EFFET OF MICROPILES IN CONTROLLING THE IMPACT OF PIPELINE DETERORTION ON ADJACENT BUILDINGS

By

NAJIA ASSEM MOHAMED MAHFOUZ

A Thesis Submitted to
The Faculty of Engineering, Cairo University
In Partial Fulfillment of the
Requirement for the Degree of
Master of Science
In
Structural Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

EFFET OF MICROPILES IN CONTROLLING THE IMPACT OF PIPELINE DETERORTION ON ADJACENT BUILDINGS

By

NAJIA ASSEM MOHAMED MAHFOUZ

A Thesis Submitted to
The Faculty of Engineering, Cairo University
In Partial Fulfillment of the
Requirement for the Degree of
Master of Science
In
Structural Engineering

Under the Supervision of

Prof. Dr. ADEL YEHIA AKL
Professor of Structural Analysis & Mechanics
Structural Engineering Department
Faculty of Engineering, Cairo University

Dr. MANAR MAHER HUSSEIN
Associate Professor
Structural Engineering Department
Faculty of Engineering, Cairo University

Dr. KAMAL GHAMERY METWALLY
Assistant Professor
Civil Engineering Department
Faculty of Engineering, Beni.-Suef University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

EFFET OF MICROPILES IN CONTROLLING THE IMPACT OF PIPELINE DETERORTION ON ADJACENT BUILDINGS

By

NAJIA ASSEM MOHAMED MAHFOUZ

A Thesis Submitted to
The Faculty of Engineering, Cairo University
In Partial Fulfillment of the
Requirement for the Degree of
Master of Science
In
Structural Engineering

Approved by the Examining Committee:

Prof. Dr. Adel Yehia Akl, Thesis Main Advisor
Professor of Structural Analysis & Mechanics, Faculty of Engineering, Cairo University

Dr. Manar Maher Hussein, Member
Associate Professor, Faculty of Engineering, Cairo University

Prof. Dr. Osman M. O. Ramadan, Internal Examiner
Professor of Structural Analysis & Mechanics, Faculty of Engineering, Cairo University

Pro. Dr. Osman El-Sayed Shallan, External Examiner
Professor of Structural Analysis & Mechanics, Faculty of Engineering, Zagazig University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2015

Engineer's Name: Najia Assem Mohamed Mahfouz
Date of Birth: 25-10-1988
Nationality: Egyptian
E-mail: Najiaassem@gmail.com
Phone: 01004777417
Address: 6th of October City – Giza.
Registration Date: 1 / 10 / 2010
A warding Date: / / 2015
Degree: Master of Science.
Department: Structural Engineering

Supervisors: Prof. Dr. Adel Yehia Akl
Dr. Manar Maher Hussein
Dr. Kamal Ghamery Metwally, Assistant Professor in Civil Engineering Dept.,Beni-Suef University

Examiners: Prof. Dr. Adel Yehia Akl
Dr. Manar Maher Hussein
Prof. Dr.Osman El-Sayed Shallan, Professor at Zagazig University
Prof. Dr. Osman M.O. Ramadan

Title of Thesis:

EFFET OF MICROPILES IN CONTROLLING THE IMPACT OF PIPELINE DETERORTION ON ADJACENT BUILDINGS

Key Words:

Pipelines, building, soil, micropile.

Summary:

Sewer pipelines deterioration had a high impact on the settlement of surrounding structures in urban areas. In this research, the effect of using micropiles in controlling the settlement of structures affected by sewer pipelines deterioration was studied. A three-dimensional finite elements model was implemented, utilizing the "ANSYS 11" software. Different parameters were investigated: the effect of the length of micropile, the distance of micropile from the footing of building, the diameter of micropile , the inclination angle from the vertical axis , and finally types of Footing.

ACKNOWLEDGEMENTS

I owe my gratitude to all those people who have made this dissertation possible and because of whom my graduate experience at Cairo University has been one that I will cherish forever.

