



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**

# **The Effect of Soil Structural Interaction on Evaluation of Seismic Response Reduction Factor of Multi-Story Concrete Buildings**

A Thesis Presented by

**Eng. Abdel-Rhman Salama Abdel-Hamid Ali**

B.Sc. Degree, Civil Engineering Department  
Faculty of Engineering-Minia University (2016)

Supervised by:

**Prof. Dr. Mohammed Nour El-Deen Fayed**

Professor of Structural department  
Faculty of Engineering  
Ain Shams University

**Ass. Prof. Dr. Nasr Eid Nasr**

Associate Professor of Structural department  
Faculty of Engineering-  
Ain Shams University

**Dr. Tamer Mohamed Sorour**

Assistant Professor of Geotechnical  
Engineering  
Faculty of Engineering-  
Ain Shams University

**2021**



AIN SHAMS UNIVERSITY  
FACULTY OF ENGINEERING

## **The Effect of Soil Structural Interaction on Evaluation of Seismic Response Reduction Factor of Multi-Story Concrete Buildings**

A Thesis submitted in partial fulfillment of the requirements of the degree of Master of Science  
in Structural Engineering

By

**Eng. Abdel-Rhman Salama Abdel-Hamid Ali**

B.Sc. Degree, Civil Engineering Department  
Faculty of Engineering-Minia University (June-2016)

### **Examiners Committee**

### **Signature**

**Prof. Dr. Hala Mohamed Gamal Eldin Elkady**

Professor of Civil Engineering Department  
National Research Center

.....

**Prof. Dr. Ahmed Abdel-Manaem Korashy**

Professor of Structural Engineering Department  
Faculty of Engineering, Ain Shams University.

.....

**Prof. Dr. Mohammed Nour El-Deen Fayed**

Professor of Structural Engineering Department  
Faculty of Engineering, Ain Shams University.

.....

**Ass. Prof. Dr. Naser Eid Naser Mansour**

Associate Professor of Civil Engineering Department  
Faculty of Engineering-Ain Shams University

.....

Date: 01 - 12- 2021

## **STATEMENT**

This thesis is submitted in partial fulfillment for the requirements for the degree of Master of Science in Structural Engineering, to be lodged at the Department of Structural Engineering, Faculty of Engineering, Ain Shams University.

The author carried out the work included in this thesis and no part of this work has been submitted for a degree or a qualification at any other scientific entity.

**Abdel-Rhman Salama Abdel-Hamid Ali**

Signature:.....

Date: 01 - 12- 2021

## Acknowledgment

First of all, I would like to express my appreciation to all my professors and superiors who taught me and guided me along with my whole educational and professional life.

I do present my deepest gratitude to **Prof. Dr. Mohamed Nour Eldin S.Fayed**, Professor of Structural Engineering, Faculty of Engineering, Ain Shams University for his valuable suggestions, support, guidance, and supervision throughout the research.

Deep appreciation is extended to thank **Dr. Nasr Eid Nasr**, Associate Professor of Structural Engineering, Faculty of Engineering, Ain Shams University, for his patient advice and helpful assistance throughout all phases of this work.

I would like to express my deepest gratitude and appreciation to **Dr. Tamer Mohamed Sorour**, Assistant Professor of Geotechnical Engineering Faculty of Engineering-Ain Shams University, who have a great effect on my whole life for their support, guidance, and patience.

Also, I express my deepest appreciation to all my family, "the most precious people in my life," for the confidence they have placed in me and the support and love they have showered me with throughout my life.

I would like to acknowledge the support of the Faculty of Engineering, at Ain Shams University for accepting this research and providing invaluable guidance throughout the research process.





