

AIN SHAMS UNIVERSITY FACULTY OF ENGINEERING STRUCTURAL ENGINEERING DEPARTMENT

BEHAVIOR OF LIGHTWEIGHT CONCRETE UNDER UNIAXIAL ECCENTRIC COMPRESSIVE STRESSES

A Thesis
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Doctor of Philosophy
In Civil Engineering

Prepared by

ENG. MAGED NASHAAT TAWFIK HANA

M.Sc. (2014) – Civil Engineering – Structural Department Faculty of Engineering – Ain Shams University B.Sc.(2011) in Civil Engineering Higher Institute of Engineering – El Shorouk Academy

Supervisors

PROF. AMR ALY ABDELRAHMAN

Professor of Concrete Structures, Ain Shams University, Cairo, EGYPT

PROF. HOSAM EI-DIN HASAN SELEEM

Professor of properties and Strength of Materials, Structural Engineering Department Housing & Building National Research Center, Cairo, EGYPT

ASS. PROF. SHERIF KAMAL ELWAN

Associate Professor at Department of Civil Eng., The Higher Institute of Engineering, El Sherouk City, Cairo, Egypt



AIN SHAMS UNIVERSITY FACULTY OF ENGINEERING STRUCTURAL ENGINEERING DEPARTMENT

BEHAVIOR OF LIGHTWEIGHT CONCRETE UNDER UNIAXIAL ECCENTRIC COMPRESSIVE STRESSES

A Thesis For The PhD. Degree in Civil Engineering (STRUCTURE ENGINEERING)

By
ENG. MAGED NASHAAT TAWFIK HANA

M.Sc. (2014) – Civil Engineering – Structural Department Faculty of Engineering – Ain Shams University B.Sc.(2011) in Civil Engineering Higher Institute of Engineering – El Shorouk Academy

THESIS APPROVAL

PROF. KHALED MOHIE-ELDIN SENNAH Professor of Structural Engineering, Civil Engineering Department Faculty of Engineering and Architecture Science, Ryerson University, Toronto, Canada PROF. EMAD EL SAYED AHMED ETMAN Professor, of Concrete Structure, Faculty of Engineering, Tanta University Prof. AMR ALY ABDEL RAHMAN Professor, of Concrete Structure, Faculty of Engineering, Ain Shams University.

STATEMENT

This dissertation is submitted to Ain Shams University, Faculty of Engineering for

the degree of PhD. in Civil Engineering.

The work included in this thesis was carried out by the author in Housing &

Building National Research Center, from November 2014 to September 2017.

No part of the thesis has been submitted for a degree or a qualification at any other

University or Institution.

The candidate confirms that the work submitted is his own and that appropriate

credit has been given where reference has been made to the work of others

Date: - /1/2018

Signature: - -----

Name: - MAGED NASHAAT TAWFIK

AUTHOR

Name:	Maged Nashaat Tawfik Hana
Date of birth:	1 December 1989
Place of birth:	Aswan, Egypt
Academic Degree:	M.Sc. in Civil Engineering
Major:	Structural Engineering
University:	Ain Shams University
Date	November 2014
Academic Degree :	B.Sc. in Civil Engineering
Major	Structural Engineering
University:	Higher Institute of Engineering – El
	Shorouk Academy
Date:	June 2011
Grade:	Distinction with Honor
Current job:	Teaching and Research Assistant
	Higher Institute of Engineering – El

