

FINITE ELEMENT MODELING OF HIGHWAY EMBANKMENTS OVER SOFT SUB-SOIL CONDITIONS

This thesis was submitted to the Department of Civil Engineering of the University of Moratuwa in partial fulfillment of the requirements for the Degree of Master of Science



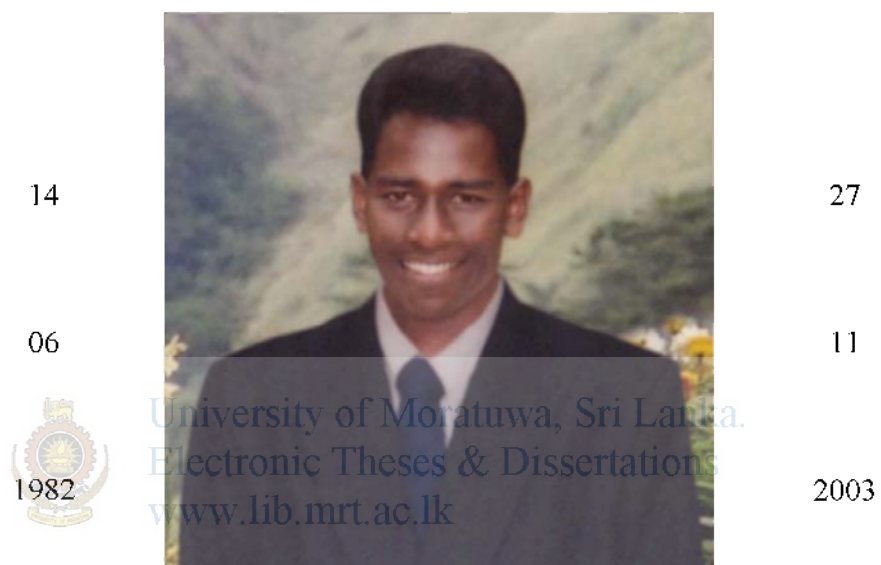
University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Ketheeswaravenayagan Rateenam

Department of Civil Engineering
University of Moratuwa
Sri Lanka

March 2006

Dedication



This thesis is dedicated to my brother Master.R.Thavaseelan (Sathees), the key person of our family, who died under tragic circumstances while I was involved in this work

DECLARATION

The work included in this thesis in part or whole, has not been submitted for any other academic qualification at any institution.

.....
Signature of the candidate.
R.Ketheeswaravenayagan
Department of Civil Engineering
University of Moratuwa
Sri Lanka



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

.....
Signature of the Supervisor
Dr.U.G.A.Puswewala
Department of Civil Engineering
University of Moratuwa
Sri Lanka

Abstract

Several major proposed infrastructure development are being planned over areas underlain by weak or soft soils. One such project is the Colombo-Katunayaka Expressway (CKE). This passes over the peaty soils of Muthurajawela marshy areas, and requires extensive ground improvement techniques. Among such techniques used so far are the installations of Pre-fabricated Vertical Drains (PVD), preloading with or without PVD's and Sand Compaction Piles.

This research considers selected CKE embankment segments to be numerically modeled using a finite element software named 'Geo-Slope'. The simulations are done under plane strain conditions, and results are compared with field monitored data obtained by the RDA through instrumentation of the CKE embankment. A large scale laboratory test conducted by Kugan (2004), with and without a central PVD installed, is also modeled using axisymmetric finite element analysis by Geo-Slope.

The finite element simulations involve an accurate evaluation of material parameters for a finite element mesh representing the actual geometrical conditions of CKE embankment segments and the large scale laboratory consolidation tests on peat taken from CKE route. The preloadings in all cases have been in stages. An extensive FE analysis program is carried out to verify the most suitable constitutive model to represent the behaviour of peaty soil, and the parameter for proper representation of the prefabricated vertical drains. It is found that the modified cam clay model combined with linear elastic models give good comparison with observed data.

The influence of equivalent geometry, different soil models, Young's moduli, geotextile, smear resistance and well resistance are taken into account for FE analysis. Here one segment is chosen for analysis as a section with composite soft ground treatment using vertical drains. Initial conditions are estimated by using the insitu analysis, and subsequent analysis is performed under different conditions to predict settlement behaviours, excess pore water pressure and Degree of Consolidation (DOC). The reported field and experimental data are compared with the predicted numerical results. Settlement characteristics, excess pore water pressure generation and dissipation and DOC are discussed in view of stage loading and the seepage of pore water.

