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

PUSPANATHAN A/L SUBRAMANIAM

UNIVERSITI TEKNOLOGI MALAYSIA

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

PUSPANATHAN A/L SUBRAMANIAM

A dissertation submitted in partial fulfillment of the requirements for the award of the degree of Doctor of Engineering (Technology and Construction Management)

> Faculty of Civil Engineering Universiti Teknologi Malaysia

> > JANUARY 2018

To my beloved parents and wife

ACKNOWLEDGEMENT

First of all, I would like to express my sincere appreciation to my academic supervisors, Prof. Ir. Dr. Hj. Ramli bin Nazir and my industry supervisor, Dato' Ir. Dr. Gue See Sew for their encouragement, guidance and advices. They have contributed towards my understanding and thoughts. Without their continue support and interest, this dissertation would not have been the same as presented here.

My sincere appreciation also extends to all my friends 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 indebted my gratitude to all my family members especially to my wife who involved indirectly in completing this research.

Thank you.

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, kve. 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

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	V
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xii
	LIST OF FIGURES	xiii
	LIST OF SYMBOLS	xvii
	LIST OF APPENDICES	xxi
1	INTRODUCTION	1
	1.1 Background of Study	1
	1.2 Problem Statements	4
	1.3 Objectives	6
	1.4 Scope of Study	6
	1.5 Research Framework	7
2	LITERATURE REVIEW	9
	2.1 Introduction	9
	2.2 Soft Clay	10

2.3 Ground Improvement on Soft Ground 11

2.4 Sustainability in Ground Improvement Design	n 19
2.5 Road Defects	20
2.6 Post Construction Maintenance	23
2.7 Piled Embankment	26
2.7.1 Piled Embankment Design Approaches	27
2.7.2 Current Empirical Design Methods	30
2.7.3 Piles for Piled Embankment	32
2.8 Pile Load Distribution	35
2.8.1 Equivalent Raft Method	35
2.8.2 Equivalent Pier Method	36
2.8.3 Comparisons of Two Methods	39
2.9 Transition Piled Embankment	40
2.10 Finite Element Modelling of Piled Embankn	nent and 43
Transition Piled Embankment	
2.11Prefabricated Vertical Drain	45
2.12 Surcharge Design	48
2.13 Finite Element Modelling of Prefabricated V	Vertical 48
Drain with Surcharge	
2.14 Soil Model for Finite Element	52
2.15 Settlement Analysis	59
2.15.1 Immediate Settlement	59
2.15.2 Primary Settlement	60
2.15.3 Secondary Settlement	60
2.16 Differential Settlement	61
2.17 Settlement Monitoring Instrumentation	63
2.18 Settlement Prediction and Interpretation by	66
Observational Method	
2.19 Concluding Comment on Literature Survey	68

3 RESEARCH METHODOLOGY

3.1 Introduction	71
3.2 Site	71

71

3.2.1 Location	72
3.2.2 General Geology	73
3.2.3 Road Alignment and Profile	74
3.3 Determination of Soil Parameter	75
3.3.1 Field Subsoil Investigation Works	75
3.3.2 Laboratory Works	76
3.4 Method of Piled Embankment Design	77
3.5 Method of Prefabricated Vertical Analytical Design	80
3.6 Method of Settlement Analysis	83
3.7 Cases of Study	85
3.8 Method of Transition Pile Embankment Design	87
3.9 Method of Analytical Design of Intersection of PVD	87
and Transition Pile Embankment.	
3.10 Method of Numerical Design	90
3.10.1 Method of Numerical Design of Case 1	90
3.10.2 Method of Numerical Design of Case 2	93
3.10.3 Method of Numerical Design of Case 3	94
3.11 Method of Field Study of Transition Pile	96
Embankment with intersection of surcharged PVD	
3.12 Method of Field Instrumentation	106
Monitoring	
3.13 Method of Interpretation of Field	108
Instrumentation Monitoring Works	
3.14 Cost and Time Estimation	109
3.15 Determination of Sustainability	110
3.16 Assumptions and Limitation	114

4 **RESULTS AND DISCUSSION**

4.1 Introduction	116
4.2 Soil Parameters	116
4.3 Piled Embankment Design Results	119
4.4 Prefabricated Vertical Drain Design Results	120

116

4.5 Analytical Design	122
4.5.1 Analytical Design for Case 1	122
4.5.2 Analytical Design for Case 2	124
4.5.3 Analytical Design for Case 3	125
4.6 Numerical Analysis Results	129
4.6.1 Results of Numerical Analysis for Case 1	129
4.6.2 Results of Numerical Analysis for Case 1	131
4.6.3 Results of Numerical Analysis for Case 3	132
4.7 Field Results	134
4.7.1 Settlement Gauge Field Results	134
4.7.2 Settlement Marker Field Results	139
4.7.3 Field Settlement Profile	143
4.8 Comparison of Settlement for Cases according to	145
methods	
4.8.1 Analytical and Numerical Assessment	145
4.8.1.1 Case 1	146
4.8.1.2 Case 2	147
4.8.1.3 Case 3	148
4.8.2 Analytical and Field Assessment	150
4.8.3 Numerical and Field Assessment	151
4.9 Differential Settlement Results	153
4.9.1 Analytical Design Cases	153
4.9.2 Numerical Design Cases	154
4.9.3 Field Results	155
4.10 Construction Cost Results	157
4.11 Construction Time Results	158
4.12 Sustainability Results	160