Shorouk Academy

TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
LIST OF FIGURES	vi
LIST OF TABLES	XV
LIST OF SYMBOLS	xvi
ABSTRACT	xviii
ACKNOWLEDGEMENTS	XX
CHAPTER 1: INTRODUCTION	1
1.1 Overview	1
1.2 Study Objectives	1
1.3 Study Methodology	2
1.4 Study Layout	2
CHAPTER 2 : LITERATURE REVIEW	4
2.1 Overview	4
2.2 Historical Background	4
2.3 Definition of Lightweight Concrete	5
2.4 Types of Lightweight Concrete	5
2.4.1 No-Fines Concrete	5
2.4.2 Lightweight Aggregate Concrete	6
2.4.3 Aerated Concrete	8
2.5 Materials Used in Producing LWC	9
2.5.1 Cement	10
2.5.2 Fly Ash	10
2.5.3 Silica Fume	10
2.5.4 Slag	10
2.5.5 Water Reducing Additives	10
2.5.6 Aggregates	11
2.5.7 Polystyrene Foam	11
2.6 Mechanical Properties of LWC	11
2.6.1 Compressive Strength	11
2.6.2 Tensile Strength	13
2.6.3 Flexural Strength	14
2.6.4 Pores of Light-Weight Foamed Concrete	14
2.6.5 Modulus of Elasticity and Stress-Strain Relationship	16
2.6.7 Stress Block Parameter of LWC	17
2.7 Mechanism of Achieving Self-Compacting Concrete	18
2.8 Light-Weight Concrete in Codes	19
2.8.1 American Codes	19
2.8.2 British Codes	19
2.8.3 European Codes	20
2.8.4 Japanese Codes	20
2.9 Previous Researchers Concerning In Structure Element And LWC Mixes	20

2.10 Previous Researches Concentering on Stress Block Parameters	26
2.10.1 Test Setup for Stress Block Parameters Specimens	27
CHAPTER 3: EXPERIMENTAL WORK	30
3.1 Overview	27
3.2 Materials Characteristics	30
3.2.1.Coarse Aggregates	30
3.2.2 Fine Aggregates	31
3.2.3 Mixing Water	32
3.2.4 Cement	33
3.2.5 Super-Plasticizer	33
3.2.6 Silica Fume	33
3.2.7 Polystyrene Foam	34
3.2.8 Polypropylene Fibers	34
3.2.9 Reinforcing Steel	34
3.3 Experimental Program	35
3.3.1 First Phase Specimens	35
3.3.2 Second Phase Specimens	36
3.3.3 Third Phase Specimens	37
3.4 Preparation of Specimens	38
3.5 Instrumentation	40
3.5 .1 LVDT	40
3.5.2 Electrical Strain Gauges	40
3.6 Test Setup and Loading Scheme	40
3.6.1 Test Setup for Specimens in First Phase	41
3.6.2 Test Setup for Specimens in The Second Phase	41
3.6.3 Test Setup for Specimens in The Third Phase	45
CHAPTER 4: EXPERIMENTAL RESULTS ANALYSIS	47
4.1 Outline	47
4.2 Experimental Results	47
4.2.1 Experimental Results of The First Phase	47
4.2.2 Experimental Results of The Second Phase	50
4.2.2.1 First Specimen	50
4.2.2.2 Second Specimen	52
4.2.3 Experimental Results of The Third Phase	53
4.2.3.1 Column (C1)	53
4.2.3.2 Column (C2)	58
4.2.3.3 Column (C3)	62
4.2.3.4 Column (C4)	66
4.2.3.5 Column (C5)	70
4.2.3.6 Column (C6)	74
4.3 Experimental Results Comparative Discussion	79
4.3.1 Comparative Discussion of The Second Phase	79
4 3 1 1 Stress Block Parameters	82