ACKNOWLEDGEMENT

This thesis has been prepared for “Finite Element Modeling highway embankments over soft sub-soil conditions”. Even a small research owes its existence to many more people than the one whose name appears as researcher. Among those who deserve credit for the assistance extended during the research programme, Dr.U.G.A.Puswewala, who proved an excellent supervisor to work with, has contributed a great deal to this research. His guidance, support, motivation in the correct time and stimulating criticisms made the research a complete success. I wish to acknowledge and express my gratitude to Mr.M.B.S.Fernando, who guided me throughout the study period as well as arranged the industry contacts. The support of the Dr.S.A.S.Kulathilake is highly appreciated. His devotion in the subject of soft ground improvement is also acknowledged. I express my sincere thanks to Dr.H.S.K.Thilakasiri and Dr.T.A.Peiris for giving necessary support and guidance. This research was conducted as part of a post-graduate degree program funded by the Ministry of Science and Technology Personnel Development Project of Sri Lanka, and the Asian Development Bank. The author wishes to express their appreciation to these funding organizations and their consideration is very much appreciated.

The writer gratefully appreciates the support of the Road Development Authority (RDA). The author would like to express their gratitude to the CKE Division of RDA for providing the instrumentation, monitoring, and relevant field and lab data of the trial embankment area results as well as their cooperation and support. The author would like to place on record gratitude and indebtedness to the General Manager, RDA and Mr. W.A.S Weerasinghe-Project Director, CKE Division, RDA, for the permission to collect the relevant data as well as the motivation on to do this research. The writer also wishes to acknowledge the assistance of Senior Engineer Mr.J.N.Lodiwick and Engineer Mr.P.W.A.Samanpali from CKE Soft Ground Improvement division, RDA and also the gratitude to Engineer Mr.K.A.S.Somapala; CKE Division, RDA.

Heartfelt thanks are to Transportation Engineering Division, University of Moratuwa, Sri Lanka for providing the research laboratory and relevant facilities. I would like to acknowledge the assistance extended by traffic engineering laboratory staff. The

assistance received from computer unit of Department of Civil engineering of the University of Moratuwa, during the analysis period is acknowledged. I take this opportunity to thank to all people names who may not have been mentioned above.

Rateanam Ketheeswaravenayagan

22-12-2005



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

CONTENTS

	Page No.
Declaration	i
Abstract	ii
Acknowledgement	iii
Contents	v
List of Figures	ix
List of Tables	xiii
CHAPTER 1	
Introduction	01
1.1 General background	01
1.2 Land, infrastructure and traffic problems in Sri Lanka	03
1.3 Local Peaty soils	04
1.4 Problems on embankment construction over soft soil and possible solutions	05
1.5 Scope and Objective of research	08
1.6 Arrangement of the thesis	10
CHAPTER 2	
SGI techniques, monitoring and the CKE project	11
2.1 Soft Ground Improvement (SGI) methods	11
2.1.1 Excavation and backfill	13
2.1.2 Deep mixing method	13
2.1.3 Electro osmosis process	14
2.1.4 Vacuum consolidation	15
2.1.5 Dynamic compaction	16
2.1.6 Vibro compaction	16
2.1.7 Geotextiles	16
2.1.8 Preloading	17
2.1.9 Piling	18
2.2 SGI composite treatments	20
2.2.1 Preloading with berm	20
2.2.2 Preloading with Sand Compaction Pile or Stone Column as Vertical Drains	20
2.2.3 Preloading with PVD	22

