



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم

بسم الله الرحمن الرحيم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



HANAA ALY



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT

STABILIZATION OF EARTH SLOPE USING PILES

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

MASTER OF SCIENCE
In
CIVIL ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT
By
Mai Elsayed Abd-Elfatah

Supervised by

Prof. Dr. Mohammed Mounir Morsy

Professor of Geotechnical Engineering

Structural Engineering Department

Faculty of Engineering

Ain Shams University

Prof. Dr. Ayman Lotfy Fayed

Professor of Geotechnical Engineering

Structural Engineering Department

Faculty of Engineering

Ain Shams University

Cairo – 2021

CURRICULUM VITAE

Name	Mai Elsayed Abd-Elfatah Elsayed
Date of Birth	22 May 1993
Place of Birth	Cairo, Egypt
Nationality	Egyptian
Scientific degree	BSc. of Structural Engineering, Faculty of Engineering, Ain Shams University, 2016
Current Job	Formwork design engineer at PERI

STATEMENT

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

The author carried out the work included in this thesis 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: Mai Elsayed Abd Elfatah

Signature:

Date: 00 / 00 / 2021

Acknowledgement

First and foremost , I would like to praise and thank god, the munificent, who give me countless blessings and knowledge so that I have been finally able to accomplish the thesis.

I am extremely grateful to my supervisors Prof. Dr. Mohammed Mounir Morsy and Prof. Dr. Ayman Lotfy Fayed for their invaluable advice, continuous support, and patience during my MSc study. Their great knowledge and plentiful experience have encouraged me in all the time of my academic research.

I would also like to thank my friends for their kind help and support especially my friend George Samy.

Finally, I would like to express my gratitude to my parents, my brothers and my fiancé. Without their tremendous understanding and encouragement in the past few years, it would have been impossible for me to complete my study.

Abstract

The stability of earth slopes is a major concern of geotechnical engineers. Various construction activities require analyzing earth slopes such as highway tracks, canals, mining, earth dams, and excavations for foundations' construction.

Failure of earth slopes is always associated with the movement of the human-made fills or natural slopes. Geologists study the cause of natural slope movement and failure. At the same time, Engineers apply the principles of soil mechanics to assess the safety and develop protection and rehabilitation methods to satisfy the serviceability requirements.

Several methods could be used in stabilizing the earth slopes, such as the removal and protection method using excavation and adding a lightweight material, drainage water to decrease the pore water pressure, and reinforcement. If the removal and protection method and water drainage method are not available, reinforcement is recommended to stabilize the slope. Strengthening the slope can be adopted by many approaches: bolts, soil nails, ground anchor, and piles as a supporting element. Using piles has been considered effective and economical.

Piles are positioned either vertically or at an angle to transfer loads from the moving layers to a more stable deep substratum. The piles are installed to the ground by driving them to or drilling them into the holes.

Piles are driven into the ground or placed in drilled holes. The piled slopes' analysis methods are based on the numerical method containing the finite element method, the finite difference method, the traditional method, and the limit equilibrium method.

In this thesis, a numerical study was performed to investigate the efficiency of stabilizing slopes with piles. The verification of the models was divided into two parts. First, a 3D finite element model was developed using PLAXIS 3D V20 and verified with literature. A comparison was then made between the finite element model results and the results using the limit equilibrium method or the finite difference method. Second, another 3D finite element model was verified with a large-scale experimental model made at the University of Missouri-Columbia (2009). A parametric study was then conducted to identify the pile position's effect, inclination, length, configuration, and pile diameter. It also studied the effect of the spacing between the pile on the slope's safety and compared the results with the literature. It was found that the optimum pile's position was in the middle of the slope. The spacing between the piles has a slight effect on the factor of safety, mostly when the piles were near the crest or the toe of the slope. The vertical piles also gave a factor of safety bigger than the piles that are normal to the slope.

Keywords: Numerical analysis, pile, slope stability, factor of safety, pile position, pile direction, 3D finite element, strengthening earth slopes.

Table of content

Chapter 1 : Introduction	1
1.1. Causes of failure	1
1.2. Modes of failure	3
1.2.1. The rotational failure.....	3
1.2.2. Planner Failure	3
1.2.3. Wedge Failure	4
1.3. Methods of stabilization	5
1.3.1. Removal and Protection.....	5
1.3.2. Drainage water	6
1.3.3. Reinforcement	7
1.3.4. Piles	8
1.4. The research objectives	9
1.5. Thesis outlines	9
Chapter 2 : Literature review	11
2.1. Introduction	11
2.2. Slope stability analysis methods	11
2.3. Limit equilibrium method	13
2.3.1. Single body methods.....	15
2.3.2. Method of slices	17
2.3.3. Taylor's stability number	21
2.4. Numerical method	24

