

Embankment construction projects on very soft soil often give rise to serious problems. This volume on geotechnics and soft soil engineering therefore treats all phases of the design and construction process exhaustively, from the first investigation step to the monitoring of constructed work. The book presents the development concepts necessary for the project stages and discusses in great detail construction methods, displacement estimations, stability analyses, monitoring, and various other aspects involved. Extensive attention is furthermore paid to the application of geosynthetics as a tool to improve the stability of soft soils and embankments. Including various tables and practical data for many geographical areas in the world, this reference volume is essential reading for engineers and researchers in geotechnical engineering, construction, and related disciplines.

Design and Performance of Embankments on
Very Soft Soils

Márcio de Souza Almeida &
Maria Esther Soares Marques

Design and Performance of Embankments on Very Soft Soils

*Márcio de Souza Almeida &
Maria Esther Soares Marques*

 **CRC Press**
Taylor & Francis Group
an informa business
www.crcpress.com

6000 Broken Sound Parkway, NW
Suite 300, Boca Raton, FL 33487
Schipholweg 107C
2316 XC Leiden, NL
2 Park Square, Milton Park
Abingdon, Oxon OX14 4RN, UK

 **HUESKER**
series
engineering
with geosynthetics



 **CRC Press**
Taylor & Francis Group
A BALKEMA BOOK

Table of contents

<i>Preface</i>	xi
<i>About the authors</i>	xiii
<i>Acknowledgements</i>	xv
<i>List of symbols</i>	xvii
<i>Introduction</i>	xxvii
I Construction methods of embankments on soft soils	I
1.1 Replacement of soft soils and displacement fills	1
1.1.1 Replacement of soft soils	1
1.1.2 Displacement fills	3
1.2 Conventional embankment with temporary surcharge	5
1.3 Embankments built in stages, embankments with lateral berms and reinforced embankments	6
1.4 Embankment on vertical drains	6
1.5 Lightweight fills	7
1.6 Embankments on pile-like elements	9
1.7 Construction methodologies for harbor works	9
1.8 Final remarks	12
2 Site investigation	15
2.1 Preliminary investigations	15
2.1.1 Borings	15
2.1.2 Characterization	17
2.2 Complementary investigations	18
2.2.1 <i>In situ</i> tests	19
2.2.2 Laboratory tests	19
2.3 Vane tests	21
2.3.1 Equipment and procedures	21
2.3.2 Undrained strength	21
2.3.3 Clay sensitivity	22
2.3.4 Stress history	24
2.3.5 Clay anisotropy	24
2.3.6 Test correction	25
2.4 Piezocone test	26
2.4.1 Equipment and procedures	26
2.4.2 Correction of cone resistance	26

2.4.3	Preliminary soil classification	27
2.4.4	Undrained strength (S_u)	27
2.4.5	Stress history	29
2.4.6	Coefficient of consolidation	31
2.5	T-bar test	33
2.6	Soil sampling for laboratory tests	33
2.7	Oedometer consolidation tests	34
2.7.1	Other consolidation tests	35
2.7.2	Sample quality	35
2.8	Triaxial tests	38
2.9	Final remarks	38
3	Geotechnical properties of very soft soils: Rio de Janeiro soft clays	41
3.1	Overall behavior of very soft soils: Cam clay models	41
3.1.1	Stress and strain variables	41
3.1.2	Model parameters	42
3.1.3	Yield conditions	45
3.2	Index properties of some Rio de Janeiro clays	47
3.3	Compressibility and stress history	49
3.3.1	Compressibility	49
3.3.2	Overconsolidation ratio (OCR)	50
3.4	Hydraulic conductivity and coefficient of consolidation	50
3.5	Soil strength	52
3.5.1	Undrained strength – laboratory and <i>in situ</i> data	52
3.5.2	Effective strength parameters	54
3.6	Deformation data	55
3.7	Viscous behavior	56
3.7.1	Strain rate during shearing	56
3.7.2	Strain rate during constant loading oedometer tests	56
3.8	Field studies	58
3.8.1	Embankment I	58
3.8.2	Embankment II	59
4	Prediction of settlements and horizontal displacements	63
4.1	Types of settlements	63
4.1.1	Immediate settlement	64
4.1.2	Primary consolidation settlements	64
4.1.3	Secondary compression settlement	72
4.2	Staged embankment settlements	76
4.3	Prediction of horizontal displacements	79
4.4	Final remarks	82
5	Acceleration of settlements: use of vertical drains and surcharge	83
5.1	Embankments on vertical drains	83
5.2	Vertical drains	84
5.2.1	Theoretical solutions	84
5.2.2	Consolidation with purely radial drainage	85
5.2.3	Diameter of influence and equivalent diameter of PVDs	86

