



**AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL DEPARTMENT**

**BEHAVIOR OF STEEL JACKETED REINFORCED
CONCRETE COLUMN UNDER ECCENTRIC FORCES**

BY

Ahmed Gamal Mohamed Ali

BSc (honours) 2013,
MSc 2018, Structural Division,
Structural Engineering Dept. Ain Shams University

A Thesis

**SUBMITTED IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS OF THE
DEGREE OF MASTER OF SCIENCE**

In

Structural Engineering

SUPERVISED BY

Professor Dr. Ayman Hussein Hosny Khalil

Professor of Concrete Structures,
Structural Engineering Department, Ain Shams University

Dr. Ayman Sayed Abou Beih

Assistant Professor,
Structural Engineering Department, Ain Shams University

Cairo, 2018



**Ain Shams University
Faculty of Engineering**

APPROVAL SHEET

Thesis : Master of science in Civil Engineering (Structural)
Student Name : AHMED GAMAL MOHAMED ALI
Thesis Title : BEHAVIOR OF STEEL JACKETED REINFORCED
CONCRETE COLUMN UNDER ECCENTRIC FORCES

Examiners Committee:-

Signature

Prof .Dr / Hatem Mostafa Mohamed Ahmed

Prof .of RC. Structures,
Faculty of Engineering
CairoUniversity

.....

Prof .Dr / Omar Ali Mousa El-Nawawy

Prof .of RC. Structures,
Faculty of Engineering
Ain Shams University

.....

Prof .Dr / Ayman Hussein Hosny Khalil

Prof .of RC. Structures,
Faculty of Engineering
Ain Shams University

.....

Date: 31 -10-2018

STATEMENT

This thesis is submitted to Ain Shams University, Cairo, Egypt, for the Degree of Master of Science in Civil Engineering (Structural).

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

Date : 31/10/2018

Name : AHMED GAMAL MOHAMED ALI

Signature:

AIN SHAMES UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURE ENGINEERING DEPARTMENT

Abstract of the MSc thesis submitted by
Eng. AHMED GAMAL MOHAMED ALI

**Title of thesis: " BEHAVIOR OF STEEL JACKETED REINFORCED
CONCRETE COLUMN UNDER ECCENTRIC FORCES "**

SUPERVISORS:
DR \ AYMAN HUSSEIN HOSNY KHALIL
DR \ AYMAN SAYED ABOU BEIH

ABSTRACT

RC columns often need strengthening to increase their capacity to sustain the applied load. Strengthening using concrete jacket, composite material and steel jacket are common different techniques applied in many scenarios. In this research, the behavior of RC columns with and without strengthening using steel jacketing subjected to different eccentricities of loads upon failure were studied.

To achieve the behavior of strengthened columns upon failure under eccentric loads, Six reinforced concrete columns of 1000 mm height & (200×200)mm cross section area and concrete compressive strength 38 N/mm² with different strengthening techniques were tested under eccentric loads (small eccentricity and big eccentricity) in the RC laboratory of Ain Shams University (Faculty of engineering). The testing program divided into two groups of specimens, The first group (Group No. 1) consists of three specimens under small eccentricity ($e = 7\text{cm}$) with various steel jacketing

technique for each specimen (full steel tube jacket, partially steel jacket (4 angles for the column corners and 5 straps equally distributed throughout the column height) and also another partially steel jacket (4 angles for the column corners and 3 straps equally distributed throughout the column height). The second group (Group No. 2) consists of three specimens under big eccentricity ($e = 15\text{cm}$) having the same various steel jacketing technique of the first group.

Using F.E package (ANSYS 14.0) the behaviour of eight models were investigated, analysed and verified. This Program has wide varieties of elements, a large library for material properties and several load types which covers almost aspects needed to model the experimental work conducted in this thesis. Eight reinforced concrete column models having the same dimensions of experimental testing were modeled. In the theoretical program, two models were more than experimental specimens. These two models are reference model 1 (RC concrete without strengthening under eccentric load with 7 cm eccentricity) as a reference model for Group No. 1 and reference model 2 (RC concrete without strengthening under eccentric load with 15 cm eccentricity) as a reference model for Group No. 2.