2.3 CKE project	23
2.3.1 Methodology adopted for the CKE embankment constructions	23
2.3.2 Brief description of trial areas and test embankment	25
2.4 Ground monitoring techniques	26
CHAPTER 3	
Basic concepts and application of Geo-slope	28
3.1 Basic concepts	28
3.1.1 Stress-strain behaviour of soil	28
3.1.2 Components of settlements	29
3.1.3 Excess Pore Pressure and Degree of Consolidation	33
3.1.4 Prefabricated Vertical Drain (PVD)	34
3.1.5 Cylindrical drain equivalent area	36
3.1.6 Smear resistance	37
3.1.7 Well resistance	37
3.1.8 Effect of horizontal to vertical permeability ratio	38
3.2 Material models	38
3.2.1 Linear elastic model and relevant parameters	38
3.2.2 Modified Cam Clay (MCC) model	40
3.3 Finite Element Method (FEM)	42
3.4 Applications of Geo-Slope	44
3.4.1 Introduction to the software tools of Geo-Slope	44
3.4.2 Finite element stress and deformation analysis using Sigma/W	44
3.4.2.1 Linear elastic model	46
3.4.2.2 Constitutive equation for soil structure	46
3.4.2.3 Flow Equation for Water Phase	47
3.4.3 Seep/W for seepage analysis	47
3.5 Coupled consolidation analysis using soft clay model	48
3.5.1 Modified Cam Clay (MCC) model	49
3.5.2 Finite Element formulation for coupled analysis	50
3.6 Brief descriptions of the general aspects for the modelling	51
3.6.1 Defining and modelling the coupled consolidation problem using Sigma/w and Seep/W	51
3.6.2 Techniques for establishing initial in-situ conditions	55

3.6.3 Applications of initial Insitu stresses and Pore Water Pressures using Sigma/W	56
3.6.4 Techniques to establish hydraulic conditions for coupled analysis	57
CHAPTER 4	
Finite Element simulation of CKE segments (with and without VD) using Geo-slope and sensitivity analysis	58
4.1 Case study of 11340 11440 and 11240 sections	58
4.2 Parametric study	59
4.3 Equivalent diameter and permeability for vertical drain	60
4.4 Sensitivity of software and evaluation of basic parameters for soft peaty clay	60
4.4.1 Methodology adopted by Kugan et.al, (2003) for the test using the large-scale consolidation model	60
4.4.2 Numerical simulation of the model test	61
4.5 General modelling sequence for embankments over soft soil	64
4.5.1 Preloading (PL) segment 11950	67
4.5.2 Preloading with Sand Compaction Pile segment (PL+SCP- 19190)	71
4.5.3 Preloading with PVD (PL+PVD)	74
4.5.3.1 Modelling of PVD section with preloading (PL+PVD 19390)	75
4.5.3.2 Modelling and simulation of CKE PVD improved segment with Preloading (PL+PVD 11240)	78
4.5.4 Preloading with SCP and PVD (PL+SCP+PVD-11840)	81
CHAPTER 5	
Results	84
5.1 Parameter evaluations	84
5.2 Proposed equivalent diameter equation and formula derivation for combined approach	84
5.2.1 Equivalent diameters for cylindrical drains	84
5.2.2 Combined approach scheme for derivation of permeability for the VD modelling in plain strain	85
5.3 Case Study of trial sections	86

5.4 Large-scale consolidation test (Kugan 2004) prediction and parameter study	88
5.4.1 Comments on the limitations of the software	92
5.5 Numerical predictions and comparisons of embankment segments	93
5.5.1 Preloading segment-11950	93
5.5.2 Preloading with SCP segment –19190	98
5.5.3 Preloading with PVD segments	105
5.5.3.1 Numerical results for 19390	106
5.5.3.2 Numerical results for 11240 segment	110
5.5.4 Numerical results for preloading with VD improved composite segment -11840	113
CHAPTER 6	
Discussion and general comments	118
6.1 Linear elastic parameter evaluation for soft peaty soil	118
6.2 Equivalent influence diameter for cylindrical drains and formula applicable for VD modeling under plane strain seepage	118
6.3 Case study of trial areas	118
6.4 Concluding comments for large scale prediction and comparison	121
6.5 Discussion for embankment sections	122
6.5.1 Special concluding remarks for preloading section	124
6.5.2 Special concluding remarks for preloading with SCP	125
6.5.3 Concluding remarks for preloading with PVD sections	125
6.5.4 Special concluding remarks for composite segment 11840 (PL+PVD+SCP)	126
CHAPTER 7	
Summary and conclusions	128
7.1 Summary	128
7.2 Conclusions	129
7.3 Observation and recommendations	131
7.4 Suggestion for future research areas	131
REFERENCES	132