5 CONCLUSIONS AND RECOMMENDATIONS 162

5.1 Introduction	162
5.2 Conclusions	162
5.3 Innovation & Benefits	164

	5.3 Recommendation	165
REFERENCES Appendices A-K		166-176 177-314

LIST OF TABLES

TABLE NO.TITLE

PAGE

2.1	Partial safety factor	32
2.2	Properties of Prefabricated Vertical Drain	47
2.3	Discharge Capacity of Prefabricated Vertical Drain	47
2.4	Properties of Filter Jacket	47
2.5	Limiting Angular Distortion for Various Structures	62
2.6	Time Factor as Function of Consolidation Percentage	66
2.7	Summary of Research Gaps addressed in this research	70
3.1	Prefabricated Vertical Drain Dimension and Parameter	83
3.2	Soil Parameters for Settlement Analysis	84
3.3	Stages of Construction in PLAXIS for Case 1	92
3.4	Stages of Construction in PLAXIS for Case 2	94
3.5	Stages of Construction in PLAXIS for Case 3	96
3.6	Material and Product for Construction for Full Scale Model	97
3.7	Full Scale Model Configuration and Stages of Construction	97
3.8	Installed Instrumentation at Full Scale Study Embankment	106
3.9	Typical Construction Time	109
4.1	General Soil Properties And Compressibility Parameters	118
	Results	
4.1	Embankment Net Fill Height	119
4.2	Pile Embankment Design Corresponding to Embankment	119
	Height	
4.3	Geotechnical and Structural Capacity	120

LIST OF FIGURES

FIGURE NO. TITLE

PAGE

1.1	Distribution of Road in Malaysia	2
1.2	Quaternary Sediments in Peninsular Malaysia	3
1.3	Undulating Road at Structure Approach	4
2.1	Recommended procedure of selecting an appropriate	12
	Solution	
2.2a	Summary of Ground Improvement	15
2.2b	Summary of Ground Improvement	16
2.3	Maintenance Cost and Differential Settlement	17
2.4	Schematic Arrangement of Hybrid Pile	18
2.5	Road Depression	22
2.6	Road Diagonal Crack	23
2.7	Total Periodic Maintenance Works from 2005 to 2007	24
2.8	Percentage of Periodic Maintenance of Federal Roads in	25
	Term of Length from 2005 to 2007	
2.9	Incurred cost for Periodic Maintenance Activities from 2005	25
	to 2007	
2.10	Section through a piled embankment and general layout of	27
	reinforcement	
2.11	Design approaches (a) Catenary Theory (b) Beam Theory	27
2.12	Pile Supported Embankment (a) on End Bearing Piles (b) on	29
	Floating Piles	
2.13	Typical Rigid Slab Piled Embankment	31
2.14	Pile Group Settlement with respective to Pile Spacing and	33
	Pile Length	
2.15	The Skin Friction Distribution in Pile	34

	2.16	Load transfer to soil from pile groups	36
	2.17	Equivalent Pier Method	38
	2.18	Pile Embankment with transition pile	40
	2.19	Details of Bridge Approach Support Pile	41
	2.20	Column approach (CA) by cement column	42
	2.21	Methodology for Column Approach (CA) by Cement Column	42
	2.22	Conventional Theory of Radial Consolidation	45
	2.23	Assessment of Equivalent Diameter of Band Shaped Vertical	46
		Drain	
	2.24	Conversion of Axisymmetric Radial Flow to Plain Strain	50
		Flow	
	2.25	Principle for Evaluating Creep Model	53
	2.26	Inverse Creep Strain Rate	55
	2.27	Idealized Stress-Strain Curve from Oedometer Test With	56
		Division of Strain Increment into an Elastic and a Creep	
		Component	
	2.28	Differential Settlement	62
	2.29	Ground Settlement Marker	64
	2.30	Rod Settlement Gauge	65
	2.31	Graphical Method of Asaoka Plot	67
	2.32	Graphical Method of Hyperbolic Plot	67
	3.1	Site Location Plan	72
	3.2	Geological Map of Selangor, Sheet 93, 1975	73
	3.3	Road Alignment	74
	3.4	Road Profile	74
	3.5	SI Layout Plan	76
	3.6	Installation pattern of PVD	81
	3.7	Profile of Case 1 Ground Treatment Approach	85
	3.8	Profile of Case 2 Ground Treatment Approach	86
	3.9	Profile of Case 3 Ground Treatment Approach	87
	3.10	Schematic Diagram for Settlement Analysis for Intersection	88
		of PVD and Transition Pile Embankment	
	3.11	Typical Analytical Design Steps for Intersection of PVD	89
`		and Transition Pile Embankment	

3.12	Model Mesh for Case 1	90
3.13	Model up to Designed Surcharge Level for Case 1	92
3.14	Model Mesh for Case 2	93
3.15	Model up to Designed Surcharge Level for Case 2	93
3.16	Model Mesh for Case 3	95
3.17	Model up to Designed Surcharge Level for Case 3	95
3.18a	Profile of Case 3	98
3.18b	Plan of Case 3	99
3.19	Piled Embankment Construction Details	100
3.20	Pile to set Installation at Abutment	101
3.21	Installed PVD at Transition Pile	101
3.22	Transition Pile Installation	102
3.23	Pile Head Preparation for Slab Casting	102
3.24	Steel Fabrication for Slab	103
3.25	Casted Slab for Piled Embankment	103
3.26	Backfilled Embankment up to Platform Level	104
3.27	Installed Settlement Gauge	104
3.28	Installation of Ground Settlement Marker	105
3.29	Installed Ground Settlement Marker	105
3.30	Details of Settlement Gauge	106
3.31	Details of Settlement Marker	107
3.32	Location of Instrumentation for Case 3 Field Study	107
3.33	Asaoka Plot	108
3.34	Flow Chart of Sustainability Scoring System	113
3.35	Flow Chart of Research Methodology	115
4.1	Summary of Degree of Consolidation for Square Grid	121
	Prefabricated Vertical Drain	
4.2	Summary of Degree of Consolidation for Square Grid	121
	Prefabricated Vertical Drain	
4.3	Settlement Profile of Analytical Design for Case 1	123
4.4	Settlement Profile of Analytical Design for Case 2	125
4.5	Settlement Profile of Analytical Design for Case 3	127
4.6	Settlement Profile of Numerical Design for Case 1	130
4.7	Settlement Profile of Numerical Design for Case 2	131
	č	