The results showed a good match between both experimental tests and F.E models.

Key Words: Columns, Steel jacket techniques of RC columns, Eccentric load, Big eccentricity, Small eccentricity and Non-linear structural analysis.

ACKNOWLEDGEMENTS

First of all, I would like to express my great thanks to **Allah**, who gave me the strength, ability, and conciliation to achieve this work, wishing that my work would ever last to be beneficial materials to future researchers. I also wish to thank Allah again for his valuable gift, my great supervision committee, who strongly supported me to achieve this study.

The writer is deeply indebted to **Prof. Dr. Ayman Hussein Hosny Khalil**, Professor of RC structures Ain Shams University, for his kind and constant supervision, planning, guidance, valuable suggestions, precise advice and constant encouragement during all phases of this research work.

I would like to thank Associated **Dr. Ayman Sayed Abou Beih** for his valuable aid and advice throughout the research and I am also gratefully acknowledge the support & encouragement received from him.

I owe special thanks to the technicians at Structural & Material Laboratory for their assistance to complete my research. Also, I owe many thanks to all my colleagues who have helped & supported me throughout this research.

To **my family members**, “my **Mother**, my **Father**, and my **Brothers**” who have given unconditional support at home, with my family & research, I owe much debt of gratitude.

TABLE OF CONTENTS

	page
APPROVAL SHEET	i
NOTION (STATEMENT)	ii
ABSTRACT	iii
ACKNOWLEDGMENT	v
TABLE OF CONTENTS	vi
LIST OF TABLES	xi
LIST OF FIGURES	xii

Chapter 1 Introduction

1.1 General	1
1.2 Research Objectives	3
1.3 Outlines of Research	4

Chapter 2 Review of Previous Works

2.1 General	7
2.2 structural properties of reinforced concrete column	7
2.2.1 strength.....	8
2.2.2 stiffness	8
2.2.3 Ductility.....	8
2.3 strengthening (confinement) of RC columns	9
2.4 steel jacket.....	9
2.5 Behaviour of Strengthened RC. Columns under Eccentric Loads.....	17
2.5.1 Strengthening of RC. Columns by Steel Jacket Techniques	19
under eccentric loads	
2.6 Modelling and Analysis of Structures Using the Finite Element Method.	23
2.6.1 Review of Finite Element Method (FEM).....	24

Chapter 3 Experimental Program

3.1 General	27
-------------------	----

3.2	Testing Program	27
3.3	Description of Specimen Models	28
3.3.1	Group No.1	29
3.3.2	Group No.2	31
3.4	Material Properties	34
3.4.1	Concrete	34
3.4.1.1	Concrete Mixtures	34
3.4.2	Reinforcing Steel	36
3.4.3	Steel Jackets	37
3.4.4	Epoxy.....	38
3.5	Sample Processing	39
3.5.1	Formworks and Casting	39
3.5.2	Testing Setup	42
3.5.3	Instrumentation and Control	44

Chapter 4 Discussion of Results of Experimental Examination

4.1	General	49
4.2	Discussion the Results of Failure Mode Behaviour	50
4.2.1	The First Group (C1, C2 and C3)	51
4.2.1.1	Specimen C1	51
4.2.1.2	Specimen C2	52
4.2.1.3	Specimen C3	53
4.2.2	The second Group (C4, C5 and C6)	54
4.2.2.1	Specimen C4	55
4.2.2.2	Specimen C5	56
4.2.2.3	Specimen C6	57
4.3	Discussion and Evaluation of Specimen Results	58
4.4	The First Group	59
4.4.1	Specimen C1	60
4.4.2	Specimen C2	65

