



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Structural Engineering

# Performance of Steel Fiber Reinforced Concrete Corbels

A Thesis

submitted in partial fulfillment of the requirements of the degree of

Master of Science in Civil Engineering

(Structural Engineering)

by

**Moaz Abdel Naser Abdel Raouf Mansour**

Bachelor of Science in Civil Engineering

(Structural Engineering)

Misr Higher Institute for Engineering and Technology, Mansoura, 2011

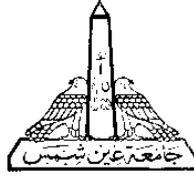
Supervised By

**Prof. Dr. Amin Saleh Aly**

**Assoc. Prof. Ahmed Fathy Abdel-aziz**

**Assoc. Prof. Ahmed Farouk Deifalla**

Cairo - (2019)



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Structural

# Performance of Steel Fiber Reinforced Concrete Corbels

by

**Moaz Abdel Naser Abdel Raouf Mansour**

Bachelor of Science in Civil Engineering

(Structural Engineering)

## Examiners' Committee

**Name and Affiliation**

**Signature**

**Prof. Dr.** Gouda Mohamed Ghanem

Structural , Al-Sherouq Academy

.....

**Prof Dr.** Mohamed Nour El-dein

Structural , Ain Shams University

.....

**Prof. Dr** Amin Saleh Aly

Structural , Ain Shams University

.....

**Assoc. Prof.** Ahmed Fathy Abdel-aziz

Structural , Ain Shams University

.....

Date: 06 August 2019

# Statement

This thesis is submitted as a partial fulfilment of Master of Science in Civil Engineering Engineering, Faculty of Engineering, Ain shams University.

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

## **Student name**

Moaz Abdel Naser Abdel Raouf Mansour

## **Signature**

.....

Date: 06 August 2019

# Researcher Data

Name : Moaz Abdel Naser Abdel Raouf  
Mansour.

Date of birth : 1-4-1989.

Place of birth : Sharkia, Egypt.

Last academic degree : Bachelor of Science

Field of specialization : Civil Engineering.

Date of issued degree : May 2011.

Current job : Demonstrator at Al-Obour Institute for  
Engineering and Technology

# Thesis Summary

Seven full-scale reinforced concrete corbel specimens were tested to study performance of steel fiber reinforced concrete corbels with and without fibers. The test variables were steel fiber content ( $V_f$  %) and shear span-to-depth ratio ( $a/d$ ), with constant concrete compressive strength ( $f_{cu}$ ), area of main steel reinforcement ( $A_s$ ) and presence of horizontal stirrups.

Both ACI Building Code provisions and Fattuhi equation agree with the test result specimen's. One of the experimental test results with 1% fiber reinforcement was checked using ANSYS. Test results showed that, addition of steel fibers up to 2 percent improves both shear strength and ductility of the tested corbels, and results in a more ductile failure mode.

There is a considerable increase in the ultimate shear strength of steel fiber reinforced concrete corbels with the addition of steel fibers for specific range and. The test result showed an increase in the ultimate load up to 2% fiber content as shear span to depth ratio changed from 0.80 to 0.65.

# **Acknowledgment**

**I would like to thank ALLAH for blessings that ALLAH granted to me all the way till I finished this research, and all through my life.**

I wish to express my profound gratitude and deep appreciation to my supervisors for their great effort in solving all the problems during this research and for direct supervision, valuable advice and encouragement during the research.

**Prof. Dr. Amin Saleh Aly Saleh**

**Assoc. Prof. Dr. Ahmed Fathy Abdel-aziz**

**Assoc. Prof. Dr. Ahmed Farouk Deifalla**

In addition, I would like to thank my doctors **Assoc. Prof. Dr. Khalid Fawzy - Dr. Ahmed El-Barbary** - my friends (**Mahmoud Rehab, Elsadek Hussien, Mohamed Mohamed Abdel Moneem**) for their help and advice during this research.