4.8	Settlement Profile of Numerical Design for Case 3 during	133
	Ground Treatment Period	
4.9	Asaoka Plot for Settlement Gauge SG1	135
4.10	Asaoka Plot for Settlement Gauge SG2	136
4.11	Asaoka Plot for Settlement Gauge SG3	137
4.12	Asaoka Plot for Settlement Gauge SG4	138
4.13	Asaoka Plot for Settlement Marker SM1	140
4.14	Asaoka Plot for Settlement Marker SM2	141
4.15	Asaoka Plot for Settlement Marker SM3	142
4.16	Asaoka Plot for Settlement Marker SM4	143
4.17	Settlement Profile of Field Study for Case 3	144
4.18	Analytical and Numerical Settlement Profile for Case 1	146
4.19	Analytical and Numerical Settlement Profile for Case 2	148
4.20	Analytical and Numerical Settlement Profile for Case 3	149
4.21	Analytical and Field Settlement Profile for Case 3	151
4.22	Numerical and Field Settlement Profile for Case 3	152
4.23	Differential Settlement computed from Analytical Design	153
4.24	Differential Settlement computed from Numerical Design	155
4.25	Differential Settlement computed from Field Full Scale	156
	Study	
4.26	Field Performance after 5 Years	157
4.27	Construction and Maintenance Cost	157
4.28	Percentage of Comparison of Construction and Maintenance	158
	Cost	
4.29	Percentage of Comparison of Construction Time	159
4.30	Construction Time According to Site Activities	160
4.31	Sustainability Chart	160

LIST OF SYMBOLS

μ	-	Micron
W_L	-	Liquid Limit
W_p	-	Plastic Limit
γm	-	Partial Factor for Material
γFL	-	Partial Factor for Fill and Loading
γ гз	-	Partial Factor for Forces
σ_s	-	Tension Stress
\mathcal{T}_{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
ks	-	Horizontal Permeability in the Smear Zone of PVD
q_{u}	-	Compressive Strength
Su	-	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
ť'	-	Difference between Start and End of Primary Consolidation
C_{α}	-	Modified Material Constant
ε^{H}	-	Logarithmic Strain
V	-	Volume
V ₀	-	Initial Volume
е	-	Void Ratio
e_0	-	Initial Void Ratio
κ^{*}	-	Modified swelling index
ν	-	Poisson's Ratio
μ^*	-	Modified Creep Index
λ^*	-	Modified Compression Index
σ_p	-	Preconsolidation Pressure
ψ	-	Dilantacy Angle
Φ	-	Friction Angle

с	-	Effective Cohesion
$\mathrm{K_0}^{\mathrm{nc}}$	-	Stress Ratio in a State of Normal Consolidation
\mathbf{C}_{α}	-	Secondary Compression Index
$ ho_i$	-	Immediate Settlement
E_u	-	Undrained Young's Modulus of the subsoil
Ι	-	Influence factor
dh	-	Thickness of Soil Layer
q	-	Applied Stress / Pressure on the subsoil
ρο	-	Consolidation Settlement Magnitude
σ'vo	-	Initial Vertical Effective Stress
σ' vf	-	Final Vertical Effective Stress
σ' _{vc}	-	Preconsolidation Pressure / Yield Stress
Hi	-	Initial thickness of incremental soil layer, i of n.
C _C	-	Compression Index
C_r/C_s	-	Recompression Index
Т	-	Time for secondary consolidation
β_{\max}	-	Angular Distortion
Cv	-	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

APPENDIX TITLE

PAGE

А	Design Calculation of Adopted Pile Capacity	177
В	Design Calculation of Piled Embankment	179
С	Design Calculation for Adopted Prefabricated Vertical Drain	186
D	Loading Distribution for Pile Length and Summary of Settlement	190
E	Input and Output of Numerical Analysis for Case 1, 2 and 3	193
F	Summary of the Analytical Settlement for Case 1, 2 and 3	282
G	Summary of the Numerical Settlement for Case 1, 2 and 3	283
Н	Summary of the Field Settlement for Case 3	284
Ι	Quantity Taking Off and Bill of Quantities for All Three Cases	285
J	Time Estimation All Three Cases	312
Κ	Sustainability Assessment in Term of Performance, Cost and	313
	Time	

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 km² 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).