4.4.3	Specimen C3	71
4.5	The second Group	76
4.5.1	Specimen C4	76
4.5.2	Specimen C5	82
4.5.3	Specimen C6	87
4.6	Effect of steel jacket shape	93
4.6.1	The First Group	93
4.6.2	The second Group	102
4.7	Effect of eccentricity (Small & Big Eccentricity)	111
4.7.1	Discussion of column displacement.....	111
4.7.2	Discussion of column concrete strains.....	113
4.7.3	Discussion of column reinforcement strains.....	115
4.7.4	Discussion of column steel jacket strains.....	117
<u>Chapter 5 Three Dimensional Modelling and Analysis (ANSYS Program)</u>		
5.1	General	119
5.2	ANSYS Overview.....	120
5.2.1	Basic Analysis Procedures of ANSYS	121
5.2.2	Structural Analyses of ANSYS	124
5.2.2.1	Static analysis.....	125
5.2.2.2	Nonlinear analysis.....	126
5.3	Description of the Models	130
5.4	Three Dimensional Finite Element Modelling of the Columns	133
5.4.1	Modelling Approach	134
5.4.2	Generation of the Finite Element Model	135
<u>Chapter 6 Discussion of Results of Theoretical Analyses (FE Analyses)</u>		
6.1	General	147
6.2	Discussion and Evaluation of Model Results (Failure Mode Behaviour).	149
6.2.1	Group No.1	151
6.2.1.1	Reference Model 1	151
6.2.1.2	Model Col.1	155

6.2.1.3	Model Col.2	159
6.2.1.4	Model Col.3	163
6.2.2	Group No.2	167
6.2.2.1	Reference Model 2	168
6.2.2.2	Model Col.4	171
6.2.2.3	Model Col.5	175
6.2.2.4	Model Col.6	180
6.3	Effect of shape of steel jackets	184
6.3.1	load-displacement relationship	185
6.3.1.1	The First Group	186
6.3.1.2	The second Group	190
6.3.2	load-strain relationship	194
6.3.2.1	The First Group	194
6.3.2.2	The second Group	204
6.4	Effect of eccentricity (Small & Big Eccentricity)	214
6.4.1	load-displacement relationship	214
6.4.2	Load-Strain Relationship	217
6.5	Result Analysis of Models	222

Chapter 7 Comparison between Experimental and Finite Element Analysis Results

7.1	General	227
7.2	Comparison between experimental and finite element results	227
7.2.1	Ultimate load and vertical displacement	229
7.2.2	Ultimate load and lateral displacement	230
7.2.3	Ultimate load and vertical strain	234
7.2.3.1	Ultimate load and concrete strain	234
7.2.3.2	Ultimate load and reinforcement strain	236
7.2.3.3	Ultimate load and steel jacket strain	238
7.2.4	Ultimate load and horizontal strain	241

TABLE OF CONTENTS

7.2.4.1	Ultimate load and concrete strain	241
7.2.4.2	Ultimate load and stirrup strain	242
7.2.4.3	Ultimate load and steel jacket strain	244
7.3	Crack pattern and mode of failure	245
7.4	Analysis and Discussion of Column Behaviour	252
 <u>Chapter 8 Summary, Conclusions, and Recommendations</u>		
8.1	Summary	253
8.2	Experimental study.....	253
8.3	Theoretical study.....	254
8.4	Conclusions.....	254
8.5	Recommendations for Future Researches	256
References		257

