



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT

**THE EFFECT OF TRSNSVERSE CONFINMENT ON THE BEHAVIOR OF
CIRCULAR COLUMNS UNDER CYCLIC LOADS**

By
Eng. AHMED M. ABD ELRAHMAN MASSOUD
B.Sc. Civil Engineering
Zagazig University, 1992

A Thesis
Submitted in Partial Fulfillment for the Requirements of the Degree of Master of
Science in Structural Engineering

Supervisors

Dr. OSAMA HAMDY ABD EL-WAHED
Prof. of Reinforced Concrete Structure
Structural Engineering Department
Faculty of Engineering
Ain Shams University

Dr. AYMAN HUSSEIN HOSNY
Prof. of Reinforced Concrete Structure
Structural Engineering Department
Faculty of Engineering
Ain Shams University

Dr. HADDAD SAYIED HADDAD
Associate Prof. Structural Engineering
Department
Housing and Building Research Center

Cairo –EGYPT
٢٠١٠

Statement

This thesis is submitted to Ain Shams University for the degree of Master of Science in Structural Engineering.

No part of this thesis has been previously submitted for obtaining a degree or a qualification before.

Name : **AHMED M. ABD ELRAHMAN MASSOUD**

Date :

Signature :



جامعة عين الشمس

كلية الهندسة

إسم الطالب: أحمد محمد عبد الرحمن مسعود

الدرجة العلمية: بكالوريوس الهندسة

القسم التابع له: الهندسة المدنية

أسم الكلية: كلية الهندسة بشبرا

الجامعة: الزقازيق- فرع بنها

سنة التخرج: ١٩٩٢

سنة المنح: ٢٠١٠

ABSTRACT

Circular columns have been widely used in various types of reinforced concrete structures such as bridges piers. The normal compression capacity of the reinforced concrete circular column depends on the confinement shape. The main purpose of this study is to investigate the influence of the lateral confinement type on the behavior and capacity of the circular columns subjected to lateral cyclic loads. The concrete strength and main reinforcement ratio are additional factors were taken into consideration. Six small scaled columns divided into two categories according to the stirrups type were chosen to represent the effect of the mentioned factors. For category one, the circular hoops were used and spiral reinforcement was used in the second category. The tested specimens were subjected to top displacement saw-tooth acting lateral force.

The study has reached to some major conclusions such as:-

- 1- The main failure mode was similar in all specimens.
- 2-Using spiral stirrups with the same volumetric ratio increase the failure strength of the columns by about 15% and the cycles required for failure is increased accordingly.
- 3- The circular reinforced concrete columns casted with high strength concrete (60Mpa) has an increased failure strength value (about 50%) compared with the same columns casted with normal concrete strength (25Mpa).
- 4- Increasing the ratio of the main reinforcement improve the ductility in addition to the failure strength of columns to resist cyclic loads.
- 5- Using spirall stirrups eliminate the tendency of the local buckling of main rebars which decrease the strains on these rebars and delay the time required for the concrete cover spalling.

6-Strength losses in reinforced concrete columns casted by using normal concrete strength is much more these ones casted by using high strength concrete,

Finally, the study has highlighted that, The circular column laterally confined with spirally circular stirrups, casted with high concrete strength and longitudinally reinforced by about 2.5% has a much more improved behavior than that for the column with the circular hoops; this behavior appeared in the capacity of columns and the strength losses, the maximum drift ratio, the energy dissipation and stiffness degradation.

ACKNOWLEDGEMENTS

All praise belongs to God, Most Gracious, and Most Merciful. Only Through His Grace and Guidance, This Work was Completed.

I wish to express my deepest appreciation to Dr. Osama Hamdy Abd El-Wahed for enlightening, direction and supporting me at all times.

All appreciation and gratefulness to Dr. Ayman H.H.Khalil who provided, support, enlightening, direction, and supervision without which this work would have not been present as such.

I wish to express my gratitude to Dr. Haddad Sayied Haddad . I can not find the suitable words to express my respect, I thank him for his guidance and support, providing me all information I need, enlightening me to finish this research.