First and foremost I would especially like to thank my advisor, ***Prof. Dr. Adel Yehia Akl*** for his generous time and commitment. Throughout my master work, he encouraged me to develop independent thinking and research skills. He continually stimulated my analytical thinking and greatly assisted me with scientific writing. He is one of the rare advisors that students dream that they will find. In the same vein, I am also obliged to my advisors ***Dr. Manar Maher Hussein*** and ***Dr. Kamal Ghamery Metwely for*** their guidance, continuous support, helpful suggestions, comments and encouragement throughout this thesis. Without their support, I could not have completed the thesis. Most importantly, all of these wouldn't have been possible without the love and patience of my family. I feel a deep sense of gratitude to ***My Parents,*** who always show persisting love and support my decision. ***My Sister and My Brother,*** have been a constant source of love, concern, support, and strength all these years.

Table of content

ACKNOWLEDGEMENTS ……...……..…….. I

TABLE OF CONTENT ……..…..……II

LIST OF TABLES ……...……..……III

LIST OF FIGURES ……..……..IV

ABSTRACT ……..…….VII

Chapter 1 : INTRODUCTION 1

1.1 Background.....1

1.2 Scope of research.....2

1.3 Layout of Thesis.....3

Chapter 2 : LITERATURE REVIEW 4

2.1 Introduction.....4

2.2 Failure in sewer pipeline.....4

2.2.1 Sewer depth..... 5

2.2.2 Age of sewer..... 6

2.2.3 Sewer size..... 7

2.3 Ground disturbance.....7

2.4 Soil/backfill type.....7

2.5 Surface movements.....8

2.5.1 Transverse behavior..... 8

2.5.2 Longitudinal behavior..... 9

2.5.3 Subsurface movements..... 9

2.6 Building damage assessment.....9

2.7 Micropile history.....10

2.8 Micropiles classification.....11

2.9 Numerical studies of soil-pipe-building interaction.....12

2.10 Building settlement due to deterioration of pipeline.....13

2.11 Fuzzy logic to predict building damage.....13

2.12 Use of micropiles to strengthening Soil 14
2.12.1 Use micropiles in foundation 14
2.12.2 Numerical modeling of micropile square footing 14
2.12.3 Numerical study on the behavior of inclined micropiles 14
2.12.4 Effect of the inclination and length of micropile 15
2.12.5 Skin friction of micropiles embedded in gravelly soils..... 15
2.12.6 Bond strength of micropile-to-grout..... 16
2.12.7 Compressive strength of micropile-to-grout 16
2.12.8 Performance of footing with micropiles 16
Chapter 3 : THEORETICAL DEVELOPMENT 17
3.1 Introduction 17
3.2 Finite element method 17
3.2.1 Solution for FEM..... 17
3.2.2 Nonlinear finite element..... 18
3.3 Material models for soil.....19
3.3.1 Linear elastic model 19
3.3.2 Mohr-Coulomb model..... 19
3.4 Material model for reinforced concrete structures 20
3.4.1 General 20
3.4.2 Concrete..... 20
3.4.3 Steel reinforcement..... 21
3.5 Interface elements.....23
3.5.1 Description 23
3.5.2 Interface model 24
Chapter 4 : FINITE ELEMENT MODELING 31
4.1 Introduction 31
4.2 The used software.....31
4.3 Validation of micropile results using ANSYS 32