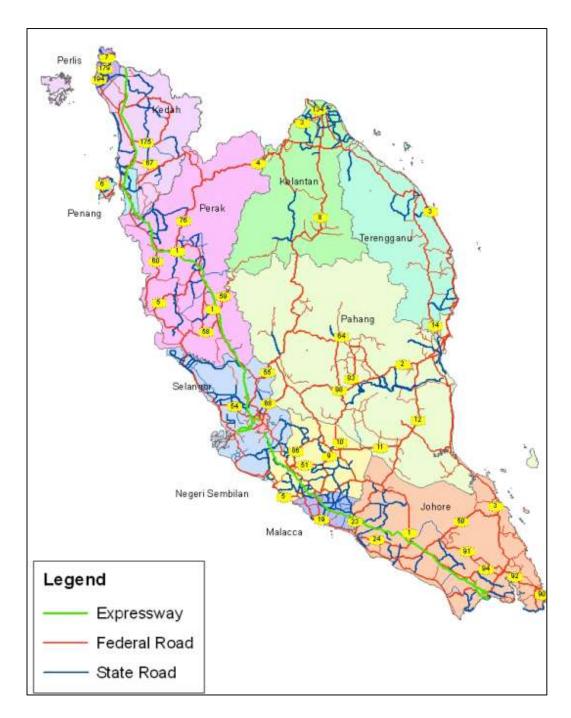


Figure 1.1: Distribution of roads in Peninsular of Malaysia (source: Jabatan Kerja Raya Malaysia, 2009)

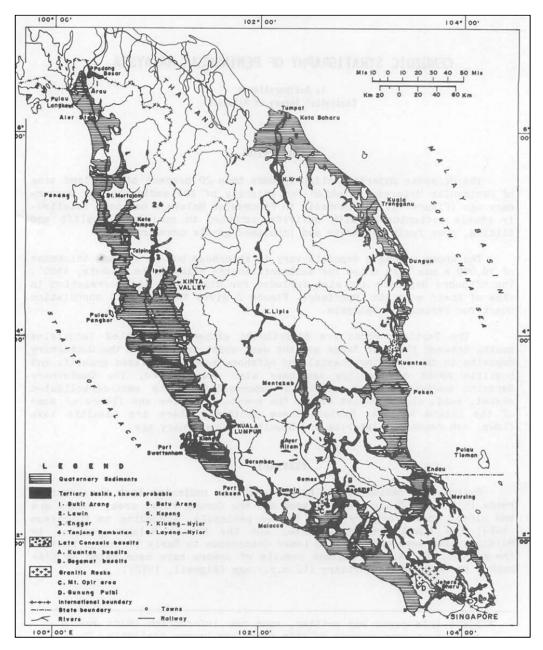


Figure 1.2: Quaternary sediments in Peninsular Malaysia (after Stauffer, 1973)

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/m³ 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.

REFERENCES

- Adachi, T. & Oka, F., (1982). "Constitutive equation for normally consolidated clays based on elasto-viscoplasticity". Soils and Foundations, Vol. 22, pp. 57-70.
- Aditi M. & Dipanjan B., (2011). "Sustainability in Geotechnical Engineering".
 Department of Civil and Environmental Engineering University of Connecticut Storrs, Connecticut.
- Alzamora, D. E., Wayne, M. H., and Han, J., (2000). "Performance of SRW supported by geogrids and jet grout columns." Proc., Sessions of ASCE Specialty Conf. of Performance Confirmation of Constructed Geotechnical Facilities, A. J. Lutenegeer and D. J. DeGroot, eds., ASCE Geotechnical Special Publication, Reston, Va., Vol. 94, 456–466.
- American Association of State Highway Officials/Federal Highway Administration (2002). Innovative technology for accelerated construction bridge and embankment foundations, Preliminary Summary Rep. Prepared for Federal Highway Administration, U.S. Dept. of Transportation, Washington, D.C.
- Andrea L. (2011) "Design Guidelines for Increasing Lateral Resistance of Bridge Pile Foundations" National Cooperative Highway Research Program Report 697
- Aniket S. S. & Kambekar A. R., (2013). "Working Of Prefabricated Vertical Drain- A Case Study." International Journal of Innovative Research in Science, Engineering and Technology (ISO 3297: 2007 Certified Organization) Vol. 2, Issue 8, August 2013.
- Asaoka A., (1978). "Observational Procedure of Settlement Prediction". Soil and Foundation Vol. 18 No. 4 87-101.
- Balasubramaniam A. S., Cai H., Surarak C. & Oh E. Y. N., (2010). "Settlements of Embankments in Soft Soils". Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol 41 No.2 June 2010 ISSN 0046-5828.
- Barron R. A., (1948). "Consolidation of fine-grained soils by drain wells." Trans. ASCE, 113, 718–742.

- Basu, D., Misra, A. Puppala, A.J. and Chittoori, C.S. (2013) "Sustainability in Geotechnical Engineering". Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013, (ii), 3171–3174.
- Bjerrum L., (1967). "Engineering geology of Norwegian normally-consolidated marine clays as related to settlement of buildings". Geotechnique, 17(2), 81-118.
- Bo, M.W., Chu, J., Low, B.K. & Choa, V. (2003), "Soil Improvement: Prefabricated Vertical Drain Technique". Singapore: Thomson Learning.
- Bo, M., Arulrajah A. & Nikraz H., (2007). "Preloading and prefabricated vertical drains design for foreshore land reclamation projects: A Case Study". Ground Improvement.
- British Standard Institute, BS5400-1988. British Standard "Steel, concrete and composite bridges".
- British Standard Institute, BS5930, 1999. Code of practice for site investigations. Licensed Copy: iclsll203 iclsll203, Imperial College of Science and Technology (JISC), 07 February 2005, Uncontrolled Copy, (c) BSI
- British Standard Institute. Steel, concrete and composite bridges, BS5400-1988. Code of practice for design and construction. Licensed Copy: iclsll203 iclsll203, Imperial College of Science and Technology (JISC), 07 February 2005, Uncontrolled Copy, (c) BSI.
- British Standard Institute. Structural use of Concrete, BS8110-1988. Code of practice for design and construction. Licensed Copy: iclsll203 iclsll203, Imperial College of Science and Technology (JISC), 07 February 2005, Uncontrolled Copy, (c) BSI
- Brundtland, G. H., (1987). "Our Common Future: Report of the World Commission on Environment and Development". Oxford University Press, UK.
- British Standard Institute, BS3811: 1984. British Standard "Glossary of maintenance management terms in terotechnology".
- Bujang, K. H. (1993). "Pile Embankment on Soft Clay: Comparison Between Model and Field Performance". Third International Conference on Case Histories in Geotechnical Engineering. Missouri University of Science and Technology.