2.4.1.	Finite element method (FEM).....	24
2.4.2.	Finite difference method (FDM).....	25
2.4.3.	Shear strength reduction method	26
2.5.	Analysis of the piles	27
2.5.1.	Pressure based method.....	28
2.5.2.	Displacement-based Method.....	34
2.5.3.	Numerical method (coupled analysis)	40
2.6.	Experimental analysis	45
2.7.	Parameters affect the factor of safety of the slope	51
2.7.1.	The best position for the stabilizing piles	51
2.7.2.	The effect of the pile length.....	56
2.7.3.	Truncation of the piles	57
Chapter 3	: Case study 1	64
3.1.	Introduction	64
3.2.	Case study geometry and material	67
3.3.	Numerical model	69
3.3.1.	Constitutive model	70
3.3.2.	Mesh type	70
3.3.3.	Boundary conditions	71
3.3.4.	Model's geometry	71
3.3.5.	Model's Material.....	72
3.3.6.	Method of analysis	74

3.3.7.	Unpiled slope	74
3.3.8.	Piled slope	75
3.4.	Effect of pile position on the failure mechanism of the slope	76
3.4.1.	The piles at $X_F=9.95\text{m}$	76
3.4.2.	The piles at $X_F=12.56\text{m}$	77
3.4.3.	The Piles at $X_F=14.69\text{m}$	78
3.5.	Effect of pile spacing on the failure mechanism.....	78
3.5.1.	The spacing between the Piles = $2.5D$	79
3.5.2.	The spacing between the Piles = $3D$	80
3.5.3.	The spacing between the Piles= $3.5D$	80
3.6.	Parametric study	81
3.6.1.	Effect of the pile spacing on the factor of safety	81
3.6.2.	Effect of the pile position on the factor of safety	84
Chapter 4	: Case study 2	88
4.1.	Experiment apparatus.....	88
4.2.	Soil Properties	92
4.3.	Model geometry	93
4.4.	Model Reinforcement.....	94
4.5.	Measuring systems for collecting the data.....	96
4.6.	Testing Procedure.....	99
4.7.	Tests types	101
4.8.	Numerical model.....	102

4.8.1.	Constitutive model	103
4.8.2.	Mesh Type	103
4.8.3.	Model Boundary condition	104
4.8.4.	Material Properties	105
4.8.5.	Model geometry	107
4.8.6.	Method of analysis	108
4.8.7.	Comparing the result from the plaxis model with the experimental model	109
Chapter 5 : parametric study		113
5.1.	Material properties	113
5.2.	Model geometry	114
5.3.	Un-Piled slope	115
5.4.	The effect of pile position	117
5.5.	The effect of the spacing between piles	122
5.6.	The effect of changing the pile Length	125
5.7.	The effect of pile length under the slope on the factor of safety	126
5.8.	The effect of the pile diameter on the safety factor	128
5.9.	The effect of pile configurations	129
5.10.	The effect of the interface rigidity on the safety factor	133
5.11.	The effect of the soil properties on the safety factor	134
Chapter 6 : Summary, conclusion, and recommendations		137
5.12.	Summary	137

5.13. Conclusion.....	138
5.14. Recommendations	139
References.....	140

Table of Figures

Figure1-1 Types of the rotational failure	3
Figure 1-2 Planner Failure	4
Figure 1-3 Wedge Failure	4
Figure1-4 Removal and protection method (Wyllie and Mah, 2004).	6
Figure 1-5 Sub-horizontal drains to lower groundwater level (Holtz et al. 1996). ...	7
Figure 1-6 Rock anchors and soil nailing (Holtz et al. 1996).....	8
Figure 1-7 piled slope system (Kourkoulis et al. 2012).	9
Figure 2-1 Forces acting on a free body. (a) Culmann method (1866); (b) friction circle method (Felienius, 1927); (c) Bishop method (1955); (d) Lowe and Karafiath method (1960); (e) Spencer method (1967) (Hsai-Yang 1991).....	15
Figure 2-2 Geometry of the infinite slope.	16
Figure 2-3 Diagram for Logarithmic Spiral Analysis.....	17
Figure 2-4 Diagram for the forces acting on the slope using the ordinary method of slices.....	19
Figure 2-5 Bishop simplified method assumptions.	20
Figure 2-6 Taylor's stability number for circles passing through the toe and.....	22
Figure 2-7 Taylor's stability number for $\phi' = 0$ (Taylor 1937).....	23
Figure 2-8 Deforming the Ground between the Plies plastically [Ito and Matsui (1975)].....	30
Figure 2-9 Forces acts on un piled slope (Hassiotis et al. (1997)).	32
Figure 2-10 Forces acted on the piled slope (Hassiotis et al. 1997).	34
Figure 2-11 Basic Problem of a Pile in Unstable Slope after Poulos (1995).	36
Figure 2-12 Flow Mode after Poulos (1995).	37
Figure 2-13 Intermediate Mode Poulos (1995).....	37
Figure 2-14 Short Pile Mode Poulos (1995).....	38