Finally, I make all the meaning of love, gratitude and appreciation to my family (my father, my mother (peace be upon her), my wife, my brother and my daughter).for their love and engorgement.me. Whatever I do for them do not fulfilled their right. All what I hope is pleasing ALLAH then my father and my wife they have all love and thanks.

**August 2019**

# TABLE OF CONTENTS

<b>THESIS SUMMARY</b> .....	v
<b>ACKNOWLEDGMENT</b> .....	vi
<b>TABLE OF CONTENTS</b> .....	vii
<b>LIST OF FIGURES</b> .....	xii
<b>LIST OF TABLES</b> .....	xv
<b>LIST OF ABBREVIATIONS</b> .....	xvi
<b>CHAPTER 1</b> .....	1
<b>INTRODUCTION</b> .....	1
1.1 General .....	1
1.2 Object of the study (SFRC) .....	1
1.3 Research Methodology .....	2
1.4 Thesis Outline .....	2
<b>CHAPTER 2 LITERATURE REVIEW</b> .....	4
2.1 Introduction .....	4
2.2 Experimental Research on Corbels .....	4
2.3 Literature Review on Influence of Fibers .....	10
<b>CHAPTER 3</b> .....	14
<b>EXPERIMENTAL WORK</b> .....	14
3.1 Introduction .....	14
3.2 Tests of Used Materials .....	15
3.2.1 Coarse Aggregates .....	15
3.2.2 Fine Aggregates .....	17
3.2.3 Tests of Combined Aggregates .....	19
3.2.4 Cement .....	21
3.2.5 Reinforcement Steel .....	22

3.2.6	Testing Cubes .....	23
3.3	Preparing Specimens.....	26
3.3.1	Describing the Specimens .....	26
3.3.2	Specimens Cross Section.....	28
3.3.3	Specimens Reinforced Details.....	29
3.3.3.1	Specimen (C-0.80-0%).....	30
3.3.3.2	Specimen (C-0.80-1%) .....	31
3.3.3.3	Specimen (C-0.80-2%) .....	33
3.3.3.4	Specimen (C-0.80-3%) .....	34
3.3.4	Casting and Curing .....	36
3.3.5	Testing the Specimens .....	38
3.3.6	Arranging the Measuring Devices .....	39
3.3.6.1	Linear Variable Displacement Transducer (LVDT).....	40
3.3.6.2	Electrical Strain Gauges .....	41
3.3.6.3	Test Procedure .....	42
3.4	Comments .....	44
<b>CHAPTER 4.....</b>		<b>45</b>
<b>PRESENTAION OF TEST RESULTS .....</b>		<b>45</b>
4.1	Introduction.....	45
4.2	Experimental Results .....	46
4.2.1	Results of control Specimen (C-0.80-0%).....	47
4.2.1.1	Cracking Patterns and Failure Modes .....	47
4.2.1.2	Load Deflection Response .....	49
4.2.1.3	Strain in Stirrups of Specimen (C-0.80-0%) .....	49
4.2.1.4	Strain in Main Steel of Specimen (C-0.80-0%) .....	50
4.2.1.5	Strain in Concrete of Specimen (C-0.80-0%) .....	52
4.2.2	Results of Concrete Specimen (C-0.80-1%).....	53
4.2.2.1	Cracking Patterns and Failure Modes .....	54
4.2.2.2	Load Deflection Response .....	55
4.2.2.3	Strain in Stirrups of Specimen (C-0.80-1%) .....	56
4.2.2.4	Strain in Main Steel of Specimen (C-0.80-1%) .....	57
4.2.2.5	Strain in Concrete of Specimen (C-0.80-1%) .....	58