4.3.2 Third Phase Comparative Discussion	83
4.3.2.1 Effect of Eccentricty Ratio for Columns Have Transverse	84
Reinforcement (V _S /V _C) of 0.4%	
4.3.2.2 Effect of Eccentricty Ratio for Columns Have Transverse	88
Reinforcement (V _S /V _C) of 0.6%	
4.3.2.3 Effect of Transverse Reinforcement for Columns Have	91
Concentric Load	
4.3.2.4 Effect of Transverse Reinforcement for Columns Have	94
Eccentricity Ratio Equal (e/t) to 0.2	
4.3.2.5 Effect of Transverse Reinforcement for Columns Have	96
Eccentricity Ratio Equal to (e/t) 0.4	
CHAPTER 5: NUMERICAL MODELLING WORK	99
5.1 Overview	99
5.2 Finite Element Idealizations	99
5.3 Finite Element Method	100
5.4 Modeling LWC Column by Ansys-15.0	100
5.4.1 Elements Types	100
5.4.1.1 Lightweight Concrete Element	101
5.4.1.2 Steel Reinforcement Element	101
5.4.1.3 Lead Plates and Supports	102
5.4.2 Real Constants	103
5.4.2.1 Concrete Elements	103
5.4.2.2 Steel Reinforcement Element	103
5.4.2.3 Lead Plates and Supports	104
5.4.3 Material Properties	104
5.4.3.1 Concrete Element	104
5.4.3.2 Steel Reinforcement Element	105
5.4.3.3 Lead Plates and Supports	105
5.4.4 Numbering Controls	105
5.4.5 Loads and Boundary Conditions	105
5.4.6 Analysis Type	106
5.4.7 Analysis Process for The Finite Element Model	107
5.4.8 Finite Element Failure Definition	108
5.5 ANSYS Finite Element Model for Lightweight Column	108
5.5.1 Elements Types for Column	109
5.5.2 Real Constants for Column	109
5.5.3 Material Properties for Column	110
5.6 Detailing of The Model for Column	111
5.6.1 Solid65	111
5.6.2 Link 180	112
5.7 Numbering Controls	113
5.8 Loads and Boundary Conditions	114
5.9 Type of Analysis	115

5.10 Analysis Process for The Finite Element Model	115
5.11 Verification of The Analytical Model	115
5.11.1 Verification for Column C1	115
5.11.2 Verification for Column C2	119
5.11.3 Verification for Column C3	129
5.11.4 Verification for Column C4	126
5.11.5 Verification for Column C5	130
5.11.6 Verification for Column C6	133
CHAPTER 6: PARAMETRIC STUDY & DESIGN GUIDELINES	137
6.1 Outline	137
6.2 Parametric Study	137
6.2.1 Parametric Study Database Analysis and Results	139
6.2.2 Disussion of The Results	141
6.2.2.1 Group One: Longitudinal Reinforcement Steel	141
6.2.2.1.1 Effect of Longitudinal Reinforcement on Concentric	141
Columns	
6.2.2.1.2 Effect of Longitudinal Reinforcement on Eccentric	143
Loaded Columns Equal (e/t) to 0.2	
6.2.2.1.3 Effect of Longitudinal Reinforcement on Eccentric	145
Loaded Columns Equal to (e/t) 0.4	
6.2.2.2 Group Two: Slenderness Ratio	147
6.2.2.2.1 Effect of Slenderness Ratio on Concentric Columns	147
6.2.2.2.2 Effect of Slenderness Ratio on Eccentric Columns	148
6.2.2.3 Group Three: Transverse Reinforcement Steel	149
6.2.2.3.1 Effect of Transverse Reinforcement on Concentric	149
Columns	
6.2.2.3.2 Effect of Transverse Reinforcement on Eccentric Columns	151
6.2.2.4 Group Four: Eccentricity Ratio	154
6.2.2.4.1 Effect of Eccentricity Ratio on Short Columns	154
6.2.2.4.2 Effect of Eccentricity Ratio on Long Columns	155
6.3 Predicted Analytical Model	157
CHAPTER 7: SUMMARY AND RECOMMENDATIONS	162
7.1 Conclusions	162
7.2 Recommendations	165
REFERENCES	166
Appendices	169