List of Figures

	Page No.
Figure 1.1 Location of proposed and on going highways	04
Figure 1.2 Location of Colombo Katunayaka Expressway (CKE)	06
Figure 2.1 SGI selection flow chart with preloading and vertical drains (RDA, 1999)	12
Figure 2.2 The arrangement of the vacuum consolidation	15
Figure 2.3 Dynamic compaction in progress	16
Figure 2.4 Different load effects on preloading	18
Figure 2.5 Dry bottom feed vibro displacement method	21
Figure 2.6 Vertical drains connected to the permeable layer	22
Figure 2.7 Typical type of PVD cross section	22
Figure 2.8 Seepage under preloading and preloading with PVD	23
Figure 2.9 Geotextile spread over the original ground and the construction of sand mat and fill	24
Figure 2.10 Trial segment areas and selected sections for analysis	25
Figure 2.11 Typical sectional view of the instrumented highway embankment	26
Figure 2.12 Typical plan view of the positions of monitoring equipment installed in the embankment	27
Figure 2.13 Settlement plate installation and monitoring	27
Figure 3.1 Graph for calculating immediate settlement under embankment load (Giroud, 1973)	30
Figure 3.2 Graph of influence factors for calculation of immediate settlement	31
Figure 3.3 Equivalent diameter of a PVD (After Rixner et al, 1986)	35
Figure 3.4 Square and triangular grid pattern; equivalent diameter of PVDs	35
Figure 3.5 Equivalent area geometry for the cylindrical VD's	36
Figure 3.6 Definition of soil parameters for Modified Cam Clay model	41
Figure 3.7 Plan view of the water dissipation in unit cell	42
Figure 3.8 Yield curve for the Cam-Clay model	49
Figure 3.9 Yield function for Modified Cam-Clay	49
Figure 3.10 Typical Volumetric Water Content curve	54
Figure 3.11 Typical insitu analysis embankment mesh	56

Figure 4.1 Schematic diagram of model test apparatus	60
Figure 4.2 Finite Element meshes with PVD and drain material	63
Figure 4.3 Typical embankment modelling using Sigma/W	65
Figure 4.4 Typical embankment modelling using Seep/W	66
Figure 4.5 Profile of subsurface conditions across 11950 location	67
Figure 4.6 Finite element mesh for 11950 section	70
Figure 4.7 Finite Element Mesh for 19190 section	72
Figure 4.8 Finite Element Mesh for 19390 section	76
Figure 4.9 Finite Element Mesh for 11240 Section	79
Figure 4.10 The sub surface profile of 11840 location	82
Figure 4.11 11840 Finite element mesh with vertical drains	83
Figure 5.1 Equivalent area geometry for the cylindrical VD's	85
Figure 5.2 Monitored field data on surface settlement with construction of embankment and development of PP (11340 Section; CKE)	86
Figure 5.3 Monitored field data on surface settlement with construction of embankment and development of PP (11440 section; CKE)	87
Figure 5.4 Monitored field data on surface settlement with construction of embankment and developed PP (11240 section; CKE)	88
Figure 5.5 Monitored field data on surface settlement at the centre and heaving away from 3.0m and 6.0m from the toe (11240 section; CKE)	88
Figure 5.6 (a) (b) Comparisons of simulated settlement versus time curves for with PVD and without PVD modelled conditions for equivalent geometry. (Experimental results after Kugan (2004))	89
Figure 5.7 Comparisons of simulated FEA results with experimental data for EPP	90
Figure 5.8 Presence of PVD the PP Variations with in the system (PWP contour values are in kPa)	91
Figure 5.9 Variations of DOC with and without PVD	92
Figure 5.10 Comparison of the consolidation settlement for 2D plane strain analysis at 11950 centre	93
Figure 5.11 Predicted settlement 12.5m away from the centre of embankment	94
Figure 5.12 Predicted EPP below 2.0m and 4.0m depth at the centre of embankment	94
Figure 5.13 X-Y deformation patterns	95
Figure 5.14 Deformation pattern and heaving for Case 3	95