4.2.3	Results of Concrete Specimen (C-0.80-2%).....	59
4.2.3.1	Cracking Patterns and Failure Modes .....	60
4.2.3.2	Load Deflection Response .....	62
4.2.3.3	Strain in Stirrups of Specimen (C-0.80-2%) .....	62
4.2.3.4	Strain in Main Steel of Specimen (C-0.80-2%) .....	63
4.2.3.5	Strain in Concrete of Specimen (C-0.80-2%) .....	64
4.2.4	Results of concrete Specimen (C-0.80-3%) .....	65
4.2.4.1	Cracking Patterns and Failure Modes .....	66
4.2.4.2	Load Deflection Response .....	68
4.2.4.3	Strain in Stirrups of Specimen (C-0.80-3%) .....	68
4.2.4.4	Strain in Main Steel of Specimen (C-0.80-3%) .....	69
4.2.4.5	Strain in Concrete of Specimen (C-0.80-3%) .....	70
4.2.5	Results of concrete Specimen (C-0.75-2%) .....	71
4.2.5.1	Cracking Patterns and Failure Mode .....	72
4.2.5.2	Load Deflection Response .....	74
4.2.5.3	Strain in Stirrups of Specimen (C-0.75-2%) .....	74
4.2.5.4	Strain in Main Steel of Specimen (C-0.75-2%) .....	75
4.2.5.5	Strain in Concrete of Specimen (C-0.75-2%) .....	76
4.2.6	Results of concrete Specimen (C-0.70-2%) .....	77
4.2.6.1	Cracking Patterns and Failure Mode.....	78
4.2.6.2	Load Deflection Response .....	80
4.2.6.3	Strain in Stirrups of Specimen (C-0.70-2%) .....	80
4.2.6.4	Strain in Main Steel of Specimen (C-0.70-2%) .....	81
4.2.6.5	Strain in Concrete of Specimen (C-0.70-2%) .....	82
4.2.7	Results of control Specimen (C-0.65-2%).....	83
4.2.7.1	Cracking Patterns and Failure Modes .....	84
4.2.7.2	Load Deflection Response .....	86
4.2.7.3	Strain in Stirrups of Specimen (C-0.65-2%) .....	86
4.2.7.4	Strain in Main Steel of Specimen (C-0.65-2%) .....	87
4.2.7.5	Strain in Concrete of Specimen (C-0.65-2%) .....	89
	<b>CHAPTER 5.....</b>	<b>90</b>
	<b>EVALUATION OF TEST RESULTS .....</b>	<b>90</b>

5.1	Introduction.....	90
5.2	Analysis of Test Results.....	90
5.2.1	Relation between Load and Deflection for (G-1).....	91
5.2.2	Relation between Load and Deflection for (G-2).....	92
5.2.3	Relation between Load and Strain in concrete for (G-1).....	94
5.2.4	Relation between Load and Strain in concrete for (G-2).....	95
5.2.5	Relation between Load and Strain in Main Steel for (G-1).....	97
5.2.6	Relation between Load and Strain in Main Steel for (G-2).....	98
5.2.7	Failure Mode: .....	100
	<b>CHAPTER 6.....</b>	<b>102</b>
	<b>FINITE ELEMENT VALIDATION .....</b>	<b>102</b>
6.1	Introduction.....	102
6.2	ANSYS Program Description.....	103
6.3	Non-linear Behavior in ANSYS Program.....	103
6.4	Structural Element Types.....	104
6.4.1	SOLID 65 .....	104
6.4.2	LINK 180.....	104
6.4.3	SOLID 186 .....	105
6.5	Modeling of Reinforcement.....	106
6.6	Verification of ANSYS Program .....	107
6.6.1	Element Type.....	109
6.6.2	Real Constants .....	109
6.6.3	Material Properties .....	110
6.6.4	Modeling and Meshing .....	115
6.6.5	Loading and Boundary Conditions.....	117
6.6.6	Nonlinear Solution and Failure Criteria .....	118
6.6.7	Verification of the Proposed Finite Element Model.....	119
	<b>CHAPTER 7.....</b>	<b>121</b>
	<b>CODE VALIDATION.....</b>	<b>121</b>
7.1	Introduction.....	121
7.2	ACI code equation .....	121
7.3	Fattuhi equation : .....	122