**Ain Shams University**  
**Faculty of Engineering**  
**Department of Structural Engineering**

**Researcher Name: Abdel-Rhman Salama Abdel-Hamid Ali**

**Research Title:**

**The Effect of Soil Structural Interaction on Evaluation of Seismic  
Response Reduction Factor of Multi-Story Concrete Buildings**

**ABSTRACT**

It has been observed that the seismic behavior of concrete structures is strongly influenced not only by the seismic response of the structure but also by the seismic response of the soil under the foundations. Several studies have been conducted to consider the analysis of the seismic response of the hollow concrete structure, including the structural system of the structure, foundations, and the soil structure interaction. However, these studies are not sufficient to cover the effect of soil structural interaction on the evaluation of seismic response reduction factor of multi-story concrete buildings. Therefore, the fundamental objectives of this research study can be summarized as follows: investigating the previous studies on Soil Structural Interaction and its effect on Seismic Response Reduction Factor; investigating the effects of the SSI on the performance of seismic of multi-story Structures; and investigating the effect of different soil types and the modulus of subgrade reaction ( $k_s$ ) on the seismic design of the structural elements resisting the lateral loads. To achieve these objectives, the methods mentioned in the FEMA 2020 report are used, and a structural analysis has been applied for three buildings consisting of three, six and nine floors before and after implementing the effect of the interaction between the soil under the foundations and the structure in order to calculate the reaction modification factor “R” using the SAP2000 program. The effect of the interaction between the soil models and the fixed ones is determined according to the different types of soil by nonlinear analysis, plotting the base shear curve and displacement and determining the reaction modulation factor (R). The results discussed throughout the provided tables hereinafter together with the graphs and recommendations suggest properly rational values of the response reduction factor for the analyzed multi-story buildings when taking the soil structural interaction, to be considered in the Egyptian Design Code. Conclusions and recommendations for future work have been summarized.



## Table of Contents

<b>STATEMENT .....</b>	<b>iii</b>
<b>Acknowledgment.....</b>	<b>iv</b>
<b>Table of Contents .....</b>	<b>ii</b>
<b>List of Figures .....</b>	<b>v</b>
<b>List of Tables .....</b>	<b>xi</b>
<b>CHAPTER 1: INTRODUCTION .....</b>	<b>1</b>
1.1 AMBIT OF WORK .....	1
1.2 OBJECTIVE .....	2
1.3 FRAMEWORK OF THESIS.....	2
<b>CHAPTER 2: LITERATURE REVIEW .....</b>	<b>4</b>
2.1 INTRODUCTION .....	4
2.2 LITERATURE REVIEW .....	6
2.2.1 Soil Structural Interaction.....	6
2.2.2 Response Modification Factor.....	13
2.2.3 Pushover Analysis (P.O.A).....	21
2.3 CONCEPT OF SOIL STRUCTURE INTERACTION (SSI) .....	24
2.3.1 Determination Of The (Ks) Modulus .....	25
2.3.2 Determination Of Surface Stiffness.....	27
2.3.3 Finite Element Method For SSI.....	28
2.4 DETERMINATION OF RESPONSE MODIFICATION FACTOR (R) .....	30

2.4.3 Provisions Of The R Factor In International Codes And Guidelines.....	32
2.5 PUSHOVER ANALYSIS (NONLINEAR STATIC ANALYSIS) AND PERFORMANCE LEVEL .....	33
<b>CHAPTER 3: VERIFICATION .....</b>	<b>38</b>
3.1 GENERAL.....	38
3.2 COMPARISON EXAMPLE MODEL (1): TWO STORY RC FRAME.....	38
3.3 COMPARISON EXAMPLE MODEL (2 & 3): FOUR – EIGHT STORIES RC FRAME .....	42
<b>CHAPTER 4: NUMERICAL STUDY FOR SEISMIC PERFORMANCE FOR MULTI-STORY BUILDING CONSIDERING SSI.....</b>	<b>49</b>
4.1 GENERAL.....	49
4.2 DESCRIPTION OF MODELS AND MATERIAL PROPERTIES .....	50
4.2.1 Column And Beam Sections Of Models (Design By ECP) .....	51
4.2.2 Cases of Study .....	60
<b>CHAPTER 5: RESULTS AND DISCUSSION .....</b>	<b>61</b>
5.1 GENERAL.....	61
5.2 FUNDAMENTAL NATURAL PERIOD OF THE STRUCTURES (T) ..	61
5.3 THE PUSHOVER CURVE (P.O.C.) FOR THE STUDIES BUILDING.....	66
5.4 ESTIMATION OF RESPONSE MODIFICATION FACTOR R.....	71
FOR RC FRAMED BUILDINGS WITH 3, 6, AND 9 STORIES .....	71
FOR DIFFERENT TYPES OF SUPPORTS.....	71

