved to improve the rate of settlement and the dissipation of pore water pressures. The rate of settlement decreases as the smear disturbance and drain spacing increase. Modelling of PVD with smear ratio \( k_s/k_v \) of 6.0 and drain spacing of 1.0 m shows good agreement with the field measurement.
ABSTRAK

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**LIST OF SYMBOLS**

- \( S_i \) - Immediate settlement
- \( S_c(t) \) - Primary consolidation settlement
- \( S_s(t) \) - Secondary compression.
- \( C_s \) - Coefficient of consolidation
- \( C_c \) - Coefficient of compression
- \( \sigma_0 \) - Overburden pressure of soil
- \( U \) - Degree of consolidation
- \( \nu \) - Poisson ratio
- \( E \) - Modulus of Elasticity
- \( \gamma_b \) - Bulk Density
- \( \gamma_{sat} \) - Wet Density
- \( c_v \) - Coefficient of consolidation for vertical drainage
- \( c_h \) - Coefficient of consolidation for horizontal drainage
- \( k_v \) - Coefficient of vertical permeability
- \( k_{ve} \) - Equivalent vertical permeability
- \( m_v \) - Coefficient of volume change = \( \Delta \varepsilon / \Delta \sigma_v \)
- \( \gamma_w \) - Unit weight of water
- \( H_d \) - Height of drainage path
- \( T_h \) - Time factor for radial drainage
- \( r \) - Distance from the axis of the pattern of flow lines
- \( r_s \) - Radius of the smear zone
- \( \psi \) - Dilatancy of soil
- \( \varphi \) - Friction angle of soil
- \( c \) - Soil cohesiveness
- \( q \) - Discharge capacity
$C_c$  -  Compression index  
$C_r$  -  Recompression index  
$CR$  -  Compression ratio  
$RR$  -  Recompression ratio  
$d_m$  -  Equivalent diameter of mandrel  
$d_w$  -  Equivalent diameter of the drain  
$D_e$  -  Diameter of equivalent soil cylinder  
$e$  -  Void ratio  
$F(n)$  -  Vertical drain spacing factor  
$Fr$  -  Well resistance factor for vertical drain  
$Fs$  -  Smear effect factor  
$Pc$  -  Preconsolidation pressure  
$q_w$  -  Discharge capacity of PVD  
$U_h$  -  Degree of consolidation in horizontal direction  
$\beta_1$  -  Slope in Asaoka’s plot  
$\Delta$  -  Difference  
$\lambda^*$  -  Modified compression index  
$k^*$  -  Modified swelling index
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CHAPTER 1

INTRODUCTION

1.1 Background of the study

The road embankment construction over a soft ground and compressible soil can cause problems to the civil engineer. Road embankment construction over weak saturated clays and silts requires ground improvement to speed up construction and to avoid failure. Without strengthening the ground these soils do not have the strength to support such embankments by itself. For the road embankments construction on soft soil, various factors need to be taken into consideration. The most important factor is in the aspect of time reduction is analysed in regard of the consolidation of the soft subsoil. Prefabricated vertical drains (PVDs) are usually utilized to fasten the consolidation of soft subsoils (e.g. Holtz et al., 2001; Bergado et al., 1996; Chai et al., 1996; Hansbo, 1981; Jamiolkowski et al., 1983; Rixner et al., 1986). The vertical hydraulic conductivity for soft subsoil can be increased using PVD’s by micro-sense with above one order of the magnitude. (Bergado et al., 1996; Hansbo, 1981). From the case studies have shown that longer time is required to complete the consolidate on process due to some factors that can affect the performance of PVD. Lee and Chung (2010) proposed that for typical PVD and mandrel size, the diameter of smeared would be approximately 2 – 7 times of the PVD diameter. Soil permeability around the PVD is substantially reduced due to smear effect. The previous study shows permeability
ratio for undisturbed soil against remoulded one ranges from 2 to 10 (Hansbo et al., 1981; Bergado et al. 1993). Well resistance is another concern and should be taken into account due to such factors as deterioration of the drain, filter and reduced area and folding of the drain in practice, (Holtz, 1991). However, Lee and Chung (2010) concluded from their study that the effect of drainage resistance is insignificant for \( q_w > 100 \text{ m}^3/\text{yr} \) and \( k_h < 5 \times 10^{-9} \text{ m/sec} \).