Figure 5.15 Basin analysis for case 3	96
Figure 5.16 Prediction of horizontal displacements 3.0m away from the toe for case 3	96
Figure 5.17 Predicted total stress variation under the embankment for case 3	97
Figure 5.18 Predicted effective stress variation under the embankment for case 3	97
Figure 5.19 Predicted PWP variation under the embankment for case 3	97
Figure 5.20 Total head variation and seepage vector for case 3	98
Figure 5.21 Comparison of the surface settlement for plane strain analysis under different situations	99
Figure 5.22 Comparison of the surface settlement 12.5m away from the centre; with and without SCP	99
Figure 5.23 Comparisons of EPP variations under 2.0m depth from the surface	100
Figure 5.24 Comparisons of Y heave 3m and 6m away from the toe	100
Figure 5.25 Comparisons of predicted and measured XY heave 3m and 6m variations away from the toe	101
Figure 5.26 Total stress variations with the stage loading for case 4	102
Figure 5.27 PWP variations with time for case 4	103
Figure 5.28 Y displacement variation contours for case 4	104
Figure 5.29 Total head and PWP variations with the seepage vectors under with and without SCP situation	105
Figure 5.30 Settlement and displacement for the embankment with vertical drain for case 4	105
Figure 5.31 Comparison of the average surface settlement for equivalent plane strain analysis	106
Figure 5.32 Comparison of surface settlement behaviour 12.5m away from the centre	106
Figure 5.33 Comparison of predicted and measured EPP under 2m depth from the surface	107
Figure 5.34 Comparison of predicted and measured DOC under 2m depth from the surface	107
Figure 5.35 Vertical displacements at ground surface of the embankment with vertical drains for case 2	108
Figure 5.36 Lateral inclination profile for case 2, 3m away from the toe	108
Figure 5.37 Prediction of XY heave at the toe region	109

Figure 5.38 Total stress variation for case 2	109
Figure 5.39 Y displacement variation for case 2	109
Figure 5.40 PP variation for case 2	110
Figure 5.41 Comparisons of Predicted surface settlements at centre of embankment	110
Figure 5.42 Comparisons of Predicted surface settlement 12.5m away from centre	111
Figure 5.43 Comparisons of Predicted and Field EPP variations	111
Figure 5.44 Comparisons of Predicted and Field DOC variations	112
Figure 5.45 The variation of total stress with time and loading	112
Figure 5.46 Total head and PWP contours on 334 day	113
Figure 5.47 Pore water dissipation and total head without PVD situation	113
Figure 5.48 Comparison of the average surface settlement at the centre for 2D plane strain analysis	114
Figure 5.49 Compared settlement 12.5m away from the centre of embankment	114
Figure 5.50 Predicted and monitored EPP below 5.3m depth at the centre of embankment	115
Figure 5.51 Observed and predicted EPP below 2.5m depth at the centre of embankment	115
Figure 5.52 Total stress variations for case 2	116
Figure 5.53 Y displacement variations for case 2	116
Figure 5.54 Total head and seepage variations for case 2	117
Figure 5.55 PWP and seepage variations for case 2	117

List of Tables

	Page No.
Table 2.1 Criteria of soft ground classification (RDA, 1999)	13
Table 3.1 The relationship between SPT's 'N' value and Young's modulus (Bowels, 1996)	39
Table 3.2 The different relative bearing term used for unit weight of the soil	40
Table 4.1 Linear Elastic parameters for settlement and PWP analysis (after Kugan (2004) and Bowels (1996))	62
Table 4.2 Relevant MCC parameters	63
Table 4.3 Relevant parameter for the seepage analysis	63
Table 4.4 Summary of Linear Elastic and other relevant parameters for the coupled consolidation analysis of 11950 PL segment	68
Table 4.5 Relevant Modified Cam Clay parameters for organic soil (case 2) (RDA, 1999)	69
Table 4.6 Linear Elastic and other relevant parameters for the coupled consolidation analysis for 19190 SCP section	72
Table 4.7 Modified Cam Clay parameters for Peaty soil-19190 (RDA, 1999)	73
Table 4.8 Coupled consolidation analysis parameters and relevant soil properties for 19390 PVD section	77
Table 4.9 Relevant Modified Cam Clay parameter for Peaty clay-19390	77
Table 4.10 Summary of Linear Elastic parameters and relevant parameters for seepage analysis	80
Table 4.11 Relevant Modified Cam Clay parameter for Peat	81
Table 4.12 Summary of Linear Elastic model parameters and relevant soil properties for the coupled consolidation analysis for PL+SCP+PVD, 11840, section	84
Table 4.13 Relevant Modified Cam Clay parameter for Peaty soil	85
Table 5.1 Summary of Young modulus from CD test (after Kugan, 2004)	84
Table 5.2 Summary of Young modulus from UU test (after Kugan, 2004)	84