LIST OF FIGURES

	Page
Figure (2.1) Pantheon of LWC building is in Rome Ramachandran V.S.(1995)	5
Figure (2.2) No-fines concrete	6
Figure (2.3) Different types of LWA and their use according to their dry unit	7
weight (ACI 213R-03, 2003)	
Figure (2.4) Light-weight aggregate concrete, Mohd Roji Samidi,(1997)	7
Figure (2.5) Aerated Concrete Mohd Roji Samidi,(1997).	8
Figure (2.6) Unit weight and CS HW.Song. (Seoul 120-749, Korea)	12
Figure (2.7) 7 and 28 days CS in unit weight HW.Song. (Seoul 120-749, Korea)	13
Figure (2.8) CS and splitting TS HW.Song.(Seoul 120-749, Korea)	13
Figure (2.9) CS to FS HW.Song. (Seoul 120-749)	14
Figure (2.10) Average pore size and CS HW.Song.(Seoul 120-749)	15
Figure (2.11) Average pore ratio and average size HW.Song (Seoul 120-749)	15
Figure (2.12) 1st 4 stages of loaded cross-section R. PARK and T. PAULAY (1975)	17
Figure (2.13) Method of Okamura and Ouchi in achieving self-compatibility	18
Okamura and Ouchi (2003)	10
Figure (2.14) Okamura and Ouchi technique to attain self-compatibility	19
Okamura and Ouchi (2003)	
Figure (2.15) Tested beams Hussein O. Okail (2008)	21
Figure (2.16) CLWA Volume and 7 days CS Eethar et al. (2008)	22
Figure (2.17) Concrete cylinders cross section with different LSP, Hosny, Amr. (2010)	23
Figure (2.18) Compressive strength with LSP Hosny, Amr. (2010)	24
Figure (2.19) Cylinders Cross-section E.E. Maldonado-Bandala and D. Nieves-Mendoza(2015)	25
Figure (2.20) Compressive strength for the investigated after 14 so as 28 days	26
E.E. Maldonado-Bandala and D. Nieves-Mendoza(2015)	20
Figure (2.21) Rectangular section block parameters Hognestad (1952)	26
Figure (2.22) Details of Hognestad specimens Hognestad et al. (1955)	28
Figure (2.22) Details of Mertol specimens Mertol (2006)	29
Figure (3.1) Grading curve for coarse aggregate	31
Figure (3.2) Grading curve for fine aggregate	32
Figure (3.3) Tension test of steel bars	33
Figure (3.4) Distribution of foam in the tested specimens	36
Figure (3.5) Specimen general layout	37
Figure (3.6) Details of the columns	38
Figure (3.7) Formwork of specimens in the second phase	39
<u>→</u>	

Figure (3.8) Formwork of specimens in the third phase	39
Figure (3.9) Measurement devices	37
Figure (3.10) Test setup for the first phase	41
Figure (3.11) Details of arm of moment	42
Figure (3.12) Hinge connection	42
Figure (3.13) Second phase test set-up	43
Figure (3.14) Strain gages for the second phase	44
Figure (3.20) Test set-up of specimens in the third phase	45
Figure (3.22) Strain gages and LVDT in the third phase	46
Figure (4.1) Hardened density for different mixes	48
Figure (4.2) Compressive strength after 7 days	48
Figure (4.3) Compressive strength after 28 days	49
Figure (4.4) Tensile strength after 28 days	49
Figure (4.5) Crushing of the first specimen	51
Figure (4.6) Average strain in first specimen at tension and compression	51
Figure (4.7) Crushing of the second specimen	52
Figure (4.8) Average strain in second specimen at tension and compression	53
Figure (4.9) Cracking stage for column (C1)	54
Figure (4.10) Crushing of concrete for column (C1) at load level 1206.7 kN.	55
Figure (4.11) Load-concrete strain curve for column (C1)	55
Figure (4.12) Load -longitudinal reinforcement strain at inner side curve for	56
column (C1)	
Figure (4.13) Relation between Load- longitudinal strain in concrete and long.	56
Rft. at inner side for column (C1)	
Figure (4.14) Load -longitudinal reinforcement strain at outer side curve for	57
column (C1)	
Figure (4.15) Load -transverse reinforcement strain curve for column (C1)	57
Figure (4.16) Cracking stage for column (C2)	59
Figure (4.17) Crushing of concrete for column (C2) at load level 712.081 kN	59
Figure (4.18) Load-concrete strain curve for column (C2)	60
Figure (4.19) Load -longitudinal reinforcement strain at inner side curve for	60
column (C2)	
Figure (4.20) Relation between Load- longitudinal strain in concrete and long.	61
Rft. at inner side for column (C2)	
Figure (4.21) Load -longitudinal reinforcement strain at outer side curve for	61
column (C2)	63
Figure (4.22) Load -transverse reinforcement strain curve for column (C2)	62
Figure (4.23) Crack stage for column (C3)	63
Figure (4.24) Crushing of concrete for column (C3) at load level 367.28 kN	64
Figure (4.25) Load-concrete strain curve for column (C3)	64
Figure (4.26) Load -longitudinal reinforcement strain at outer side curve for	65
column (C3)	