- Buisman, K., (1936). "Results of long duration settlement tests". Proceedings 1st International Conference on Soil Mechanics and Foundation Engineering, Cambridge, Massachusetts, USA, Vol. 1, pp. 103-107.
- Butterfield R., (1979). "A natural compression law for soils (an advance on e-log p')". Geotrechnique 29:469-480.
- Carrillo, N., (1942). "Simple two and three-dimensional cases in the theory of consolidation of soils." J. Math. Phys., 21, 1–5.
- Chai J. C. and Miura N., (1999). "Discharge Capacity Of Prefabricated Vertical Drains Confined in Clay." Geosynthetics International S 2000, Vol. 7, No. 2.
- Chai J. C., (2001). "Simple Method of Modelling PVD-Improved Subsoil." Journal of Geotechnical and Geoenvironment Engineering 2001.
- Chai, J.C., Miura, N., Sakajo, S., and Bergado, D.T. (1995). "Behaviour of vertical drain improved subsoil under embankment loading." Soils Found., 35(4), 49–61.
- Chen, R. P., Chen, Y. M., Wang S. H., and Xu Z. Z. (2009). "Theoretical Study and Field Tests on Pile-supported Embankments over Soft Ground". 2009 US-China Workshop on Ground Improvement Technologies. Advances in Ground Improvement. ASCE.
- Chen R. P., Chen Y. M., Xu Z. Z. (2006). "Interaction of Rigid Pile- Supported Embankment on Soft Soil". Advances in Earth Structures: Reseach to Practice (GSP 151) ASCE.
- Chin I., (2005). "Embankment over Soft Clay–Design and Construction Control". Geotechnical Engineering, (May), 1–15.
- Clancy, P. & Randolph, M. F. (1996). "Simple design tools for piled raft foundations". Géotechnique 46, No. 2, 313-328.
- Dey A., (2008). "Vertical Drains and Smear Effects: A Brief Review". Indian Institute of Technology, Kanpur, Uttar Pradesh, India

Dutch Design Guideline for piled embankments (CUR 226), 2010.

- Elias V., (2006) "Ground Improvement Methods" Volumes I and II, Publication No.'s FHWA NHI-06-019 and FHWA NHI-06-020, US Dept. of Transportation, Federal Highway Administration.
- Fox L., (1948). "The mean elastic settlement of a uniformly loaded area at a depth below the ground surface". Proc. 2nd Int. Conf. Soil Mech. And Found. Eng., Vol. 1, 129.

- Garlanger J. E., (1972). "The consolidation of soils exhibiting creep under constant effective stress". Géotechnique, Vol. 22, pp. 71-78.
- Gradel et. al., (1997). "Industrial Ecology: Definition and Implementation." Industrial ecology and global change, Socolow, R., Andrews, C., Berkhout, F. and Thomas, V. (eds.) 23-41.
- Gue S. S., (2000). "Innovative Geotechnical Input for Approaches to Bridges and Culverts over Compressible Soils". 4th Malaysian Road Conference – Towards Better Highway Environment.
- Gue S. S., Wong S. Y. & Tan, Y. C., (2007). "Geotechnical Engineering Challenges for Highway Design and Construction on Soft Ground". pp 1–9.
- Government of India Ministry of Railways (2005) "Guidelines on soft soils stage construction method". geo-technical Engineering Directorate, Research Designs and Standards Organisation Manak Nagar, Lucknow – 11. (Guideline No.: GE: G - 5).
- Haas R. and Hudson W. R., (1978). "Pavement Management Systems", McGraw-Hill, New York.
- Handy R. L., (2002). "First order rate equation in geotechnical engineering." J. Geotech. Geoeniron. Eng., 128(5), 416-425.
- Hansbo S., (1979). "Consolidation of Clay by band Shaped Prefabricated Drains". Ground Engineering, 12, No. 5, 16-25.
- Hansbo, S. (1981). "Consolidation of fine-grained soils by Prefabricated Drains." Proc., 10th Int. Conf. Soil Mech. and Found. Engrg., Vol. 3, 677–682.
- Hewlett, W. J. and Randolph, M. F. (1998). "Analysis of Piled Embankments." Ground Engineering, 21(3), 12-18.
- Hewlett, W. J., and Randolph, M. F. (1988). "Analysis of piled embankments." Ground Eng., 21(3), 12–18.
- Hird, C.C., Pyrah, I.C., Russell, D., and Cinicioglu, F. (1995). "Modelling the effect of vertical drains in two-dimensional finite element analyses of embankments on soft ground". Canadian Geotechnical Journal, 32: 795–807
- Hird C. C., Pyrah, I. C., and Russell, D. (1992). Finite element modelling of vertical drains beneath embankments on soft ground. Ge´o-technique, London, 42(3). pp. 499–511.

