



AIN SHAMS UNIVERSITY  
FACULTY OF ENGINEERING  
STRUCTURAL ENGINEERING DEPARTMENT

## **SOIL IMPROVEMENT USING STONE COLUMNS**

Thesis  
Submitted in Partial Fulfillment of the  
Requirements for the Degree of

**MASTER OF SCIENCE**  
In  
**CIVIL ENGINEERING (STRUCTURES)**

By

**MAHMOUD EL SHAWAF ABDUL AZIM ALY HAMMAD**

Supervised by

**Prof. Dr. Ali Abdul Fattah  
Ali Ahmed**  
Professor of Geotechnical  
Engineering  
Structural Department  
Faculty of Engineering  
Ain Shams University

**Prof. Dr. Yasser Moghazy  
El-Mossallamy**  
Professor of Geotechnical  
Engineering  
Structural Department  
Faculty of Engineering  
Ain Shams University

Cairo – 2014



AIN SHAMS UNIVERSITY  
FACULTY OF ENGINEERING  
STRUCTURAL ENGINEERING DEPARTMENT

Name : Mahmoud El Shawaf Abdul Azim Aly Hammad  
Thesis : Soil improvement using stone columns  
Degree : Master of science in civil engineering (Structural)

**EXAMINERS COMITEE**

Name and Affiliation	Signature
<b>Prof. Dr. Ashraf Abd El-Hay El-Ashaal</b> Professor at the Construction Research Institute – National Water Research Center	
<b>Prof. Dr. Mona Mohamed Mostafa Eid</b> Professor of Geotechnical Engineering Faculty of Engineering Ain Shams University	
<b>Prof. Dr. Ali Abdul Fattah Ali Ahmed</b> Professor of Geotechnical Engineering Faculty of Engineering Ain Shams University	
<b>Prof. Dr. Yasser Moghazy El Mossallamy</b> Professor of Geotechnical Engineering Faculty of Engineering Ain Shams University	
Date: 23 / 6 / 2014	



AIN SHAMS UNIVERSITY  
FACULTY OF ENGINEERING  
STRUCTURAL ENGINEERING DEPARTMENT

Name : Mahmoud El Shawaf Abdul Azim Aly Hammad  
Thesis : Soil improvement using stone columns  
Degree : Master of science in civil engineering

**SUPERVISORS COMITEE**

Name and Affiliation	Signature
<b>Prof. Dr. Ali Abdul Fattah Ali Ahmed</b> Professor of Geotechnical Engineering Faculty of Engineering Ain Shams University	
<b>Prof. Dr. Yasser El Moghazy El Mossallamy</b> Professor of Geotechnical Engineering Faculty of Engineering Ain Shams University	

Date: 23 / 6 / 2014

Postgraduate Studies

Authorization stamp: The thesis is authorized at / / 2014

College Board approval  
/ / 2014

University Board approval  
/ / 2014

# CURRICULUM VITAE

---

<b>Name</b>	Mahmoud El Shawaf Abdul Azim Aly
<b>Date of Birth</b>	19, April, 1986
<b>Place of Birth</b>	Cairo, Egypt
<b>Nationality</b>	Egyptian
<b>Scientific degree</b>	BSc. of Structural Engineering, Faculty of Engineering, Ain Shams University, 2008
<b>Current Job</b>	Demonstrator of Geotechnical Engineering and Foundations, Structural Engineering Department, Faculty of Engineering, Ain Shams University

## STATEMENT

---

This thesis is submitted to Ain Shams University for the degree of M.Sc. in Civil Engineering.

The work included in this thesis was carried out by the author at the Department of Structural Engineering, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

Name: Mahmoud El Shawaf Abdul Azim Aly

Signature:

Date: 23 / 6 / 2014

## ACKNOWLEDGMENT

---

First and foremost thanks to GOD for his many graces and blessings.

I wish to express my deepest gratitude and appreciation to Prof. Dr. Ali Abdul Fattah Aly, Professor of Geotechnical engineering, Structural Department, Faculty of Engineering, Ain Shams University for his kind supervision, fruitful comments and valuable advice.

My grateful appreciation also extends to Prof. Dr. Yasser Moghazy El Mossallamy, Professor of Geotechnical engineering, Structural Department, Faculty of Engineering, Ain Shams University for his patience, help, guidance, useful suggestions, dedication and encouragement throughout this research till its completion which is gratefully acknowledged and sincerely appreciated.