LIST OF TABLES

Table	Page
3.1 Dimension details of tested specimens	28
3.2 Strengthening technique details.....	28
3.3 Concrete mix proportions.....	34
3.4 Concrete compressive strength	35
3.5 Mechanical properties of steel reinforcement	36
3.6 Mechanical properties of steel used in the jackets of column.....	37
4.1 exp. results summary	50
4.2 Exp. lateral & vertical displacements results of all specimens	58
4.3 Exp. Reinforcement Strain Results	58
4.4 Exp. Strain Results of Steel Jackets	59
4.5 Exp. Strain Results of Specimen Concrete	59
5.1 Types used for model generation of the different materials.....	136
6.1 F.E Results Summary	150
6.2 F.E Analysis Reinforcement Strain Results	184
6.3 F.E Analysis Strain Results of Steel Jackets	185
6.4 F.E Analysis Strain Results of Model Concrete	185
6.5 F.E Analysis lateral & vertical displacements results of all column models	186
7.1 Comparison between Experimental and Analytical Failure Loads	228
7.2 Maximum values of vertical displacement of all models	229
7.3 Maximum values of lateral displacement of all models	231
7.4 Maximum values of vertical concrete strain of all models	235
7.5 Maximum values of vertical reinforcement strain of all models	236
7.6 Maximum values of vertical steel jacket strain of all models	239
7.7 Maximum values of lateral concrete strain of all models	241
7.8 Maximum values of stirrups strain of all models	243
7.9 Maximum values of lateral steel jacket strain of all models	244

LIST OF FIGURES

Figure	Page
2.1 steel jacket technique for strengthening RC column	9
2.2 specimen dimensions and steel jacket configuration.....	14
2.3 strengthened specimens after casting and jacket erection.....	14
2.4 failure load for all specimens.....	16
2.5 Details of experimental column specimen.....	20
2.6 Failure mode of eccentrically loaded column.....	22
2.7 Failure mode of eccentrically loaded strengthened column.....	22
2.8 Different types of finite element with nodal degrees of freedom.....	26
3.1 Details of tested specimen Col.1.....	30
3.2 Details of tested specimen Col.2.....	30
3.3 Details of tested specimen Col.3.....	31
3.4 Details of tested specimen Col.4.....	32
3.5 Details of tested specimen Col.5.....	33
3.6 Details of tested specimen Col.6.....	33
3.7 The main reinforcement and stirrups of column.....	36
3.8 Steel tube.....	38
3.9 Angles+5 Straps.....	38
3.10 Angles+3 Straps.....	38
3.11 Epoxy materials.....	38
3.12 Wooden formworks of column.....	40
3.13 Electrical needle vibrator.....	41
3.14 Curing of specimens.....	41
3.15 Test setup of all specimens (Col .1, 2, 3, 4, 5 & 6).....	43
3.16 Electric strain gauge.....	44
3.17 Locations of the electrical strain gauges on steel reinforcement of RC column	45
3.18 Locations of the electrical strain gauges on steel jacket of RC column .	46
3.19 Locations of the electrical strain gauges on concrete of RC column	47
3.20 Locations of the deflectometers on different points of RC column	48