- Hird, C.C., Pyrah, I.C., Russell, D. and Cinicioglu, F. (1995). "Modelling the effect of vertical drains in two-dimensional finite element analyses of embankments on soft ground". Can. Geotech. J., Ottawa, 32, 795–807.
- Holtz R. D. and Kovacs W. D., (1986). "An introduction to Geotechnical Engineering" Prentice Hall, Englewood Cliffs, New Jersey 07632.
- Holtz, R. D., and Christopher, B. R. (1987). "Characteristics of prefabricated drains for accelerating consolidation." Proc., 9th European Conf. on Soil Mechanics and Foundation Engineering, Vol. 2, Dublin, Ireland, 903±906.
- Horikoshi, K. & Randolph, M.F. (1999). "Estimation of overall settlement of piled rafts". Soils and Foundations, Vol.39, No.2, 59-68.
- Indrarathna B. et al. (2006). "Soft Soil Stabilisation with Special Reference to railway Embankments". Proc. Of 4th International Conference on Soft Soil Engineering, Vancouver, Canada, (Edited by D. Chan and K. T. Law). pp. 35-56
- Indraratna B. and Rujukiatkamjorn C., (2008). "Soft Clay Stabilisation Using Prefabricated Vertical Drains and the Role of Viscous Creep at the Sunshine Motorway, Queensland". Queensland Department of Main Roads, Brisbane, Australia.
- Indraratna, B., Bamunawita C., and Khabbaz, H., (2004). "Numerical modelling of vacuum preloading and field applications". Canadian Geotechnical Journal, Vol. 41, pp. 1098-1110.
- Indraratna B. et. al. (2006). "Soft Soil Stabilisation with Special Reference to Railway Embankments". Proc. of 4th International Conference on Soft Soil Engineering, Vancouver, Canada, (Edited by D. Chan and K. T. Law).
- Indraratna B. and Redana I. W., (2000). "Numerical modelling of vertical drains with smear and well resistance installed in soft clay". Canadian Geotechnical Journal, 37, 132-145.
- Indraratna B. and Rujikiatkamjorn C. (2007). "Soft Clay Stabilisation Using Prefabricated Vertical Drains and the Role of Viscous Creep at the Site of Sunshine Motorway, Queensland". Proceedings of the 10th Australia New Zealand Conference on Geomechanics, Brisbane, Australia, 21-24 October 2007, 2, 96-101.
- Indraratna B. and Redana I. W., (1998). "Laboratory determination of smear zone due to vertical drain installation." J. Geotech. Geoenviron.Eng. 124-2, 180–184.

- Indraratna B., Rujikiatkamjorn C. and Sathananthan I., (2005). "Analytical and numerical solutions for a single vertical drain including the effects of vacuum preloading". Canadian Geotechnical Journal, Vol. 42, pp. 994-1014.
- Indraratna B., Salim, W. and Redana I., (2000) Predicted and observed behaviour of soft clay foundations stabilised with vertical drains,GeoEng 2000, An International Conference on Geotechnical & Geological Engineering, vol 1, 2000, Invited Papers Pennsylvania,USA: Technomic Publishing Co Inc.
- Janbu J., (1963). "Soil Compressibility as Determined by Oedometer and Triaxial Tests". Proc. ECSMFE Wiesbaden, Vol. 1, pp. 19-25.
- Jenck O, Dias D, and Kastner R., (2007). "Two-Dimensional Physical and Numerical Modelling of a Pile-Supported Earth Platform over Soft Soil." J. Geotech. Geoenviron Eng. 2007
- Jenck O., Dias D. and Kastner R., (2009). "Three-Dimensional Numerical Modelling of a Piled Embankment". International Journal of Geomechanics © ASCE.
- Jia, N., Chen, R. P. and Chen Y. M. (2004). "Theoretical analysis and measurement of Hang-Yong highway widening project." Chin. J. Geotech. Eng., 26, 755–760 in Chinese.
- Jiang, Y, Han, J., and Zhang G, (2014). "Numerical analysis of a pile–slab-supported railway embankment". Acta Geotechnical (2014) 9:499–511. DOI 10.1007/s11440-013-0285-9. Springer-Verlag Berlin Heidelberg.
- Jones, C. J. F. P., Lawson, C. R., and Ayres, D. J. (1990). "Geotextile reinforced piled embankments." Proc., 4th Int. Conf. on Geotextiles, Geomembranes and Related Products, International Geosynthetics Society. pp. 155–160.
- Karun, M. and Nigee, K. (2013). "A study on ground improvement using stone column technique". International Journal of Innovative Research in Science, Engineering and Technology. Vol. 2, Issue 11, November 2013.
- Kibert C.J., (2008). "Sustainable Construction". 2nd Edition John Wiley and Sons Inc., New Jersey.
- Kishore N., (2004). "Prefabricated Vertical PVC Drainage System for Construction of Embankment on Compressible Soft Soil." Geo-Technical Engineering Directorate Research, Designs and Standards Organisation Lucknow-226 011.
- Kjellman W., (1948). "Accelerating consolidation of fine-grained soils by means of cardboard wicks". Proceedings of the Second International Conference of Soil

Mechanics and Geotechnical Engineering, Vol.2, pp.302-305. r Medium Rise Buildings on Very Soft Clay. SEAGC, Bangkok.