An appreciation and thanks to Prof. Dr. Mona Mustafa Aid and Prof. Dr. Ashraf Abdul Hay El Ashaal for their kind remarks and comments upon reviewing the thesis.

Most important, my deepest thanks and love for my father, mother and sister. Your constant and everlasting support is the reason I was able to finish this research.

Last but certainly not least, I would like to thank my gorgeous wife and my great kids for their support and patience through the ups and downs, the sleepless nights and hard times throughout this long but rewarding journey.

## ABSTRACT

---

The special nature of soft soil deposits makes it one of the most complicated soil types to work with from a geotechnical engineering point of view. There are two main problems encountered when undertaking construction projects on soft soil deposits, excessive settlement and low shear strength. Stone columns are considered one of the most effective techniques used to improve soft soil deposits. Using stone columns to reinforce soft soil deposits increases the bearing capacity, reduces the settlement and accelerates the consolidation and construction time.

Different analytical methods used to calculate and study the improvement of the soft soil deposits when reinforced with stone columns represent the final behavior of the reinforced soil, i.e. after consolidation process takes place. Finite element analysis programs can be used to study the behavior of the soft soil deposits reinforced with stone columns both during and after the consolidation process. In order to represent the problem accurately a three dimensional finite element analysis is required. However, due to the fact that two dimensional finite element analysis programs are common in practical application, a need to convert the three dimensional problem to a two dimensional configuration is needed.

One of the main objectives of this research is to investigate the different possible two dimensional configurations that can be used to model the problem of soft soil deposits reinforced with stone columns, and to recommend the configuration whose behavior is nearest to the actual behavior of the reinforced soft soil.

A case study of an embankment construction for Penchala Toll Plaza project at New Pantai Expressway, Malaysia is undertaken (Tan et al., 2008). A three dimensional finite element analysis of this case history using PLAXIS 3D is performed. A comparison between the numerically

predicted behavior and the documented actual behavior of the embankment showed a good agreement between them.

A Comparison is then done between the results of the three dimensional numerical model and different configurations for a two dimensional numerical model of the same case study. An Axisymmetric configuration, a Plane strain configuration using an equivalent width for the column and a Plane strain configuration using equivalent parameters for the column are used to numerically model the case. The results show that the axisymmetric configuration shows the best agreement with the three dimensional analysis. Also, the plane strain with equivalent parameters configuration shows more reliability by giving more accurate results than the plane strain configuration using equivalent column parameters.

A study for the performance of the stone columns is conducted. The effect of various parameters such as the embankment height, column spacing and modulus of elasticity of the column on the stress concentration factor and column load share ratio as well as settlement and time reduction factors is studied through a parametric study. The findings of this parametric study are then compared to some of the other analytical approaches used to estimate the behavior of the reinforced soft soil and a recommendation is done for the appropriate analytical methods to be used.

**Keywords:** Stone columns, soil improvement, embankments, soft soil



## SUMMARY

---

Stone columns are considered one of the most effective techniques used to improve soft soil deposits. Using stone columns as reinforcement for soft soil deposits provides the advantages of reduced settlement as well as reduction in the consolidation and hence construction time. The main objective of this research is to investigate the behavior of the soft soil reinforced using stone columns and the interaction between the soft soil and the stone columns. The research presents a numerical study using finite element analysis method using three dimensional modelling and different possible two dimensional configurations that can be used to model the problem of soft soil deposits reinforced with stone columns. A case study reported by Tan et al. (2008) of an embankment construction for Penchala Toll Plaza project at New Pantai Expressway, Malaysia, in 2003 is undertaken, and the behavior of the different models is compared to readings taken from field during and after construction. Finally, a parametric study is performed to study the effect of different factors affecting the behavior of the stone columns and its efficiency in the reduction of the settlement of the soft soil deposits and improving the soft soil behavior.

The thesis consists of seven chapters

**Chapter (1)** is the introduction to this research; it discusses the importance, the scope and the main objectives of the research.

**Chapter (2)** is a literature review which briefly discusses through the past researches the behavior of soft soil deposits reinforced with stone columns.

**Chapter (3)** presents a brief discussion about finite element method including analysis sequence and different types of elements that may be used in the analysis. Also, the finite element analysis program which is used during this research is briefly discussed.

**Chapter (4)** presents the case study description. Also, it illustrates all the three dimensional and two dimensional numerical models conducted to investigate the behavior of soft soil reinforced with stone columns under an embankment. Finally, a comparison between the numerically predicted response of different models and the monitored response is presented.