7.3.1	Relation between experimental and predicted ultimate Loads for (G-1) .....	123
7.3.2	Relation between experimental and predicted ultimate Loads for (G-2) .....	124
<b>CHAPTER 8</b> .....		125
<b>CONCLUSIONS AND RECOMMENDATIONS</b> .....		125
8.1	Introduction.....	125
8.2	Conclusions.....	125
8.3	Suggestions for Future Research .....	126
<b>REFERENCE</b> .....		127

## LIST OF FIGURES

Figure 2.2-1 Shear-Friction Hypothesis (Birkeland and Birkeland 1966).....	8
Figure 2.2-2 Examples of corbels and their truss idealization (Cook and Mitchell 1988) .....	9
Figure 3.2-1 grading curve for the implemented course aggregate .....	17
Figure 3.2-2 grading curve for the implemented fine aggregate .....	19
Figure 3.2-3 grading curve for the combined aggregate.....	21
Figure 3.2-4 materials used.....	23
Figure 3.2-5 drum mixer.....	24
Figure 3.2-6 casting the standard cubes and cylinder .....	24
Figure 3.2-7 standard cube failure shape .....	25
Figure 3.2-8 standard cylinder failure shape.....	25
Figure 3.3-1 Test specimen model.....	27
Figure 3.3-2 concrete dimensions and reinforcement details of a typical specimen. ....	28
Figure 3.3-3 Reinforcement details of corbel .....	29
Figure 3.3-4 Reinforcement of specimen (C-0.80-0%) in laboratory.....	30
Figure 3.3-5. Reinforcement Details of a Specimen (C-0.80-0%). .....	31
Figure 3.3-6 Reinforcement of specimen (C-0.80-1%) in laboratory.....	32
Figure 3.3-7 Reinforcement Details of a Specimen (C-0.80-1%). .....	32
Figure 3.3-8 Reinforcement of specimen (C-0.80-2%) in laboratory.....	33
Figure 3.3-9 Reinforcement Details of a Specimen (C-0.80-2%). .....	34
Figure 3.3-10 Reinforcement of specimen (C-0.80-3%) in laboratory.....	35
Figure 3.3-11 Reinforcement Details of a Specimen (C-0.80-3%). .....	35
Figure 3.3-12 wood forms for specimens. ....	36
Figure 3.3-13 Casting the Specimens during mixing.....	37
Figure 3.3-14 Casting the Specimens in wood form.....	37
Figure 3.3-15 Test set-up. ....	38
Figure 3.3-16 Measuring device (strains) .....	39
Figure 3.3-17 Measuring device (LVDT).....	40
Figure 3.3-18 The Strain Gauge.....	41
Figure 3.3-19 Electric Strain Gauge. ....	42
Figure 4.2-1 Cracks appear on surface of corbel specimen (C-0.80-0%).....	48
Figure 4.2-2 Shows the cracks pattern and failure mode of specimen (C-0.80-0%) Diagonal splitting (D.S).....	48
Figure 4.2-3 Load-Deflection of specimen (C-0.80-0%).....	49
Figure 4.2-4 Strain in stirrup of Specimen (C-0.80-0%) .....	50
Figure 4.2-5 Load-Strain of Main Steel Curve of specimen (C-0.80-0%) .....	51
Figure 4.2-6 Load-Strain of Concrete of specimen (C-0.80-0%) .....	52
Figure 4.2-7 Cracks appear on surface of corbel specimen (C-0.80-1%).....	54