- Kordi N. E., Endut I. R. & Baharom B., (2010). "Types of Damages on Flexible Pavement for Malaysian Federal Road". Proceeding of Malaysian Universities Transportation Research Forum and Conferences 2010. pp. 421–432.
- Leroueil, S., Tavenas, F., Brucy, F., La Rochelle, P. & Roy, M. (1979). "Behaviour of destructed natural clays". Journal of the Geotechnical Engineering Division, American Society of Civil Engineers, Vol. 105, No. 6, pp. 759-778.
- Li K. S., (2003). "Discussion of "first order rate equation in geotechnical engineering."J. Geotech. Geoeniron. Eng., 129(8), 778-780.
- Li Bo, Huang Maocai, Cheng Yue, Ye Guanbao, Xiang Peilin. (2013). "Field test and numerical analysis of composite foundation with long and short piles under embankment." Zhongguo Gonglu Xuebao/China Journal of Highway and Transport., Volume 26, Issue 1, January 2013, Pages 9-14.
- Liu H. L, Ng C.W.W, Fei K., (2007). "Performance of a geogrid reinforced and pilesupported highway embankment over soft clay: case study". J Geotech Geoenviron Eng 133(12):1483–1493
- Liu C. and Evett J. B., (2000). "Soil and Foundations." 7th Ed., Prentice Hall. Pearson.
- Lo D. O. K. (1991). "Soil improvement by Verlicoi Drains". Ph.D thesis, University of Illinois at Urbana-Champaign, 292 P.Indraratna B., and et al. 2005.
 "Analytical and Numerical Modelling of Soft Soil Stabilized by Prefabricated Vertical Drains Incorporating Vacuum Preloading". International Journal of Geomechanics, ASCE.
- Long, P.V., Bergado, D. T., Nguyen L.V. and Balasubramaniam A.S. (2013). "Design and Performance of Soft Ground Improvement using PVD with and without Vacuum Consolidation" Geotechnical Engineering Journal of the SEAGS & AGSSEA. Vol. 44 No.4 December 2013 ISSN 0046-5828
- Magnan J. P., (1994). "Methods to Reduce the Settlement of Embankments on Soft Clay: A Review". In: Yeung, A.T., Félio, G.Y. (Eds.), Vertical and Horizontal Deformations of Foundations and Embankments, p.77-91
- Mc. Gown A., Cook, J. R., (1994). "Origin and nature of Malaysian weathered rocks and soils". Keynote Paper, Geotropika '94, Regional Conference in Geotechnical Engineering, Malacca, Malaysia

- Mesri G. And Vardhanabhuti B., (2005). "Secondary Compression." Journal of Geotechnical and Geoenvionmental Engineering © ASCE/March 2005.10.1061/(ASCE)1090-024(2005)131:3(398)
- Mesri G., and Godlewski P. M., (1977). "Time and Stress Compressibility Interrelationship." J. Geotech. Eng. Div Am Soc. Civ. Eng., 103(5), 417-430.
- Mesri, G. and Khan, A. Q., (2012). "Ground improvement using vacuum loading together with vertical drains". J. Geotech. Geoenviron. Eng. ASCE, 138(6): 680-689.
- Mikasa M., (1965). "The consolidation of soft clay—a new consolidation theory and its application". Tokyo: Japan Society of Civil Engineering 1965:21–6.
- Muhamad Suhail Badrul Jamil, Majdi Bin Mohamad and Nafisah Abdul Aziz., (2002). "Privatization of Maintenance for Federal Roads in Peninsular Malaysia". Fifth Malaysian Road Conference. Paper No.23
- Naughton P. J. and Kempton G. T., (2005). "Comparison of Analytical and Numerical Analysis Design Methods for Piled Embankments". GSP 131 Contemporary Issues in Foundation Engineer. Geo-Frontiers 2005, Austin.
- NYSDOT Geotechnical Design Manual, 2013. Geotechnical Design Manual Chapter 14 Page 14-1. Ground Improvement Technology
- O'Riordan N. J. & Seaman, J. W., (1993). "Highway Embankments over Soft Compressible Alluvial Deposits: Guidelines for Design and Construction". Contractor Report 341, Transport Research Laboratory, Department of Transport, U.K
- Olson R., (1998). "Settlement of embankments on soft clays." J. Geo-tech. and Geoenvir. Engrg., ASCE, 124(4), 278–288.
- Pavement Failure Identification (PFI), (2010). Retrieved from <u>http://www.apai.net/cmdocs/apai/designguide/Appendix_A-B.pdf</u>
- Pavement Interactive, (2010). "Pavement Distress". Retrieved from <u>http://pavementinteractive</u>.org/index.php? title=Surface_Distress
- Poulos H. G., (2007). "Design Charts for Piles Supporting Embankments on Soft Clay". Journal of Geotechnical and Geoenvironmental Engineering, 133(5), 493–501.
- Poulos H. G. & Davis E. H., (1980). "Pile foundation analysis and design". John Wiley and Sons, New York