4.3.1 Micropile interface element 32

4.3.2 Sewer pipeline deterioration and its effect on adjacent buildings 32

4.4 Case study.....33

4.4.1 Soil Media..... 33

4.4.2 Modeling of structure elements..... 34

4.5 Material properties.....34

4.5.1 Soil media 34

4.5.2 Modeling of structure elements..... 35

4.6 Interface element 35

4.6.1 Building and pipeline with soil media..... 36

4.6.2 Soil media and micropiles..... 37

4.7 Numerical model 38

4.8 Boundary conditions.....41

Chapter 5 : RESULTS AND DISUSSION 42

5.1 Introduction 42

5.2 Description of the analyzed models 42

5.3 Parametric study 45

5.3.1 Without failure in pipeline..... 45

5.3.2 With failure in pipeline 45

5.4 Effect of pipe settlement on building 45

5.5 Effect of micropile distance.....47

5.6 Effect of micropile length.....50

5.7 Effect of micropile angle of inclination.....53

5.7.1 Effect of angle without pipeline settlement 53

5.7.2 Effect of angle with pipeline settlement..... 54

5.7.3 Effect of angle with pipeline settlement for same vertical projection..... 56

5.8 Effect of micropile diameter.....58

5.9 Effect of number and arrangement of micropiles.....60

5.10 Effect of micropiles on types of foundation 65

Chapter 6: SUMMARY AND CONCLUSION 70

6.1 Summary.....70

6.2 Conclusions 70

6.3 Recommendations for future research work.....71

List of Tables

Table 4.1. Geotechnical parameters 35

Table 4.2. Structural elements properties 35

List of Figures

Figure 2.1: A sewer pipe deteriorating to the point of collapse due to deformation [6].. 6

Figure 2.2: Geometry of the tunnel induced settlement [16] 8

Figure 2.3: A typical construction sequence the drilling pile shaft to the required depth [23].....10

Figure 2.4: Micropile Classification based on Grouting Method [23]..... 12

Figure 2.5: Negative and positive battered piles [29] 15

Figure 3.1. Newton-Raphson method [36]..... 19

Figure 3.2: Failure criterion of Mohr-Coulomb model. [36] 20

Figure 3.3. Typical uniaxial compressive and tensile stress-strain curve for concrete. [36].....21

Figure 3.4. Idealized stress-strain diagram for reinforcing steel [36] 22

Figure 3.5: Interface element [36]..... 23

Figure 3.6. Interface points between body A and body B [36] 27

Figure 3.7. Sign convention of contact forces and displacements [36] 28

Figure 4.1. Bearing capacity graph for micropile 3m length with various inclinations .32

Figure 4.2: Effect of building location on vertical settlement of building [25]. 33

Figure 4.3: 8-Node solid element geometry[36] 34

Figure 4.4: Orientation of interface element.[36] 36

Figure 4.5: Friction model [36]..... 37

Figure 4.6: Node-to-Node Contact Elements [36]. 38

Figure 4.7: Half-space mesh of the soil, micropiles and pipe. 39

Figure 4.8: Elevation for finite element mesh for model 39

Figure 4.9: 3-D finite element mesh for R.C. building with isolated footings 40

Figure 4. 10: 3-D finite element mesh for R.C. building with strip footings..... 40

Figure 5.2: Plan of model 44

Figure 5.3: Settlement of building with and without damage in pipeline in longitudinal direction 46

Figure 5.4: Settlement of building with and without damage in pipeline in transversal direction 46

Figure 5.5: Elevation of parametric study of distance between micropile and foundation 48

Figure 5.6: Effect of micropile distance in the settlement of building without pipe failure 48

Figure 5.7: Effect of micropile distance in the settlement of building in the longitudinal direction 49

Figure 5.8: Effect of micropile distance in the settlement of building in the transverse direction 49

Figure 5.9: Elevation of parametric study of effect of micropile length 51

Figure 5.10: Effect of micropile length in the settlement of building without pipeline settlement 51

Figure 5.11: Effect of micropile length in the settlement of building in the longitudinal direction 52

Figure 5.12: Effect of micropile length in the settlement of building in the transverse direction 52

Figure 5.13: Illustration of the studied angle inclination of micropile. 53

Figure 5.14: Effect of micropile angle in the settlement of building without pipeline settlement 54

Figure 5.15: Effect of angle of micropile on the settlement under building in longitudinal direction 55

Figure 5.16: Effect of angle of micropile in the settlement under building in transverse direction 55

Figure 5.17: Effect of inclined angle 10° with the same vertical length 57

Figure 5.18: Effect of inclined angle 20° with the same vertical length 57

Figure 5.19: Elevation of parametric study of effect of micropile diameter 58

Figure 5.20: Effect of diameter of micropile in the settlement under building without pipeline settlement 59

Figure 5.21: Effect of diameter of micropile in the settlement under building in longitudinal direction 59