5.2.4	Consolidation with combined radial and vertical drainage	87
5.2.5	Influence of smear in PVD performance	88
5.2.6	Influence of mandrel size on soil disturbance	88
5.2.7	Parameters for consideration of disturbance (smear)	89
5.2.8	The effect of well resistance	91
5.2.9	Specification of PVD	92
5.2.10	Sequence for radial drainage calculations	92
5.3	Design of the horizontal drainage blanket	93
5.4	Use of temporary surcharge	95
5.4.1	Use of surcharge with and without vertical drains	96
5.4.2	Vacuum preloading	97
5.4.3	Use of surcharge to minimize secondary compression settlements	99
5.5	Final remarks	100
6	Stability of unreinforced and reinforced embankments	103
6.1	Design parameters	103
6.1.1	Undrained strength of clay	103
6.1.2	Embankment strength	104
6.1.3	Geosynthetic reinforcement parameters	106
6.2	Failure modes of embankments on soft soils	111
6.3	Foundation failure: Critical height of embankment	111
6.4	Global stability analysis of unreinforced embankments	112
6.4.1	Circular failure surfaces	112
6.4.2	Non-circular failure surfaces	113
6.5	Reinforced embankments	115
6.5.1	Effects of reinforcement	115
6.5.2	Foundation failure	116
6.5.3	Failure due to lateral sliding of embankment	116
6.5.4	Global failure	118
6.5.5	Definition of tensile force in reinforcement	118
6.6	Stability analysis of stage constructed embankments	120
6.6.1	Conceptual aspects	120
6.6.2	Undrained strength of the clay for staged construction	120
6.6.3	Illustration of stability analysis of staged construction	122
6.6.4	Considerations on the stability analysis for staged constructed embankments	124
6.7	Sequence for stability analysis of embankments on soft soils	124
6.7.1	Unreinforced embankments	124
6.7.2	Reinforced embankments	125
6.7.3	Reinforced embankment built in stages	126
6.8	Final remarks	126
7	Embankments on pile-like elements	127
7.1	Piled embankments with geosynthetic platform	129
7.1.1	The working platform settlement and overall embankment behavior	130

7.1.2	Arching effect on soils	131
7.1.3	Defining the geometry of piled embankments	132
7.1.4	Calculation of vertical stresses acting on the geosynthetic	133
7.1.5	Calculation of tensile force acting on the reinforcement	134
7.1.6	Case histories of piled embankments	135
7.2	Embankments on traditional granular columns	137
7.2.1	Traditional granular columns using the vibro-replacement method	137
7.2.2	Design and analysis principles	138
7.2.3	Settlement reduction factor (soil improvement factor)	140
7.2.4	Settlement computations	141
7.2.5	Stability analysis	143
7.2.6	General behavior of embankments on granular columns	143
7.3	Encased granular columns	148
7.3.1	General description	148
7.3.2	Execution methods	149
7.3.3	Calculation methods	150
7.3.4	Case histories for applications of embankments over encased granular columns	153
7.4	Final remarks	156
8	Monitoring embankments on soft soils	159
8.1	Monitoring vertical displacements	159
8.1.1	Settlement plates	159
8.1.2	Depth extensometers	161
8.1.3	Settlement Profiler	162
8.2	Measurement of horizontal displacements	162
8.3	Measurements of pore pressures	164
8.4	Monitoring of the tensile forces in geosynthetic reinforcements	165
8.5	Interpretation of monitoring results	166
8.5.1	Asaoka's method (1978)	166
8.5.2	Pore pressure analysis	167
8.5.3	Discussion on obtaining c_v and c_h from monitoring data	168
8.5.4	Stability of embankment by horizontal displacements analysis	170
8.5.5	<i>In situ</i> compression curves	171
8.6	New trends in geotechnical instrumentation	174
8.7	Final remarks	174
	References	175
	Annex	193
	Subject index	197