<b>CHAPTER 6: SUMMARY AND CONCLUSION .....</b>	<b>79</b>
6.1 SUMMARY .....	79
6.2 CONCLUSION.....	80
6.3 RECOMMENDATION FOR FUTURE RESEARCH .....	82
<b>References .....</b>	<b>83</b>
<b>APPENDIX A THE RATIO OF STRESS OF COLUMNS.....</b>	<b>90</b>
<b>APPENDIX B THE DISTRIBUTION OF PLASTIC HINGES OF ALL STUDIES</b>	
<b>BUILDINGS .....</b>	<b>105</b>
<b>APPENDIX C PROPERTIES OF SOIL .....</b>	<b>166</b>
C.1 Soil Tests .....	166
C.2 Order Of Soil Suitability For Foundation Support .....	166
C.3 The Plasticity Index (PI) .....	167
C.4 The Typical Mass Densities Of Basic Soil Types .....	167
C.5 The modulus of elasticity (Es) .....	168
C.6 The Subgrade reaction (Ks) .....	169
C.7 The Poisson's ratio ( $\nu$ ) .....	169
C.8 Allowable bearing Pressures on soils.....	170
C.9 Interface Friction Angles. ....	171
C.10 Typical values of fundamental period for soil deposits. ....	172
C.11 Mean shear wave velocities (m/s).....	172
<b>APPENDIX D FOUNDATIONS IMPEDANCES .....</b>	<b>174</b>

## List of Figures

<b>Figure 1.1</b> the relation between super structure, the foundation, and the foundation soil interaction	1
<b>Figure 2.1</b> model of research of Seismic Analysis on Soil-Structure Interaction of Buildings over Sandy Soil) Matinmanesh and Asheghabadi 2011)	8
<b>Figure 2.2</b> model of research of Soil-structure interaction (Aydemir and Ekiz 2013)	10
<b>Figure 2.3</b> model of research of SOIL-STRUCTURE INTERACTION EFFECTS (Raheem, Ahmed, and Alazrak 2014)	11
<b>Figure 2.4</b> Winkler foundation model (Tabatabaieifar and Clifton 2016)	12
<b>Figure 2.5</b> Force displacement response of elastic and inelastic systems.	13
<b>Figure 2.6</b> Three dimensional view of example building having irregularity in the plan (Bholebhavi Rahul and Inamdar 2016)..	18
<b>Figure 2.7</b> 3D Finite Element Model (Nour, Aboul, Fayed, and El-Masry 2018)	20
<b>Figure 2.8</b> Two methods for foundation modeling approaches with vertical and rotational springs presented in FEMA (2020).	24
<b>Figure 2.9</b> Determination of subgrade reaction ( $k_s$ ).	26
<b>Figure 2.10</b> Finite element method for SSI	28
<b>Figure 2.11</b> Relationship beten force reduction factor ( $R$ ), structural over-strength ( $\Omega$ ), and ductility reduction factor ( $R_\mu$ ).	30
<b>Figure 2.12</b> Typical target performance levels.	32
<b>Figure 2.13:</b> Capacity and demand performance levels (Buyukozturk and Gunes, 2002)	34
<b>Figure 3.1</b> Material stress-strain properties.	39
<b>Figure 3.2</b> Details of Frame ( Vecchio and Emara 1992).	40
<b>Figure 3.3</b> Base shear Vs. Displacement Curves.	40
<b>Figure 3.4</b> Distribution of plastic hinges for Vecchio and Emara Frame using SAP 2000 program.	41
<b>Figure 3.5</b> Typical fixed-and Flexible base models	42
<b>Figure 3.6</b> Pushover curve of 4 and 8 story buildings for soil type ZA and ZE.	44
<b>Figure 3.7</b> Distribution of plastic hinge for fixed and flexible base.	45

