SUSTAINABLE DESIGN AT TRANSITION RIGID PILED EMBANKMENT WITH SURCHARGED VERTICAL DRAIN OVER SOFT GROUND

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To my beloved parents and wife

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ABSTRACT

The repair of undulating road involves enormous time and high cost for repetitive remedial works over the time. Intolerable differential settlement is the main cause of the undulating roads. Differential settlement frequently occurs at the intersection of different ground pressure, ground condition, ground treatment and foundation system such as surcharged prefabricated vertical drain (SPVD) and rigid piled embankment which shall be arrested to overcome the undulating road problem. In this research, the intersection of SPVD at transition of rigid piled embankment is introduced to regulate post construction differential settlement between the two conventional ground treatments. This dissertation presents analytical, numerical and field studies of a sustainable design for high and long filled embankment over soft clay at structure approach. Generally, soil settlement is computed based on equivalent raft method and settlement equation proposed by Terzaghi and Boussinesq. Prefabricated vertical drain is designed based on method proposed by Janbu. Whilst, numerical design was modelled in PLAXIS 2012 using soft soil creep (SSC) model with embedded pile row and improved vertical hydraulic permeability, k_{ve}. Instrumented full scale field study was also performed to validate the performance of the proposed system where settlement gauges and settlement markers were installed to monitor the ground surface settlement. Sustainability of the proposed ground treatment approach is quantified in terms of differential settlement, cost and time of construction in comparison to Malaysia industry's conventional ground treatments. The proposed intersection ground treatment reduces post construction total settlement by about 80% to 95% of the total settlement as compared to conventional transition piled embankment. Meanwhile differential settlement is controlled within the limit of 1:500 throughout the filled embankment. The cost of construction and maintenance works is about 20% lower than conventional piled embankment. The construction time of the proposed system is about 20% to 30% faster than the conventional piled embankment systems. Hence, the proposed system is a sustainable system in term of performance, cost and time of construction.

ABSTRAK

Kerja membaik pulih jalan beralun selalunya melibatkan kos yang tinggi dan memerlukan jangka masa yang panjang untuk kerja-kerja membaikpulih. Enapan tanah yang tidak sekata merupakan faktor utama yang menyumbang kepada masalah jalan beralun. Enapan tanah yang tidak sekata yang perlu ditangani untuk mengatasi masalah jalan beralun biasanya terjadi di pertemuan antara beban tanah yang berbeza, keadaan tanah, sistem rawatan tanah dan sistem tapak seperti saliran tegak pasang siap dengan surcaj (SPVD) serta tambakan bercerucuk yang tegar. Di dalam kajian ini, SPVD di transisi tambak bercerucuk yang tegar diperkenalkan untuk mengawal perbezaan pengenapan di antara dua sistem rawatan tanah yang berbeza. Disertasi ini membentangkan kajian kelestarian secara analitikal, numerikal dan kajian lapang untuk tambak tinggi serta panjang yang menghampiri struktur tegar di atas tanah liat lembut. Secara umumnya, enapan tanah ditafsir dengan menggunakan kaedah kesamaan rakit serta persamaan enapan yang diperkenalkan oleh Terzaghi dan Boussinesq. Saliran tegak pasang siap bagi kajian analitikal direkabentuk berdasarkan kaedah yang diperkenalan oleh Janbu. Sementara itu, kajian rekabentuk numerikal dimodel dalam perisian PLAXIS 2012 mengunakan model rayapan tanah lembut (SSC) dengan model barisan cerucuk terbenam dan kaedah ketelapan hidraulik tegak yang diperbaiki, k_{ve}. Kajian lapang berskala penuh juga dilakukan untuk mengesahkan prestasi sistem yang dicadangkan di mana tolok pengenapan dan penanda pengenapan dipasang untuk memantau pengenapan permukaan tanah. Kemampanan sistem rawatan tanah yang dicadangkan dikuantifikasikan dengan membandingkan pelbagai sistem rawatan tanah konvensional di dalam industri Malaysia dari segi prestasi pengenapan, kos and masa pembinaan. Sistem rawatan tanah perantaraan yang dicadangkan dapat mengurangkan jumlah enapan pasca pembinaan di antara 80% hingga 95% berbanding sistem konvensional transisi tambakan bercerucuk yang tegar. Sementara itu, perbezaan enapan pula dapat dikawal dalam had 1:500 sepanjang tambak tanah. Kos pembinaan dan membaik pulih juga dikurangkan sebanyak 20% berbanding sistem konvensional tambakan bercerucuk yang tegar. Masa pembinaan juga dapat dipercepatkan sebanyak 20% hingga 30% berbanding sistem konvensional tambakan bercerucuk yang tegar. Oleh itu, sistem yang dicadangkan merupakan satu sistem yang mampan dari segi prestasi, kos and masa pembinaan