I am deeply indebted to my Family, Friends and Work's Mates for their help patience and support at all times.

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

رَبَّنَا لَا تُزِغْ قُلُوبَنَا بَعْدَ إِذْ هَدَيْتَنَا وَهَبْ لَنَا مِنْ
لَدُنْكَ رَحْمَةً إِنَّكَ أَنْتَ الْوَهَّابُ

صدق الله العظيم

detecated

To my father's and mother's souls.....;

TABLE OF CONTENTS

CHAPTER (1).....	8
INTRODUCTION.....	8
1.1 General	8
1.2 Objectives and Scope	9
1.3 Thesis Layout	10
CHAPTER (2).....	12
LITERATURE REVIEW.....	12
2.1 General	12
2.2 Basic Structural Properties	12
2.2.1 Strength.....	12
2.2.2 Stiffness	13
2.2.3 Ductility	15
2.3 Failure Classification of Columns under Lateral Loads.....	18
2.4 Typical Progression of Flexural Damage in R.C. Columns	22
2.5 Previous Research Results.....	25
2.5.1 Member Geometry and Reinforcement	26
2.5.1.1 Column Aspect Ratio and Length	27
2.5.1.2 Concrete Cover	28
2.5.1.3 Longitudinal Reinforcement Ratio	30
2.5.1.4 Confinement	32
2.5.1.5 Longitudinal Bar Diameter	35
2.5.2 Material Properties	36
2.5.2.1 Plain and Confined Concrete.....	37
2.5.2.2 Longitudinal Reinforcement.....	37
2.5.2.3 Transverse Reinforcement.....	39
2.5.3 Loading.....	40
2.5.3.1 Axial Load	40
2.5.3.2 Lateral Displacement History	43
2.5.3.3 Load Path.....	44
2.6 Damage Indices	46
2.7 Plastic Hinge Length Expressions	48
CHAPTER (3).....	52
EXPERIMENTAL PROGRAM.....	52
3.1 General	52
3.2 Materials	53
3.2.1 Concrete.....	53
3.2.2 Reinforcement	58
3.3 Test Specimens.....	59
3.4 Preparing Forms and Placing Reinforcement.....	65
3.5 Preparing Specimens	65
3.5.1 Casting, Compacting and curing	65
3.5.2 Pre-Stressing.....	67
3.5.3 Calculation of Pre-stressing Force.....	72
3.6 Strain Measurements	74
3.7 Instrumentation.....	74

3.8 Test System Configuration	75
3.8.1 Measurement Devices	75
3.8.2 Control Station and Data Acquisition System	77
3.9 Test Procedure	81
CHAPTER (4).....	83
EXPERIMENTAL RESULTS.....	83
4.1 Introduction	83
4.2 Modes of failure, crack pattern and general observations	84
4.2.1 Group (A)	85
4.2.1.1 Model (A-1)-Reference Model	85
4.2.1.2 Model (A-2).....	85
4.2.2 Group(B).....	86
4.2.2.1 Model (B1-1)	86
4.2.2.2 Model (B1-2)	87
4.2.2.3 Model (B2-1)	88
4.2.2.4 Model (B2-2)	88
4.3 Load-displacement relationships	89
4.3.1 Group (A)	89
4.3.1.1 Model (A-1) -REFERENCE MODEL	89
4.3.1.2 Model (A-2).....	90
4.3.2 Group (B).....	90
4.3.2.1 Model (B-1-1).....	90
4.3.2.2 Model (B-1-2).....	91
4.3.2.3 Model (B-2-1).....	92
4.3.2.4 Model (B-2-2).....	92
4.4 Strength, Stiffness and Energy Dissipation Characteristics	105
4.4.1 General	105
4.4.2 Group(A)	105
4.4.2.1 Model (A-1) –Reference Model	105
4.4.2.2 Model (A-2).....	106
4.4.3 Group (B).....	106
4.4.3.1 Model (B1-1)	106
4.4.3.2 Model (B1-2)	107
4.4.3.3 Model (B2-1)	108
4.4.3.4 Model (B2-2)	108
CHAPTER (5).....	115
ANALYSIS AND DISCUSSION.....	115
5.1 Introduction	115
5.2 Displacement Ductility Analysis.....	115
5.2.1 Yield Displacement	115
5.2.2 Displacement Ductility Factor and Accumulated Displacement Ductility	117
5.2.3 Drift Ratio.....	118
5.3 Strength Evaluations.....	119
5.4 Stiffness Analysis	119
5.5 Energy Dissipation	124