Figure (4.27) Load -transverse reinforcement strain curve for column (C3)	65
Figure (4.28) Cracking stage for column (C4)	67
Figure (4.29) Crushing of concrete for column (C4) at load level 1349.8 kN	67
Figure (4.30) Load-concrete strain curve for column (C4)	68
Figure (4.31) Load -longitudinal reinforcement strain at inner side curve for	68
column (C4)	
Figure (4.32) Relation between Load- longitudinal strain in concrete and long. Rft. at inner side for column (C4)	69
Figure (4.33) Load -longitudinal reinforcement strain at outer side curve for column (C4)	69
Figure (4.34) Load -transverse reinforcement strain curve for column (C4)	70
Figure (4.35) Cracking stage for column (C5)	71
Figure (4.36) Crushing of concrete for column (C5) at load level 780.718 kN	72
Figure (4.37) Load-concrete strain curve for column (C5)	72
Figure (4.38) Load -longitudinal reinforcement strain at inner side curve for column (C5)	73
Figure (4.39) Relation between Load-longitudinal strain in concrete and long.	73
Rft. at inner side for column (C5)	
Figure (4.40) Load -transverse reinforcement strain curve for column (C5)	74
Figure (4.41) Cracking stage for column (C6)	75
Figure (4.42) Crushing of concrete for column (C6) at load level 445.74 kN	76
Figure (4.43) Load-concrete Strain curve for column (C6)	76
Figure (4.44) Load -longitudinal reinforcement strain at inner side curve for	77
column (C6)	
Figure (4.45) Relation between Load- longitudinal strain in concrete and long. Rft. at inner side for column (C6)	77
Figure (4.45) Load -longitudinal reinforcement strain at outer side curve for column (C6)	78
Figure (4.46) Load -transverse reinforcement strain curve for column (C6)	78
Figure (4.47) Applied forces on eccentric bracket specimens	79
Figure (4.48) Two similar stress-strain relationships for the first specimen	81
Figure (4.49) Two similar stress-strain relationships for the second specimen	81
Figure (4.50) Average stress-strain relationship of LWC specimens	82
Figure (4.51) Generalized rectangular stress block parameters	83
Figure (4.52) Failure of specimens under different eccentric ratios	84
Figure (4.53) Load-concrete strain curve for columns with transverse	86
reinforcement having ratio of 0.4%	
Figure (4.54) Load -longitudinal reinforcement strain at inner side curve for	86
columns with transverse reinforcement having ratio of 0.4%	
Figure (4.55) Load -longitudinal reinforcement strain at outer side curve for columns with transverse reinforcement having ratio of 0.4%	87
Figure (4.56) Load -transverse reinforcement strain curve for columns with	87