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

`

LIST OF SYMBOLS

μ	-	Micron
W_L	-	Liquid Limit
W_p	-	Plastic Limit
γ_m	-	Partial Factor for Material
γ_{FL}	-	Partial Factor for Fill and Loading
γ_{F3}	-	Partial Factor for Forces
σ_s	-	Tension Stress
τ_s	-	Shear Stress
d_w	-	Equivalent Diameter of PVD
a	-	Width of PVD
b	-	Thickness of PVD
d_e	-	Diameter of PVD
O_{90}	-	Apparent pore size for PVD
q_w	-	Discharge Capacity of the Drain
k_h	-	Horizontal Permeability in the Undisturbed Zone of PVD
k_s	-	Horizontal Permeability in the Smear Zone of PVD
q_u	-	Compressive Strength
S_u	-	Undrained Shear Strength
k_{hp}	-	Coefficient of Horizontal Permeability of Undisturbed Soil
α	-	Geometric Conversion Parameter
β	-	Smear Zone Effects Parameter
k'_{hp}	-	Coefficient of Horizontal Permeability of Disturbed Soil
s	-	Ratio between Radius of Smear Zone over Radius of Band
n	-	Ratio between Radius of Drain over Radius of Band
d_s	-	Diameter of Smear Zone
b_s	-	Half Width of Smear Zone

b_w	-	Half Width of Band
U_{vr}	-	Degree of Consolidation
U_v	-	Vertical Degree of Consolidation
U_r	-	Radial Degree of Consolidation
T_h	-	Time Factor
l	-	Drainage Length
k_{ve}	-	Equivalent Vertical Hydraulic Conductivity
k_v	-	Hydraulic Conductivity in the Vertical Direction
ε	-	Soil Strain
ε_c	-	Strain up to End of Consolidation
C_B	-	Material constant
t_c	-	Time to end of primary consolidation
t'	-	Difference between Start and End of Primary Consolidation
C_α	-	Modified Material Constant
ε^H	-	Logarithmic Strain
V	-	Volume
V_0	-	Initial Volume
e	-	Void Ratio
e_0	-	Initial Void Ratio
κ^*	-	Modified swelling index
v	-	Poisson’s Ratio
μ^*	-	Modified Creep Index
λ^*	-	Modified Compression Index
σ_p	-	Preconsolidation Pressure
ψ	-	Dilantacy Angle
Φ	-	Friction Angle

c	-	Effective Cohesion
K_0^{nc}	-	Stress Ratio in a State of Normal Consolidation
C_α	-	Secondary Compression Index
ρ_i	-	Immediate Settlement
E_u	-	Undrained Young's Modulus of the subsoil
I	-	Influence factor
dh	-	Thickness of Soil Layer
q	-	Applied Stress / Pressure on the subsoil
ρ_c	-	Consolidation Settlement Magnitude
σ'_{vo}	-	Initial Vertical Effective Stress
σ'_{vf}	-	Final Vertical Effective Stress
σ'_{vc}	-	Preconsolidation Pressure / Yield Stress
H_i	-	Initial thickness of incremental soil layer, i of n.
C_C	-	Compression Index
C_r / C_s	-	Recompression Index
T	-	Time for secondary consolidation
β_{max}	-	Angular Distortion
c_v	-	Coefficient of Consolidation
T_v	-	Time Factor
f_s	-	Shaft Friction Resistance
f_b	-	Base Resistance
A_s	-	Surface Area of Pile Shaft
A_b	-	Surface Area of Pile Base
FOS_G	-	Global Factor of Safety against Global Failure
FOS_{ps}	-	Partial Factor of Safety for Shaft Frictional Resistance
FOS_{pb}	-	Partial Factor of Safety for Base Resistance
f_{cu}	-	Characteristic Strength of Concrete

$F(n)$	-	Drain Spacing Factor
$F(s)$	-	Smear Effect
$F(r)$	-	Well Resistance
SPT-N	-	Standard Penetration Test Blow Count
γ_{sat}	-	Bulk Unit Weight of Soil
CR	-	Compression Index Ratio
RR	-	Recompression Index Ratio
OCR	-	Overconsolidation Ratio

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Soft clay is commonly found in most of the countries in South East Asia especially in Thailand, Vietnam and Malaysia (Long et al., 2013) . Out of total land coverage of 329,758 km^2 in Peninsular of Malaysia about 82,144 km is covered by roads and mostly are paved roads as shown in Figure 1.1.

Road embankment development includes roads, ramps and bridges. Based on Figure 1.1 and 1.2, it can be noticed that development on the thick soft clay is not vastly explored unless road access is inevitably required. Road planning and construction are preferred to be carried on stiffer ground instead of the thick soft ground as required extensive ground treatment design and involve high cost of construction. However, lack of land for construction leave no choice for developers to explore the ground underlain by thick soft clay to construct road (Chin, 2005).