5.6 Ductility	125
CHAPTER (6).....	126
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS	126
6.1 Summary.....	126
6.2 Conclusions	126
6.3 Recommendations for Practice	128
6.4 Proposals for the Future Studies	128
APPENDIX (A).....	130
EFFECT OF THE CONFINEMENT TYPE ON THE CIRCULAR COLUMNS ACCORDING TO DESIGN CODE	130
Effect of the Confinement Type on Axially Loaded Columns.....	130
Effect of the Confinement Type on Eccentric Columns	131
List of References.....	132

LIST OF FIGURES

Figure 2- 1 Axial compressive Load-displacement relationship for reinforced concrete member[1].....	14
Figure 2- 2 Moment-curvature relationship for reinforced concrete member[1].....	17
Figure 2- 3 Plastic-Hinge Analysis [1].....	18
Figure 2- 4 Failure Classifications[4].....	23
Figure 2- 5 Force-Displacement Response of a Conventional Reinforced Concrete Column and a Column with a Steel Jacket [Chai 1991] [17].....	30
Figure 2- 6 Axial Strain Capacity vs. Spiral Reinforcement Ratio [44]34	
Figure 2- 8 Displacement Histories of Specimens 1 To 6 [47].....	46
Figure 3-1 Reinforcement Details Of Tested Specimen Type (B).....	62
Figure 3-2 Reinforcement Details Of Tested Specimen Type (A).....	63
Figure 3-3 Reinforcement Details Of Stub (I).....	64
Figure 3-4 Reinforcement Details Of Stub (II)	64
Figure 3-5 Reinforcement Steel of Specimens.....	66
Figure 3-6 Wooden Form for The Location of Anchor.....	66
Figure 3-7 Placing Steel Reinforcement in Wooden Forms.....	66
Figure 3-8 Plastic Pipe at The Location of Anchor	66
Figure 3-9 Column Form.....	68
Figure 3-10 Adjusting Column Reinforcement.....	68
Figure 3-11 Additional Reinforcement at Bottom Connection	68
Figure 3-12 Transferring Reinforcement Steel Using Crane	68
Figure 3-13 Strain Gauges on Circular Stirrups	69
Figure 3-14 Strain Gauges on Main Reinforcement.....	69
Figure 3-15 Casting Lower Stub Using vibrator	69
Figure 3-16 Plastic Pipe at The Location of Anchor.....	69
Figure 3-17 Casting Concrete Standard Cubes	70
Figure 3-18 Forming The Column Forms	70
Figure 3-19 Adjusting Verticality of Column	70
Figure 3-20 Casting Concrete for Column	70
Figure 3-21 Transporting Specimen Using Crane Girder	71
Figure 3-22 Preparing Forms for Upper Stub Casting	71
Figure 3-23 Final Specimen Shape and its Relevant Standard Cubes	71
Figure 3-24 Provide Specimen Identification and Casting date.....	71
Figure 3-26 General View of The Acquisition System.....	79
Figure 3-27 Load Cell and Actuator.....	80