<b>Figure 3.8</b> the eight stories isolated footing base with ks modulus model.	46
<b>Figure 3.9</b> Pushover curves of 8 story isolated footing base buildings for soil type ZA and ZE.	47
<b>Figure 3.10</b> Distribution of plastic hinges for fixed and Isolated Footing base.	48
<b>Figure 4.1</b> Layout of studied buildings ( Framed buildings )	50
<b>Figure 4.2</b> Stress-strain curves from programs	51
<b>Figure 4.3</b> buildings with Fixed supports	56
<b>Figure 4.4</b> buildings with spring supports	47
<b>Figure 4.5</b> buildings with isolated footing with Ks.	57
<b>Figure 4.6</b> Two methods for foundation modeling approaches with vertical and rotational springs presented in FEMA (2020).	58
<b>Figure 4.7</b> Two methods for foundation modeling approaches with vertical and rotational springs presented in FEMA (2020).	59
<b>Figure 5.1</b> Fundamental Natural period for different types of supports for 3, 6 & 9 stories RC structure, seismic zone 0.15 g (spectrum type 1)	64
<b>Figure 5.2</b> Fundamental Natural period for different types of supports for 3, 6 & 9 stories RC structure, seismic zone 0.25 g (spectrum type 1)	64
<b>Figure 5.3</b> Fundamental Natural period for different types of supports for 3, 6 & 9 stories RC structure, seismic zone 0.15 g (spectrum type 2)	65
<b>Figure 5.4</b> Fundamental Natural period for different types of supports for 3, 6 & 9 stories RC structure, seismic zone 0.25 g (spectrum type 2)	65
<b>Figure 5.5</b> pushover curve (P.O.C.) for the spectrum type 1 and zone 0.15g buildings	67
<b>Figure 5.6</b> pushover curve (P.O.C.) for the spectrum type 1 and zone 0.25 g buildings	68
<b>Figure 5.7</b> pushover curve (P.O.C.) for the spectrum type 2 and zone 0.15g buildings	69
<b>Figure 5.8</b> pushover curve (P.O.C.) for the spectrum type 2 and zone 0.25 g buildings	70
<b>Figure 5.9</b> Response Modification factor ( R) for 3, 6, and 9 stories models, seismic zone 0.15 g (spectrum type 1).	76
<b>Figure 5.10</b> Response Modification factor ( R) for 3, 6, and 9 stories models, seismic zone 0.15 g (spectrum type 2).	76
<b>Figure 5.11.</b> Response Modification factor ( R) for 3, 6, and 9 stories models, seismic zone 0.25 g (spectrum type 1).	77