Preface

Even if it is an important topic in geotechnical engineering, embankments on soft or very soft soils have been the subject of few books and, to my knowledge, none recently published. This book “Design and Performance of embankments on Very Soft Soils” is thus very welcome.

The authors, Márcio Almeida and Esther Marques, have a long experience with soft soils and embankments. Indeed both did their Ph.D. on related topics. They also have an excellent knowledge of advanced soil mechanics and of new technologies for both characterizing soft soil deposits and solving settlement or stability problems, as well as field monitoring and interpretation. The book reflects this state-of-the-art knowledge. Soils are described using modern concepts of yielding and yield curves; sampling quality is considered; the use and interpretation of DMT, T-bar and piezocone soundings are described. Technologies for reducing and/or accelerating settlements and for improving stability are also described. In particular, emphasis is put on “embankments on pile-like elements” and on “vacuum preloading” with which the authors have very good experience.

With this book in English, in addition to the general technical aspects previously mentioned, Professors Márcio Almeida and Esther Marques offer the geotechnical community the remarkable and unique Brazilian experience with embankments on very soft organic soils. Very nice contribution!

Serge Leroueil,
July 2013

About the authors

Márcio Almeida earned his Civil Engineering degree at the Federal University of Rio de Janeiro, in 1974 and obtained his MSc at COPPE/UFRJ in 1977 when he joined COPPE as Assistant Lecturer. Marcio got his PhD from the University of Cambridge, UK in 1984. Then he returned to UFRJ and in 1994 became Professor of Geotechnical Engineering. His postdoc was at Italy (ISMES) and NGI, Norway in the early 1990s and he was also visiting researcher at the universities of Oxford, Western Australia and ETH, Zurich. He is currently one of the leading researchers of the National Institute of Science and Technology – Rehabilitation of Slopes and Plains (INCT-REAGEO). He has been the Director of COPPE's MBA "Post-Graduate Program in Environment" since 1998. He has published numerous articles in journals and conferences in Brazil and abroad and has supervised over 60 doctoral and master dissertations. He received the Terzaghi and Jose Machado awards from the Brazilian Association of Soil Mechanics and Geotechnical Engineering (ABMS). His experience ranges from soft clay engineering, environmental and marine geotechnics, site investigation, physical and numerical modeling as well as extensive experience in geotechnical consulting.

Esther Marques holds a degree in Civil Engineering – emphasis in Soil Mechanics, from Federal University of Rio de Janeiro. She obtained her MA and PhD in Civil Engineering from COPPE/UFRJ, with researches conducted at Université Laval, Canada. She worked at Tecnosolo and Serla and was a researcher at COPPE/UFRJ from 2001 to 2007. She is currently an associated professor at the Military Institute of Engineering, where she teaches undergraduate and graduate Transportation Engineering and Defence Engineering. She has experience in Civil Engineering with emphasis in Soil Mechanics, working mainly with the following: laboratory testing, field-testing, instrumentation, soft soils behavior, embankments on soft soils and environmental geotechnics.