Figure 5.22: Effect of diameter of micropile in the settlement under building in transverse direction 60

Figure 5.23: Section plan for projection of single micropile 61

Figure 5.24: Section plan for projection of three micropiles 62

Figure 5.25: Section plan for five micropiles 62

Figure 5.26: Section plan for nine micropiles 63

Figure 5.27: Elevation of parametric study of effect of number of micropiles 63

Figure 5.28: Effect of numbers of micropiles in the settlement under building in longitudinal direction 64

Figure 5.29: Effect of arrangement of micropiles in the settlement under building in transverse direction 64

Figure 5.30: Elevation of parametric study effect of micropile on different types of foundation 66

Figure 5.31: Plan for Raft foundation 66

Figure 5.32: Plan for Strip Footing 67

Figure 5.33: Plan for Isolated Footing 67

Figure 5.34: Effect of micropiles on the building settlement for Raft foundation 68

Figure 5.35: Effect of micropile on the building settlement for Strip footing 68

Figure 5.36: Effect of micropile in the building settlement for isolated footing 69

Figure 5.37: Effect of micropile on the building settlement for different types of foundations 69

Abstract

Sewer pipelines deterioration had a high impact on the settlement of surrounding structures in urban areas. After such incidents, adjacent structures should be supported to prevent building deterioration due to continuous settlement of pipes.

Strengthening foundations with micropiles is progressively being used, due to the major advantages that this technique presents. Nevertheless, the influence of some relevant parameters in the overall behavior of the retrofitted foundations has not yet been studied. Generally, micropiles are installed in holes drilled through the existing RC footing, which are then filled with grout.

This thesis presents the numerical analysis results of three-dimensional (3-D) Finite Elements Method, utilizing “ANSYS 11" software, to simulate the relationship between: pipes, structures, micropiles and surrounding soil ,the objective is to calculate the effect of micropiles in reducing settlement of soil under building structure.

At first a soil media with properly given properties is modeled and the damage in pipeline, and its settlement are studied. Then, micropiles with variable diameter and with various lengths; 5m to 11m are added and the settlement of footing is studied.

Then, the settlement graphs for this soil with various inclinations 0 to 20 degree with the vertical axes which are used in practical usages inserted and with various number of micropiles in this soil a settlement of footing is studied. Finally, comparisons between results obtained from these studies are done. The obtained results show that use of micropiles in sandy soils leads to decrease in settlement. The results of this study can provide valuable information about use of micropiles in soils.

Chapter 1 **: INTRODUCTION**

1.1 Background

Soil-Structure interaction is widely covering several areas of civil engineering problems. The interaction between ground and several underground structural elements has a major effect in settlement in structural building. Studying soil-structure interaction for several cases is most important to control damage in structural building. Nowadays studying numerical models for soil-structure interaction by software could appropriately simulate the real case for buildings.

One of the most important problems of soil structure interaction is sewer pipelines deterioration had a high impact on the settlement of surrounding structures in urban areas. After such incidents, adjacent structures should be supported to prevent building deterioration due to continuous settlement of pipes.

Micropiles has a recognizable effect in increasing the bearing capacity and reducing the displacement of building particularly and in strengthening the foundations.

In this research, the study of the effect of using micropiles on settlement of building under pipelines deterioration is performed with two steps; steady state and pipeline failure state. The steady state step is concerned for effect of settlement of soil.

The pipeline failure operation is modeled by settlement of the building with using micropiles to strength building. Different parameters were investigated to reach such goal: the effect of the length of micropile, the distance of micropile from the footing of building, the diameter of micropile, the inclination angle from the vertical axis, number and arrangement of micropile, and finally types of foundation.

This paper presents the numerical analysis results of three-dimensional (3-D) Finite elements Method, utilizing the "ANSYS 11" software, to simulate the relationship between: micropiles, pipes, structures and surrounding soil to calculate the effect of micropiles in reducing the settlement of soil under building structure. ANSYS software is widely used for analyzing such cases for soil mechanics, linear, and nonlinear.