Figure 4.2-8 Show the cracks pattern and failure mode of specimen (C-0.80-1%) Shear failure (C.S).....	55
Figure 4.2-9 Load-Deflection of specimen (C-0.80-1%).....	56
Figure 4.2-10 Load-Strain of Stirrups of specimen (C-0.80-1%).....	57
Figure 4.2-11 Load-Strain of Main Steel of specimen (C-0.80-1%).....	58
Figure 4.2-12 Load-Strain of Concrete Curve of specimen (C-0.80-1%).....	59
Figure 4.2-13 Cracks appear on surface of corbel specimen (C-0.80-2%).....	61
Figure 4.2-14 Show the cracks pattern and failure mode of specimen (C-0.80-2%) flexural failure (F.S).....	61
Figure 4.2-15 Load-Deflection of specimen (C-0.80-2%).....	62
Figure 4.2-16 Load-Strain of Stirrups of specimen (C-0.80-2%).....	63
Figure 4.2-17 Load-Strain of Main Steel of specimen (C-0.80-2%).....	64
Figure 4.2-18 Load-Strain of Concrete Curve of specimen (C-0.80-2%).....	65
Figure 4.2-19 Cracks appear on surface of corbel specimen (C-0.80-3%).....	67
Figure 4.2-20 Show the cracks pattern and failure mode of specimen (C-0.80-3%) Diagonal splitting (D.S).....	67
Figure 4.2-21 Load-Deflection of specimen (C-0.80-3%).....	68
Figure 4.2-22 Load-Strain of Stirrups of specimen (C-0.80-3%).....	69
Figure 4.2-23 Load-Strain of Main Steel of specimen (C-0.80-3%).....	70
Figure 4.2-24 Load-Strain of Concrete of specimen (C-0.80-3%).....	71
Figure 4.2-25 Cracks appear on surface of corbel specimen (C-0.75-2%).....	73
Figure 4.2-26 Show the cracks pattern and failure mode of specimen (C-0.75-2%) Diagonal splitting (D.S).....	73
Figure 4.2-27 Load-Deflection of specimen (C-0.75-2%).....	74
Figure 4.2-28 Load-Strain of of specimen (C-0.75-2%).....	75
Figure 4.2-29 Load-Strain of Main Steel of specimen (C-0.75-2%).....	76
Figure 4.2-30 Load-Strain of Concrete Curve of specimen (C-0.75-2%).....	77
Figure 4.2-31 Cracks appear on surface of corbel specimen (C-0.70-2%).....	79
Figure 4.2-32 Show the cracks pattern and failure mode of specimen (C-0.70-2%) Flexure failure (F.S).....	79
Figure 4.2-33 Load-Deflection of specimen (C-0.70-2%).....	80
Figure 4.2-34 Load-Strain of Stirrups of specimen (C-0.70-2%).....	81
Figure 4.2-35 Load-Strain of Main Steel of specimen (C-0.70-2%).....	82
Figure 4.2-36 Load-Strain of Concrete Curve of specimen (C-0.70-2%).....	83
Figure 4.2-37 Cracks appear on surface of corbel specimen (C-0.65-2%).....	85
Figure 4.2-38 Show the cracks pattern and failure mode of specimen (C-0.65-2%) Diagonal splitting (D.S).....	85
Figure 4.2-39 Load-Deflection of specimen (C-0.65-2%).....	86
Figure 4.2-40 Load-Strain of Stirrups of specimen (C-0.65-2%).....	87
Figure 4.2-41 Load-Strain of Main Steel of specimen (C-0.65-2%).....	88