**Chapter (5)** is a parametric study performed to investigate the effect of different parameters on the behavior and performance of stone columns.

**Chapter (6)** presents a comparison between the findings of the numerically performed parametric study with some of the analytical methods used to estimate the behavior of the soft soil reinforced via stone columns

**Chapter (7)** presents the summary and the conclusions of the research. It ends up with the suggestions for future studies and research topics relevant to the subject.

# TABLE OF CONTENTS

---

TABLE OF CONTENTS .....	i
LIST OF FIGURES.....	vii
LIST OF TABLES .....	xiv
NOMECLATURE.....	xv
Chapter (1).....	1
1.1 Introduction.....	1
1.2 Research scope and objectives .....	2
1.3 Thesis outline.....	3
Chapter (2).....	5
2.1 Introduction.....	5
2.2 Stone columns.....	6
2.2.1 Stone column installation .....	7
2.3 Engineering behavior of the composite ground .....	9
2.3.1 Unit Cell .....	9
2.3.2 Load sharing and stress concentration .....	10
2.4 Settlement and bearing capacity of stone column reinforced soil.....	18
2.4.1 Experimental Studies.....	18

2.5	Consolidation rate of soft soil reinforced with stone columns .....	28
2.6	Stone columns-soft soil reinforcement system under embankment ....	34
2.7	Discussion .....	36
Chapter (3).....		38
3.1	Introduction.....	38
3.2	Finite element method .....	38
3.2.1	General .....	38
3.2.2	Analysis procedure of finite element method .....	39
3.2.3	Elements shapes .....	41
3.2.4	Two dimensional simulation of special three dimensional problems.....	43
3.2.4.1	Plane strain .....	43
3.2.4.2	Plane stress .....	44
3.2.4.3	Axisymmetric problems .....	44
3.3	Material Modeling Basics.....	46
3.3.1	General.....	46
3.3.2	Stresses .....	46
3.3.3	Strains .....	47
3.4	Constitutive Material Models .....	48

3.4.1	Linear elastic constitutive law .....	49
3.4.2	Nonlinear elastic constitutive laws .....	49
3.4.3	Elastoplastic constitutive laws.....	50
3.4.4	Elasto-visco plasticity constitutive laws.....	55
3.5	Finite element modeling program used in this research.....	57
3.5.1	General.....	57
3.5.2	Input program .....	58
3.5.2.1	Soil elements.....	59
3.5.2.2	Types of soil behavior .....	60
3.5.2.3	Boundary conditions.....	62
3.5.2.4	Mesh Generation .....	62
3.5.2.5	Initial conditions .....	62
3.5.3	Calculation.....	63
3.5.3.1	Types of calculations .....	63
3.5.3.2	Loading types .....	64
3.5.4	Output .....	65
3.6	The Mohr Coulomb model .....	65
3.6.1	Young's Modulus .....	66
3.6.2	Poisson's ratio.....	67

3.6.3	Shear strength parameters.....	68
Chapter (4).....		70
4.1	Introduction.....	70
4.2	Case study description .....	71
4.3	Back analysis of the case study .....	74
4.3.1	Constitutive law and soil parameters .....	74
4.3.2	Model geometry and boundary conditions.....	74
4.3.3	Comparison between back analysis results and the field measurements.....	77
4.4	Numerical modeling using 2D FE analyses .....	80
4.4.1	Axisymmetric model .....	83
4.4.2	Plane strain model using equivalent width.....	86
4.4.3	Plane strain model using equivalent parameters .....	90
4.5	Comparison between the 3D and 2D FE analyses .....	93
4.5.1	Settlement.....	94
4.5.2	Excess pore water pressure .....	96
4.5.3	Development of soil shear strength.....	99
4.5.4	Stability of the embankment slope .....	102
Chapter (5).....		105

5.1	Introduction.....	105
5.2	Definitions .....	106
5.2.1	Modular ratio .....	106
5.2.2	Stress concentration factor .....	106
5.2.3	Column load share ratio.....	106
5.2.4	Settlement reduction factor.....	107
5.2.5	Time reduction factor .....	107
5.3	The effect of column spacing .....	107
5.4	The effect of Stress level .....	111
5.5	The effect of modular ratio .....	114
Chapter (6).....		118
6.1	Introduction.....	118
6.2	The stress concentration factor (SCF) .....	118
6.3	The column load share ratio .....	122
6.4	The settlement reduction factor .....	126
6.5	The time reduction factor .....	129
Chapter (7).....		133
7.1	Summary.....	133
7.2	Conclusions.....	134