Engineers face difficulties in designing road embankment over soft ground. The major difficulty faced by engineers is to control the settlement and differential settlement as soft ground consolidate over time which leads to long term settlement (Mesri & Vardhanabhuti, 2005).

Figure 1.1: Distribution of roads in Peninsular of Malaysia (source: Jabatan Kerja Raya Malaysia, 2009)

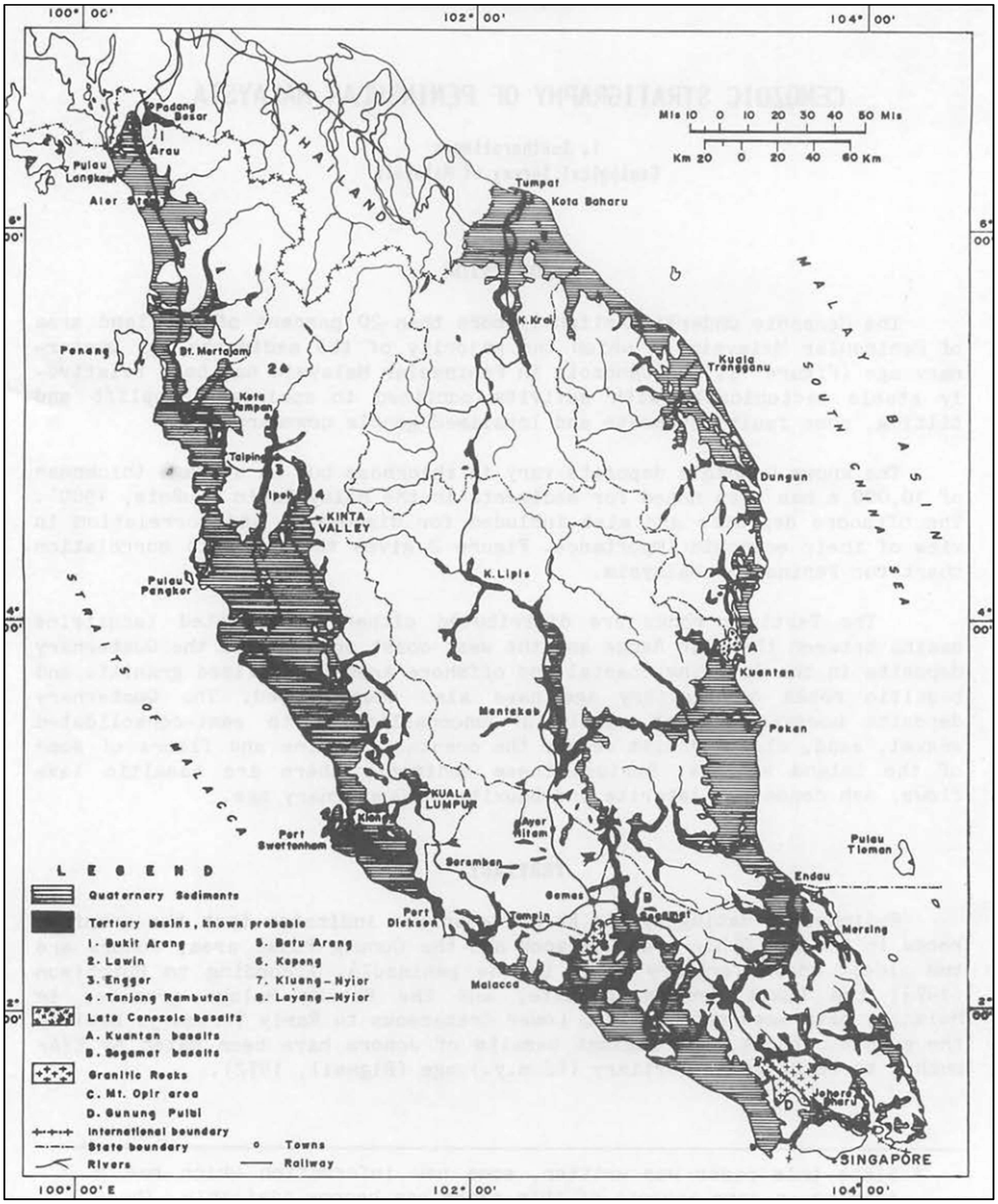

Figure 1.2: Quaternary sediments in Peninsular Malaysia (after Stauffer, 1973)

Problem gets even more complicated for construction of different road embankment approach such as road at grade and bridge. This is because differential settlements between two road embankment systems which involves two different foundation systems also need to be controlled to avoid or minimize the structures defect. Discounting post construction and differential settlement in the construction of road embankment will lead to undulating and bumpy effects (Figure 1.3) on the road or at bridge approach which is very dangerous to road users (Gue et al. 2007). Hence, engineers need to impose extra care to eliminate or to reduce these problems.