- Poulos H. G., (1993). "Settlement prediction for bored pile groups". Proc. of 2nd Int. Geot. Sem. on Deep Foundations on Bored and Auger Piles, Ghent, pp.103-117.
- Poulos, H. G., (2000). "Foundation settlement analysis Practice versus Research". The 8th Spencer J. Buchanan Lecture.
- Quigley P., O'Malley J. and Rodgers M., (2003). "Performance of a trial embankment constructed on soft compressible estuarine deposits at Shannon, Ireland."
 Proc., Int. Workshop on Geotechnics of Soft Soils, Theory and Practice, Verlag Glückauf, Noordwijkerhout, The Netherlands, 619–624.
- Randolph M. F., (1994). "Design Methods for Pile Groups and Piled Rafts". SOA Report, 13th ICSMFE, New Delhi, 5: pp.61-82.
- Rani O. A., (2007). "The Effectiveness of Pavement Rehabilitation at Kuala Lumpur Karak Highway". Master thesis, Universiti Teknologi Malaysia.
- Reid W. M. and Buchanan, (1983). "Bridge approach support piling". Proc. Conf. on Advances in Piling and Ground Treatment, ICE, London, 267-274.
- Richart F. E., (1957). "A review of the theories for sand drains". Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 83(3), pp. 1-38.
- Rujikiatkamjorn C., Indraratna B. and Chu J., (2008). "2D and 3D Numerical Modelling of Combined Surcharge and Vacuum Preloading with Vertical Drains". International Journal of Geomechanics © ASCE
- Sandyutama, Y., Samang, L., Imran, A. M. and Harianto, T. (2015). "Full Scale Model Test of Consolidation Acceleration on Soft Soil deposition with Combination of Timber Pile and PVD (Hybrid Pile)". International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163 Issue 10, Volume 2.
- Sathananthan I. and Indraratna B., (2006). "Laboratory evaluation of smear zone and correlation between permeability and moisture content." J. Geotech. Geoenviron. Eng., 132(7), 942–945
- Satibi, S., Meij, R.V.D and Leoni, M. (2007). "FE-simulation of installation and loading of a tube-installed pile". Institutsbericht no.29, IGS, Universität Stuttgart.
- Schaefer V. R. Ed, (1997). "Ground Improvement, Ground Reinforcement, Ground Treatment". Geotechnical Special Publication No.69, American Society of civil Engineers, New York.

- Shen S.-L., Hong Z.-S., & Xu Y.-S., (2007). "Reducing differential settlements of approach embankments". Proceedings of the ICE - Geotechnical Engineering, 160(4), 215–226
- Stauffer P. H., (1973). "Cenozoic. In Geology of the Malay Peninsula". Eds. Gobbert,D.J., and Hutchison, C.S.: Wiley. Interscience, New York p. 143-176
- Sukor N., (2010). "Verification and Predicted Settlement Using Soil Instrumentation". Universiti Teknologi Malaysia
- Tan S. A., (1995). "Validation of Hyperbolic Method for Settlements in Clays with Vertical Drains". Soils and Foundations, Vol35(1), pp.101-113.
- Tan, Y.C., Gue, S.S., Ng. H. B. and Lee, P. T. (2004). "Some Geotechnical Properties of Klang Clay". Seminar on Geotechnical Engineering.
- Tan, Y.C. (2005). "Embankment over Soft Clay Design and Construction Control". Geotechnical Engineering 2005.
- Tan, Y.C., Ooi, L. H., Yeow, A. Lee, P. T. and Koo, K. S. (2010). "Instrumented Trial Embankment on Soft Ground at Tokai, State of Kedah, Malaysia." The 17th Southeast Asian Geotechnical Conference, Taipei, Taiwan.
- Tan Y. C., Chow C. M. & Gue S. S., (2008). "A Design Approach for Piled Raft with Short Friction Piles for Low Rise Buildings on Very Soft Clay". Proceedings Malaysian Geotechnical Conference.
- Tan, Y. C. (2016). "Design and Construction of Road Embankment on Soft Ground". Sabah Road Day 2016. Sustainable Road for Development Conference. Paper No. 10.
- Terzaghi K. (1925). "Principles of soil mechanics. IV. Settlement and consolidation of clay". Engineering News-Record 1925; 95:874–8.
- Terzaghi, K. and Peck, R.B., (1967). "Soil Mechanics in Engineering Practice", John Wiley And Sons, 729p.
- Thompson R., (2011). "Design Guidelines" for Increasing the Lateral Resistance of Highway-Bridge Pile Foundations by Improving Weak Soils". NCHRP Report 697.
- Tomlinson M. J., (1986). Foundation design and Construction. 5th Ed., Harlow. Longman.
- Vermeer P. A. and Neher, H. P., (1999). "A soft soil model that account for creep". Beyond 2000 in computational geotechnics, Balkema, 249-261.

- Wijeyakulasuriya V., Hobbs G. and Brandon, A., (1999). "Some experiences with performance monitoring of embankments on soft clays". 8th ANZ Conference on Geomechanics, Hobart, Vol. 2, 783-788.
- Wood, H. J., (2003). "The design and construction of pile-supported embankments for the A63 Selby Bypass." Proc., Foundations: Innovations, Design and Practice, Dundee, Scotland, 941–950.
- Yin J. H., (1999). "Non Linear Creep of Soil in Oedometer Tests." Geotechnique. 49(5), 699-707.
- Yin, J.-H. & Zhu, J. G., (1999). "Elastic visco-plastic consolidation modelling and interpretation of pore water pressure responses in clay underneath Tarsiut Island". Canadian Geotechnical Journal, 36(4), 708-717.
- Yoshihiko T.; Hidetoshi O.; Yoshinori S. and Kazuya Y. (1988), "Case Studies on Long-term Settlement of Soft Clay Ground". International Conference on Case Histories in Geotechnical Engineering. June 1-5,1988, St. Louis, Mo., Paper No. 3.23.
- Zaidi, M. (2007). "Effectiveness of road maintenance management in Klang district" Master's thesis, Universiti Teknologi Malaysia, Faculty of Civil Engineering.
- Zanziger H. and Gartung E., (2002). "Performance of a geogrid reinforced railway embankment on piles." Proc., 7th Int. Conf. on Geosynthetics, Swets & Zeitlinger, Nice, France, 381–386.