Figure 3-28 Steel Frame Connected to Load Cell	80
Figure 3-29 Steel Frame Connected to Upper	80
Figure 3-30 Top Displacement Recording	80
Figure 3-31a Bending Moment Diagram	82
Figure 3-31b Axial Force Diagram	82
Figure 4-01 Crack Propagation at Bottom of Column.	94
Figure 4-02 Cracks Propagation at The Top of The Column.....	94
Figure 4-03 Crack Extended Through The Column.....	94
Figure 4-04 Start Concrete Cover Spalling	94
Figure 4-05 Main Reinforcement Buckling at Bottom	95
Figure 4-06 Main Reinforcement Buckling at Top	95
Figure 4-07 Concrete Cover Spalling.....	95
Figure 4-08 Double Curvature Failure	95
Figure 4-09 Crack Pattern -Specimen (A1) at Top	96
Figure 4-10 Crack Pattern- Specimen (A2)at Bottom.....	96
Figure 4-11 Crack Pattern -Specimen (B1-1) at Top	96
Figure 4-12 Crack Pattern- Specimen (B1-2)at Top	96
Figure 4-13 Crack Pattern Specimen (B2-1) at Bottom	97
Figure 4-14 Crack Pattern Specimen (B2-2) at Bottom	97
Figure 4-15-, Displacement – History Chart	98
Figure 4-16, Load-Displacement Hystreis for Specimen A1	99
Figure 4-17, Load –No. of Cycles Chart for Specimen A1	99
Figure 4-18, Load-Displacement Hystreis for Specimen A2	100
Figure 4-19, Load –No. of Cycles Chart for Specimen A2.....	100
Figure 4-20, Load-Displacement Hystreis for Specimen B1-1	101
Figure 4-21, Load –No. of Cycles Chart for Specimen B1-1.....	101
Figure 4-22, Load-Displacement Hystreis for Specimen B1-2	102
Figure 4-23, Load –No. of Cycles Chart for Specimen B1-2.....	102
Figure 4-24, Load-Displacement Hystreis for Specimen B2-1	103
Figure 4-25, Load –No. of Cycles Chart for Specimen B2-1.....	103
Figure 4-26, Load-Displacement Hystreis For Specimen B2-2	104
Figure 4-27, Load –No. of Cycles Chart for Specimen B2-2.....	104
Figure 4-28, Stiffness–No. of Cycles Chart for Specimen A1	109
Figure 4-29, Energy Dissipations- No. of Cycles Chart for Specimen A1	109
Figure 4-30, Stiffness–No. of Cycles Chart for Specimen A-2& A-1110	
Figure 4-31, Energy Dissipations- No. of Cycles Chart for Specimen A-2&A-1	110
Figure 4-32, Stiffness–No. of Cycles Chart for Specimen B1-1&A1-1111	

Figure 4-33, Energy Dissipations-No. of Cycles Chart for Specimen B1-11&A1-1	111
Figure 4-34, Stiffness–No. of Cycles Chart for Specimen B1-2 & A-2 & B1-1	112
Figure 4-35, Energy Dissipations-No. of Cycles Chart for Specimen B1-2 & A-2 & B1-1	112
Figure 4-36, Stiffness–No. of Cycles Chart for Specimen B2-1&B1-1&A-1	113
Figure 4-37, Energy Dissipations- No. of Cycles Chart for Specimen B2-1&A-1-&B1-1.....	113
Figure 4-38, Stiffness–No. of Cycles Chart for Specimen B2-2&A-2&B1-2	114
Figure 4-39, Energy Dissipations- No. of Cycles Chart for Specimen B2-2&A-2&B1-2	114
Figure 5-2 Calculation of Energy Dissipations	120
Figure 5-3 Hysteresis Loops Envelope Of Lateral Load versus Disp. A-1	120
Figure 5-4 Hysteresis Loops Envelope Of Lateral Load versus Disp. A-2	121
Figure 5-5 Hysteresis Loops Envelope Of Lateral Load versus Disp. B1-1	121
Figure 5-6 Hysteretic Loops Envelope Of Lateral Load versus Disp. B1-2	122
Figure 5-7 Hysteresis Loops Envelope Of Lateral Load versus Disp. B2-1	122
Figure 5-8 Hysteresis Loops Envelope Of Lateral Load versus Disp. B2-2	123