Figure 1.3: Undulating road at structure approach

However, engineers tend to provide costly and time-consuming ground treatment design approach to eliminate or to reduce the settlement and differential settlement. Worst is that the proposed ground treatment approach may not be effective for long term performance and unnecessary cost and time is required to remedy defected road.

Hence, this necessitate an effective system in term of performance, cost and time to be explored to avoid wastage in term of material, cost and time.

1.2 Problem Statements

Bumping effect on road is one of the defects that is very commonly detected at the structure approach of road such as bridge and ramp. Such undulating road condition tends to cause road user to lost control and crashes their vehicles which is very unsafe to the road users. This undulating road also deteriorate vehicles condition where frequent repairing is required due to wear and tear of the vehicle parts.

Conventionally, piled embankment is a ground treatment approach for high embankment fills over soft ground particularly at the structure approach such as bridges and ramps to improve the ground bearing and overcome the large settlement problem. Although large settlement problem could be arrested by introducing piled embankment, bumping effect still occur not at the structure approach but at the piled and unpiled road embankment due to differential settlement problem (Gue et al. 2007).

For very high and long stretched embankments from structure approach, piled embankment approach may not be practical as the involved cost is high and require very long construction time. This problem has been addressed by researches and one of the recommended solution was column approach (CA) by Shen et al. (2007) where transition stone column with reducing length design was adopted to reduce the differential settlement and bumping effects for high embankment fills over soft ground. However, transition stone column which behave as drainage path and also load bearer still undergo long term settlement and may causes undulating road.

Besides researchers also introduced vertical drain, surcharge and transition piled embankment to reduce piled embankment length. This approach able to accelerate settlement during construction at the unpiled road embankment. Settlement at untreated transition piled may occur throughout the service period (Shen et al. 2007) Bumping effect still may occur at the intersection between piled embankment and unpiled road embankment due to different post construction settlement at transition piled embankment and treated ground beyond transition piled embankment area.

Over the years, several approaches have been introduced to arrest post construction settlement and differential settlement of soft ground for high road embankment at structure approach but none of the introduced approach effectively seized the problem where either the design approach is very expensive and time consuming or excessive long-term settlement and differential settlement.

1.3 Objectives

The main purpose of this study is to establish the design of transition piled embankment with intersection of surcharged vertical drain to eliminate bumping effect for high road embankment over soft ground at structure approach. The specific objectives of this study are as follows:

a) To establish practical analytical design of the transition piled embankment with intersection of surcharged vertical drain.
b) To simulate practical numerical transition piled embankment with intersection of surcharged vertical drain.
c) To determine the field performance of the transition piled embankment with intersection of surcharged vertical drain.
d) To assess analytical design, finite element design and instrumented field study performance of the transition piled embankment with intersection of surcharged vertical drain.
e) To establish sustainability of the transition piled embankment with intersection of surcharged vertical drain as compared to conventional design approaches.

1.4 Scope of Study

Scope of study for ground is limited to soft clay with S_u is less than 20kPa. The ground treatment at the intersection of transition piled embankment is specified as surcharge and vertical drain. The surcharge consists of suitable material with unit weight of 20kN/m^3 and vertical drain proposed to be adopted is prefabricated vertical drain.

The road embankment scoped in this study is road at grade approaching bridge abutment and the thickness of the embankment fill is about 10m to 20m. This study only covers the rigid piled embankment with transition pile embankment. The pile utilized in this study is 250mm x 250mm square reinforced concrete pile. Piled embankment is designed based on the guideline and specification of BS5400 and BS8110.

In this study, the sustainability of the proposed system is established based on the performance, cost and time of construction. Performance of the design is evaluated in term of design satisfaction of the yielded differential settlement. Cost and time required for construction for both conventional and alternative approach is based on the typical cost and construction time adopted in Malaysia in year 2015.

Conventional design approaches in this study is scoped to full piled embankment and transition piled embankment without surcharged prefabricated vertical drain.

1.5 Research Framework

The framework of the research to achieve each specific objective listed in section 1.3 is elaborated below: -

i) To establish the analytical design of the transition piled embankment with intersection of surcharged vertical drain.
   - Identify the available methods and to establish suitable method to compute settlement for varies pile length.
   - Identify the available methods and to establish suitable method to design Surcharged Vertical Drain.
   - Establish the differential settlement based on the calculated total settlement.

ii) To simulate numerical transition piled embankment with intersection of surcharged vertical drain.
   - Identify the available soil models and to recognize the suitable soil model to simulate the ground behavior.
   - Identify the available methods to model Piled Embankment and to recognize the suitable method to model Piled Embankment in finite element.

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