transverse reinforcement naving ratio of 0.4%	
Figure (4.57) Load-concrete strain curve for columns with transverse	89
reinforcement ratio of 0.6%	
Figure (4.58) Load -longitudinal reinforcement strain at inner side curve for	89
columns with transverse reinforcement ratio of 0.6%	
Figure (4.59) Load -longitudinal reinforcement strain at outer side curve for	90
columns with transverse reinforcement ratio of 0.6%	
Figure (4.60) Load -transverse reinforcement strain curve for columns with	90
transverse reinforcement ratio of 0.6%	
Figure (4.61) Load-concrete strain curve for columns under concentric load	92
Figure (4.62) Load -longitudinal reinforcement strain at inner side curve for	92
columns under concentric load	
Figure (4.63) Load -longitudinal reinforcement strain at outer side curve for	93
columns under concentric load	
Figure (4.64) Load -transverse reinforcement strain curve for columns under	93
concentric load	
Figure (4.65) Load-concrete strain curve for columns under eccentric load	95
(e/t=0.2)	
Figure (4.66) Load -longitudinal reinforcement strain at inner side curve for	95
columns under eccentric load (e/t=0.2)	
Figure (4.67) Load -transverse reinforcement strain curve for columns under	96
eccentric load (e/t=0.2)	
Figure (4.68) Load-concrete strain curve for columns under eccentric load	97
(e/t=0.4)	
Figure (4.69) Load -longitudinal reinforcement strain at outer side curve for	98
columns under eccentric load (e/t=0.4)	
Figure (4.70) Load -transverse reinforcement strain curve for columns under	98
eccentric load (e/t=0.4)	
Figure (5.1) Solid65 LWC in ANSYS-15.0	101
Figure (5.2) Modeling discrete(a) and smeared(b) reinforcement in concrete	102
105Figure (5.3) Link180 in ANSYS-15.0	102
Figure (5.4) Element connectivity, concrete solid and link elements	102
Figure (5.5) Solid 185 elements ANSYS-15.0	103
Figure (5.6) Newton-Raphson iteration ANSYS-15.0	108
Figure (5.7) LWC stress-strain curve	111
Figure (5.8) Model mesh and column elements	112
Figure (5.9) Elements dimensions of steel reinforcement	113
Figure (5.10) Support condition and load	114
Figure (5.11) Deformed shape and total mechanical strain in y-direction for column C1	116
	117
Figure (5.12) Experimental failure compared to cracks propagation before failure from finite element model for column C1	11/
Figure (5.13) Load-concrete strain curve for column C1	117

Figure (5.14) Load -longitudinal reinforcement strain at inner side curve for	118
column C1 Figure (5.15) Load -longitudinal reinforcement strain at outer side curve for	118
column C1	110
Figure (5.16) Load -transverse reinforcement strain curve for column C1	119
Figure (5.17) Deformed shape and total mechanical strain in y-direction for	120
column C2	
Figure (5.18) Experimental failure compared to cracks propagation before failure	120
from finite element model for column C2	
Figure (5.19) Load-concrete strain curve for column C2	121
Figure (5.20) Load -longitudinal reinforcement strain at inner side curve for	121
column C1 Figure (5.21) Lood, longitudinal reinforcement strain at outer side ourse for	122
Figure (5.21) Load -longitudinal reinforcement strain at outer side curve for column C2	122
Figure (5.22) Load -transverse reinforcement strain curve for column C2	122
Figure (5.23) Deformed shape and total mechanical strain in y-direction for	123
column C3	123
Figure (5.24) Experimental failure compared to cracks propagation before failure	124
from finite element model for column C3	
Figure (5.25) Load-concrete strain curve for column C3	124
Figure (5.26) Load -longitudinal reinforcement strain at inner side curve for	125
column C3	
Figure (5.27) Load -longitudinal reinforcement strain at outer side curve for	125
column C3	
Figure (5.28) Load -transverse reinforcement strain curve for column C3	126
Figure (5.29) Deformed shape and total mechanical strain in y-direction for column C4	127
Figure (5.30) Experimental failure compared to cracks propagation before failure	127
from finite element model for column C4	
Figure (5.31) Load-concrete strain curve for column C4	128
Figure (5.32) Load -longitudinal reinforcement strain at inner side curve for	128
column C4	
Figure (5.33) Load -longitudinal reinforcement strain at outer side curve for	129
column C4	
Figure (5.34) Load -transverse reinforcement strain curve for column C4	129
Figure (5.35) Deformed shape for column and total mechanical strain in y-	130
direction C5	
Figure (5.36) Experimental failure compared to cracks propagation before failure	131
from finite element model for column C5	
Figure (5.37) Load-concrete strain curve for column C5	131
Figure (5.38) Load -longitudinal reinforcement strain at inner side curve for column C5	132
Figure (5.39) Load -longitudinal reinforcement strain at outer side curve for	132