<b>Figure 5.12</b> Response Modification factor ( R) for 3, 6, and 9 stories models, seismic zone 0.25 g (spectrum type 2).	77
<b>Figure A.1</b> the 3 stories stress ratio– Fixed Support	87
<b>Figure A.2</b> the 6 stories stress ratio– Fixed Support	88
<b>Figure A.3</b> the 9 stories stress ratio– Fixed Support	89
<b>Figure A.4</b> the 3 stories stress ratio– Spring support –type C	90
<b>Figure A.5</b> the 6 stories stress ratio– Spring support –type C	91
<b>Figure A.6</b> the 9 stories stress ratio– Spring support –type C	92
<b>Figure A.7</b> the 3 stories stress ratio– Spring support –type D	93
<b>Figure A.8</b> the 6 stories stress ratio– Spring support –type D	94
<b>Figure A.9</b> the 9 stories stress ratio– Spring support –type D	95
<b>Figure A.10</b> the 3 stories stress ratio– Isolated Footings –type C	96
<b>Figure A.11</b> the 6 stories stress ratio– Isolated Footings –type C	97
<b>Figure A.12</b> the 9 stories stress ratio– Isolated Footings –type C	98
<b>Figure A.13</b> the 3 stories stress ratio– Isolated Footings –type D	99
<b>Figure A.14</b> the 6 stories stress ratio– Isolated Footings –type D	100
<b>Figure A.15</b> the 9 stories stress ratio– Isolated Footings –type D	101
<b>Figure B.1</b> the 3 stories Distribution of plastic hinges (0.15g-sp2) – Fixed Support	103
<b>Figure B.2</b> the 6 stories Distribution of plastic hinges (0.15g-sp2) – Fixed Support	104
<b>Figure B.3</b> the 9 stories Distribution of plastic hinges (0.15g-sp2) – Fixed Support	105
<b>Figure B.4</b> the 3 stories Distribution of plastic hinges (0.25g-sp2) – Fixed Support	106
<b>Figure B.5</b> the 6 stories Distribution of plastic hinges (0.25g-sp2) – Fixed Support	107
<b>Figure B.6</b> the 9 stories Distribution of plastic hinges (0.25g-sp2) – Fixed Support	108
<b>Figure B.7</b> the 3 stories Distribution of plastic hinges (0.15g-sp2) – spring support - type D	109
<b>Figure B.8</b> the 3 stories Distribution of plastic hinges (0.15g-sp2) – spring support - type C	110
<b>Figure B.9</b> the 6 stories Distribution of plastic hinges (0.15g-sp2) – spring support - type D	111
<b>Figure B.10</b> the 6 stories Distribution of plastic hinges (0.15g-sp2) – spring support - type C	112

<b>Figure B.11</b> the 9 stories Distribution of plastic hinges (0.15g-sp2) – spring support - type D	113
<b>Figure B.12</b> the 9 stories Distribution of plastic hinges (0.15g-sp2) – spring support - type C	114
<b>Figure B.13</b> the 3 stories Distribution of plastic hinges (0.25g-sp2) – spring support - type D	115
<b>Figure B.14</b> the 3 stories Distribution of plastic hinges (0.25g-sp2) – spring support - type C	116
<b>Figure B.15</b> the 6 stories Distribution of plastic hinges (0.25g-sp2) – spring support - type D	117
<b>Figure B.16</b> the 6 stories Distribution of plastic hinges (0.25g-sp2) – spring support - type C	118
<b>Figure B.17</b> the 9 stories Distribution of plastic hinges (0.25g-sp2) – spring support - type D	119
<b>Figure B.18</b> the 9 stories Distribution of plastic hinges (0.25g-sp2) – spring support - type C	120
<b>Figure B.19</b> the 3 stories Distribution of plastic hinges (0.15g-sp2) – isolated footing- type D	121
<b>Figure B.20</b> the 3 stories Distribution of plastic hinges (0.15g-sp2) – isolated footing- type C	122
<b>Figure B.21</b> the 6 stories Distribution of plastic hinges (0.15g-sp2) – isolated footing- type D	123
<b>Figure B.22</b> the 6 stories Distribution of plastic hinges (0.15g-sp2) – isolated footing- type C	124
<b>Figure B.23</b> the 9 stories Distribution of plastic hinges (0.15g-sp2) – isolated footing- type D	125
<b>Figure B.24</b> the 9 stories Distribution of plastic hinges (0.15g-sp2) – isolated footing- type C	126
<b>Figure B.25</b> the 3 stories Distribution of plastic hinges (0.25g-sp2) – isolated footing- type D	127
<b>Figure B.26</b> the 3 stories Distribution of plastic hinges (0.25g-sp2) – isolated footing-	128