Figure 4.2-42 Load-Strain of Main Steel of specimen (C-0.65-2%) .....	89
Figure 5.2-1 Load – Deflection curves for (G-1) specimens .....	91
Figure 5.2-2 Load - Deflection Curves for (G-2) specimens .....	93
Figure 5.2-3 Load – strain of concrete Curves for (G-1) specimens .....	94
Figure 5.2-4 Load - Strain of concrete Curves for (G-2) specimens .....	96
Figure 5.2-5 Load – Strain in Main Steel Curves for (G-1) specimens .....	97
Figure 5.2-6 Load – Strain in Main Steel Curves for (G-2) specimens .....	99
Figure 6.4-1 A schematic of the elements .....	104
Figure 6.4-2 LINK8 geometry .....	105
Figure 6.4-3 SOLID 186 geometry .....	105
Figure 6.5-1 Models of reinforcement (a) discrete; (b) embedded; and (c) smeared .....	107
Figure 6.6-1 Models of reinforcement (a) discrete; (b) embedded; and (c) smeared .....	108
Figure 6.6-2 Uniaxial stress-strain curve for concrete.....	113
Figure 6.6-3 stress-strain curve for steel reinforcement .....	115
Figure 6.6-4 Element connectivity: (a) Concrete solid and link elements, (b) Concrete solid and steel solid element, Kachlakev (2001) .....	116
Figure 6.6-5 Geometric mesh of concrete, steel plate, steel support .....	116
Figure 6.6-6 Reinforcement configuration for (corbels).....	117
Figure 6.6-7 Model of boundary condition and loading .....	118
Figure 6.6.7-1 Experimental and numerical load versus mid span deflection plots of (C-0.80- 0%) .....	120
Figure 6.6.7-2 Experimental and numerical load versus mid span deflection plots of (C-0.80- 1%) .....	120
Figure 7.3-1 Relation between experimental and predicted ultimate load Loads for (G-1) ...	123
Figure 7.3-2 comparison between the loads for (G-2) as obtained from experimental studies. .....	124

## LIST OF TABLES

Table 3.2-1 Characteristics of the Implemented Coarse Aggregate .....	16
Table 3.2-2 Results of Sieve Analysis Test for Coarse Aggregate.....	16
Table 3.2-3 The Implemented Fine Aggregate Characteristics .....	18
Table 3.2-4 Results of Sieve Analysis Test for Fine Aggregate.....	18
Table 3.2-5 Results of Sieve Analysis Test for the Implemented Combined Aggregate .	20
Table 3.2-6 Characteristics of the Implemented Ordinary Portland cement .....	22
Table 3.2-7 Properties of reinforcement steel bar.....	22
Table 3.2-8 the constituent materials.....	23
Table 3.2-9 Results of Testing Concrete Specimens Cubes and Cylinder .....	26
Table 3.3-1 Details of reinforcement for all specimens.....	30
Table 4.2-1 the major test results of the specimens .....	46
Table 4.2-2 Results of Specimen (C-0.80-0%).....	47
Table 4.2-3 Results of Specimen (C-0.80-1%).....	53
Table 4.2-4 Results of Specimen (C-0.80-2%).....	60
Table 4.2-5 Results of Specimen (C-0.80-3%).....	66
Table 4.2-6 Results of Specimen (C-0.75-2%).....	72
Table 4.2-7 Results of Specimen (C-0.70-2%).....	78
Table 4.2-8 Results of Specimen (C-0.65-2%).....	84
Table 5.2-1 Two Groups to Study Variables .....	90
Table 6.6-1 Details of corbels tested under static load .....	108
Table 6.6-2 Real constant for beams (steel reinforcement) .....	110
Table 6.6-3 linear isotropic material properties for model .....	112
Table 6.6-4 Nonlinear material properties for concrete model.....	112
Table 6.6-5 Multi-linear isotropic material properties for model .....	112
Table 6.6-6 Multi-linear isotropic material properties for model .....	113
Table 6.6-7 Bilinear isotropic material properties for vertical stirrups .....	114
Table 6.6-8 linear isotropic material properties for RFT (10 mm).....	114
Table 6.6-9 Bilinear isotropic material properties for RFT (10 mm) .....	114
Table 6.6-10 linear isotropic material properties for RFT (12 mm).....	114
Table 6.6-11 Bilinear isotropic material properties for RFT (12 mm) .....	114
Table 6.6-12 Linear isotropic material properties for steel plate.....	115
Table 6.6-13 Nonlinear analysis .....	118
Table 6.6.7-1 Comparison between experimental and finite element failure load .....	119
Table 7.3-1 Corbels results and comparison between experimental and predicted ultimate load.....	122