4.1	Exp. Results of the ultimate load for all models	51
4.2	General crack pattern of specimen (C 1) and buckling	52
4.3	General crack pattern of specimen (C 2)	53
4.4	General crack pattern of specimen (C 3)	54
4.5	General crack pattern of specimen (C 4)	55
4.6	General crack pattern of specimen (C 5)	56
4.7	General crack pattern of specimen (C 6)	57
4.8	Exp. result of load-lateral displacement curves for specimen (C 1).....	61
4.9	Exp. result of load-vertical displacement curve for specimen (C 1).....	62
4.10	Exp. result of load-lateral strain curve of concrete for specimen (C 1)...	62
4.11	Exp. result of load-vertical strain curve of concrete for specimen (C 1).	63
4.12	Exp. Result of load-vertical strain curves of Reinforcement for specimen (C 1)	63
4.13	Exp. result of load-lateral strain curve of reinforcement(stirrup) for specimen (C 1)	64
4.14	Exp. result of load-vertical strain curves of steel plates for specimen (C 1)	64
4.15	Exp. result of load-lateral strain curve of steel plates for specimen(C1).	65
4.16	Exp. result of load-lateral displacement curves for specimen (C 2).....	67
4.17	Exp. result of load-vertical displacement curve for specimen (C 2).....	67
4.18	Exp. result of load-lateral strain curve of concrete for specimen (C 2)...	68
4.19	Exp. result of load-vertical strain curve of concrete for specimen (C 2).	68
4.20	Exp. Result of load-vertical strain curves of Reinforcement for specimen (C 2)	69
4.21	Exp. result of load-lateral strain curve of reinforcement(stirrup) for specimen (C 2)	69
4.22	Exp. result of load-vertical strain curves of steel plates for specimen (C 2)	70
4.23	Exp. result of load-lateral strain curve of steel plates for specimen(C2).	70
4.24	Exp. result of load-lateral displacement curves for specimen (C 3).....	72
4.25	Exp. result of load-vertical displacement curve for specimen (C 3).....	73
4.26	Exp. result of load-lateral strain curve of concrete for specimen (C 3)...	73
4.27	Exp. result of load-vertical strain curve of concrete for specimen (C 3).	74
4.28	Exp. Result of load-vertical strain curves of Reinforcement for specimen (C 3)	74
4.29	Exp. result of load-lateral strain curve of reinforcement(stirrup) for specimen (C 3)	75
4.30	Exp. result of load-vertical strain curves of steel plates for specimen (C 3)	75

4.31	Exp. result of load-lateral strain curve of steel plates for specimen(C3).	76
4.32	Exp. result of load-lateral displacement curves for specimen (C 4).....	78
4.33	Exp. result of load-vertical displacement curve for specimen (C 4).....	78
4.34	Exp. result of load-lateral strain curve of concrete for specimen (C 4)...	79
4.35	Exp. result of load-vertical strain curve of concrete for specimen (C 4).	79
4.36	Exp. Result of load-vertical strain curves of Reinforcement for specimen (C 4)	80
4.37	Exp. result of load-lateral strain curve of reinforcement(stirrup) for specimen (C 4)	80
4.38	Exp. result of load-vertical strain curves of steel plates for specimen (C 4)	81
4.39	Exp. result of load-lateral strain curve of steel plates for specimen(C4).	81
4.40	Exp. result of load-lateral displacement curves for specimen (C 5).....	83
4.41	Exp. result of load-vertical displacement curve for specimen (C 5).....	84
4.42	Exp. result of load-lateral strain curve of concrete for specimen (C 5)...	84
4.43	Exp. result of load-vertical strain curve of concrete for specimen (C 5).	85
4.44	Exp. Result of load-vertical strain curves of Reinforcement for specimen (C 5)	85
4.45	Exp. result of load-lateral strain curve of reinforcement(stirrup) for specimen (C 5)	86
4.46	Exp. result of load-vertical strain curves of steel plates for specimen (C 5)	86
4.47	Exp. result of load-lateral strain curve of steel plates for specimen(C5).	87
4.48	Exp. result of load-lateral displacement curves for specimen (C 6).....	89
4.49	Exp. result of load-vertical displacement curve for specimen (C 6).....	89
4.50	Exp. result of load-lateral strain curve of concrete for specimen (C 6)...	90
4.51	Exp. result of load-vertical strain curve of concrete for specimen (C 6).	90
4.52	Exp. Result of load-vertical strain curves of Reinforcement for specimen (C 6)	91
4.53	Exp. result of load-lateral strain curve of reinforcement(stirrup) for specimen (C 6)	91
4.54	Exp. result of load-vertical strain curves of steel plates for specimen (C 6)	92
4.55	Exp. result of load-lateral strain curve of steel plates for specimen(C6).	92
4.56	Exp. result of load-lateral displacement at point(1) curves for The first group	94
4.57	Exp. result of load-lateral displacement at point (2) curves for The first group	95
4.58	Exp. result of load-lateral displacement at point(3)curves for The first group	95