column C5	
Figure (5.40) Load -transverse reinforcement strain curve for column C5	133
Figure (5.41) Deformed shape and total mechanical strain in y-direction for	134
column C6	
Figure (5.42) Experimental failure compared to cracks propagation before failure	134
from finite element model for column C6	
Figure (5.43) Load-concrete strain curve for column C6	135
Figure (5.44) Load -longitudinal reinforcement strain at inner side curve for	135
column C6	
Figure (5.45) Load -longitudinal reinforcement strain at outer side curve for	136
column C6	
Figure (5.46) Load -transverse reinforcement strain curve for column C6	136
Figure (6.1) Cracks propagation before failure from finite element model	139
Figure (6.2) Load-concrete strain curve for concentric columns, 0.4% transverse	142
reinforcement, and slenderness ratio equal to 6	
Figure (6.3) Load-concrete strain curve for concentric columns, 0.4% transverse	142
reinforcement, and slenderness ratio equal to 15	
Figure (6.4) Load-concrete strain curve for columns under eccentric load	144
(e/t=0.2), 0.4% transverse reinforcement, and slenderness ratio equal to 6	
Figure (6.5) Load-concrete strain curve for columns under eccentric load	144
(e/t=0.2), 0.4% transverse reinforcement, and slenderness ratio equal to 15	
Figure (6.6) Load-concrete strain curve for columns under eccentric load	146
(e/t=0.4), 0.4% transverse reinforcement, and slenderness ratio equal to 6	
Figure (6.7) Load-concrete strain curve for columns under eccentric load	146
(e/t=0.4), 0.4% transverse reinforcement, and slenderness ratio equal to 15	
Figure (6.8) Load-concrete strain curve for concentric columns, 0.4% transverse	147
reinforcement, and 0.8% longitudinal reinforcement	
Figure (6.9) Load-concrete strain curve for columns under eccentric load	148
(e/t=0.2), 0.4% transverse reinforcement, and 0.8% longitudinal reinforcement	
Figure (6.10) Load-concrete strain curve for columns under eccentric load	149
(e/t=0.4), 0.4% transverse reinforcement, and 0.8% longitudinal reinforcement	
Figure (6.11) Load-concrete strain curve for concentric columns, 1.1%	150
longitudinal reinforcement, and slenderness ratio equal to 6	
Figure (6.12) Load-concrete strain curve for concentric columns, 1.1%	151
longitudinal reinforcement, and slenderness ratio equal to 15	
Figure (6.13) Load-concrete strain curve for columns under eccentric load	152
(e/t=0.2), 1.1% longitudinal reinforcement, and slenderness ratio equal to 6	
Figure (6.14) Load-concrete strain curve for columns under eccentric load	153
(e/t=0.2), 1.1% longitudinal reinforcement, and slenderness ratio equal to 15	
Figure (6.15) Load-concrete strain curve for columns under eccentric load	153
(e/t=0.4), 1.1% longitudinal reinforcement, and slenderness ratio equal to 6	
Figure (6.16) Load-concrete strain curve for columns under eccentric load	154
(e/t=0.4), 0.8% longitudinal reinforcement, and slenderness ratio equal to 15	

Figure (6.17) Load-concrete strain curve for columns under uniaxial load, 1.1%	155
longitudinal reinforcement, 0.4% transverse reinforcement, and slenderness ratio	
equal to 6	
Figure (6.18) Load-concrete strain curve for columns under uniaxial load, 1.1%	156
longitudinal reinforcement, 0.4% transverse reinforcement, and slenderness ratio	
equal to 15	
Figure (6.19) Long column effect	159
Figure (6.20) Graphical comparison between the predicted and analytical results	161