The performance of embankment on PVD treated soft ground has been analysed based on analytical method, numerical analysis and field observation data. Finite element method (FEM) is used because it produces less restrictive analysis compared to analytical methods. It also can incorporate elements relevant to the construction such as effects of reinforcement and staged construction (Hird, et al., 1992). This is because it is extremely hard to equate the embankment plain strain analysis essentially with axisymmetric consolidation behaviour of soil which surrounds the single vertical drain. The results of field monitoring and finite element analysis would assist engineers to achieve better understanding regarding true soil characteristics; in contrast with the modelling of finite element. Therefore, this study is carried out to identify the succession of prefabricated vertical drain modelling in soft soil by utilizing finite element method.

1.2 Problem of statement

Stages of construction that are involved in earth embankments is an important geotechnical consideration for a wide variety of civil engineering projects. The stability and deformation of embankments constructed over soft ground must be prospering engineered and analysed. A construction site which consists of mostly thick layered soft soil, the analytical method by Hansbo (1981) can be used. This specific design of vertical drain depends on the installation pattern which is off square grid or triangular grid. Besides this method, the design could also be done by using empirical
method or finite element method. Using this method however, depends on the designer proficiency and preference skills.

In behalf of this, the degree of consolidation would combine with the vertical and horizontal consolidation effect. Terzaqhi’s one-dimensional consolidation theory can be used to analyse vertical consolidation which is caused by vertical drainage fully. Average horizontal consolidation which is caused by horizontal drainage can be evaluated by solution of Barron (1948) in ideal conditions; which are well resistance and no smear. However, Hansbo (1979) changed the equation to input the well resistance effect and smear effect. This new equation produces a liaison by correlating, consolidation coefficient, drain size, time, the consolidation degree average and drain spacing.

Finite element method (FEM), gives reasonable option for utilization the above traditional technique on vertical drain design and in the expectation of their outcome. The advantages are usually in the application of this method whereby the condition of the subsoil are heterogenous, usually due to the disruption occurred while the drains are being installed. The usage is more applicable when complex situation occurs by Atkinson and Eldred (1982).

1.3 Objectives of study

The aim of this research is to study the effect of consolidation behaviour of embankment on the soft ground with the improvement from Prefabricated Vertical Drain (PVD) Finite element code PLAXIS 2D 2016 are used to simulate a real road embankment on soft ground case research. The research are points out a several objectives which are as following:
(i) To differentiate and estimate settlement of embankment over soft ground treated with preloading and Prefabricated Vertical Drain (PVD) which is obtained from finite element modelling and field instrumentation measurement monitoring.

(ii) To evaluate factor affecting the performance of PVD e.g smear disturbance and drain spacing.

(iii) To create a method for estimating a reliable 90% consolidation settlement utilizing finite element method.

1.4 Scope and limitation of the study

This research is carried out by initiating a road project at Pahang Technology Park, Gambang. The performance assessment was done based on the settlement monitoring data. The constitutive subsoil properties model was done using PLAXIS 2D 2016; which is a 2D plane strain modelling using Soft Soil model and Mohr Coulomb model. In this study, the permeability matching derivation is utilized to achieve the similarities between plane strain condition in Plaxis modelling and axisymmetric behaviour of the vertical drain as done by Lin et al. (2000). Asoaka’s method would be used to estimate the final settlement of the settlement data. These data are obtainable from finite element analysis and instrumentation. The comparison would be done between finite element analysis and filed instrumentation monitoring to get the time required for 90% consolidation succession.
1.5 Significant of Study

In this study, it shows the estimation of performance for ground improvement work which is called as prefabricated vertical drains with finite element modelling. It aims to verify and validate the accuracy of estimation from the finite element method by using proper conversion method to obtain a two-dimensional flow which is a representative of its three-dimensional flow. The comparison in between the field monitoring settlement result and finite element analysis would enable the prediction of the time rate settlement for projects in future. Thus, the period of resting for 90% consolidation settlement could be analysed.
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