



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT

SHEAR BEHAVIOR OF SELF COMPACTING HIGH STRENGTH CONCRETE BEAMS

BY
Ahmed Essawy Mohamed Essawy

B.SC. 2006 Structural Division
Civil Engineering Department
Ain Shams University

A Thesis
Submitted in partial fulfillment for the requirements of the
Degree of Master of Science in Structural Engineering

Supervised by
Prof. Dr. Ayman Hussein Hosny Khalil
Prof. of Reinforced Concrete Structures
Faculty of Engineering
Ain Shams University

Prof. Dr. Ahmed Hassan Ghallab
Prof. of Reinforced Concrete Structures
Faculty of Engineering
Ain Shams University

Faculty of Engineering
Ain Shams University
Cairo-2015

STATEMENT

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

The work included in this thesis was carried out by the author in the Department of Civil Engineering (Structural Division), Ain Shams University, from June 2009 to September 2014.

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

Date : 02 / 02 / 2015

Name : Ahmed Essawy Mohamed

Signature: *Ahmed Essawy*

AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
STRUCTURAL ENGINEERING DEPARTMENT
Date: 02/02/2015



Approval Sheet

Thesis : Master of Science in Civil Engineering (Structural)

Student Name: Ahmed Essawy Mohamed Essawy

Thesis Title : SHEAR BEHAVIOR OF SELF COMPACTING HIGH
STRENGTH CONCRETE BEAMS

Examiners Committee:

Prof. Dr. Adel Galal Tawfik Elattar

Professor of R.C. Structures
Faculty of Engineering – Cairo University

Prof. Dr. Omar Ali Mousa El Nawawy

Professor of R.C. Structures
Faculty of Engineering – Ain Shams University

Prof. Dr. Ayman Hussein Hosny Khalil

Professor of R.C. Structures
Faculty of Engineering – Ain Shams University
(Supervisor)

Prof. Dr. Ahmed Hassan Ghallab

Professor of R.C. Structures
Faculty of Engineering – Ain Shams University
(Supervisor)

INFORMAION ABOUT THE RESEARCHER

Name: Ahmed Essawy Mohamed Essawy

Date of Birth: October 5th, 1983

Place of Birth: Cairo

Qualification: B.Sc. Degree in civil Engineering (Structural Engineering)

Faculty of Engineering, Ain Shams University 2006

Present Job: Structural Engineer and Deputy Project Manager for Univeristy To

Work Initiative , ECG Engineering Consultants Group S.A.

Signiture: *Ahmed Essawy*

ACKNOWLEDGMENTS

First of all, Thank you Allah for everything you gave me, for everything you didn't give me, for everything you protected me from- that which I know and that which I'm not even aware of, thank you for blessings that I didn't even realize were blessings, thank you from guidance when I felt like I was slipping, and thank you for every thing else because no matter how many things I try to list, at the end of the day, I can't even come close to thanking you enough.

I would like to express my sincerest appreciation to my advisors, Prof. Dr. Ayman Hussein Hosny Khalil and Prof. Dr. Ahmed Hassan Ghallab for their guidance, continuous, valuable guidance and the investments, giving me the opportunity to be involved in such interesting research and also for their constant encouragement, support and friendship which was the motivating force that kept work on my thesis in force until completion..

Finally I would like to thank my father and mother for their continuous support and for every thing they had gave me all my life.

Ahmed Essawy

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

Abstract of the M.Sc. Thesis Submitted by

Eng. / Ahmed Essawy Mohamed

Title of the thesis:

**SHEAR BEHAVIOR OF SELF COMPACTING HIGH STRENGTH
CONCRETE BEAMS**

ABSTRACT

The shear behavior of self-compacting high strength reinforced concrete beams was experimentally and theoretically evaluated in this study. The main studied factors were the amount of web reinforcement in the beam, the shearing span to depth ratio (a/d) and the web width of the beam. Eight samples I-shaped of high strength self-compacting reinforced concrete beams with a span of 1.8m and with a cross-section that varied from 100x250 mm to 200x250 mm, while the flange width varied from 200 to 300 mm.

The results showed that tested beams without web reinforcement showed brittle failure and that the presence of web reinforcement, improved the type of failure and, increased the shear capacity of the section.

Increasing the shearing span to depth ratio decreased the shear capacity of the concrete beams without web reinforcement, accordingly failure of beam with high shearing span to depth ratio was sudden and accompanied by the formation of one failure crack, while failure of beams with smaller (a/d) ratios was more explosive due to failure in the compression strut formed between point of loading and the support. Increasing the shearing span to depth ratio led to a significant decrease in the failure load of the beam with web reinforcement.

CONTENTS

ACKNOWLEDGMENTS.....	v
ABSTRACT.....	vi
CONTENTS.....	vii
LIST OF FIGURES.....	xi
LIST OF TABLES.....	xvi
CHAPTER 1: INTRODUCTION.....	1
1.1 Background	2
1.2 Purpose of Investigation.....	3
1.3 Structure of the thesis.....	4
CHAPTER 2: LITERATURE REVIEW.....	5
2.1 Introduction.....	6
2.2 Historical background (Caldarone, Michael A., 2008).....	6
2.3 Shear and diagonal tension in beams (Nilson AH., 2010).....	8
2.3.1 Diagonal tension in homogeneous elastic beams (Nilson AH., 2010).....	8
2.3.2 Difference between arch action and beam action (Wight,j and Macgregor j ,2012).....	12
2.3.3 Reinforced concrete beams without shear reinforcement (Nilson AH., 2010).....	12
2.3.3.1Criteria for Formation of Diagonal Cracks.....	13
2.3.3.2 Behavior of Diagonally Cracked Beams.....	16
2.3.4 Reinforced concrete beams with web reinforcement (Nilson AH., 2010).....	18
2.3.4.1 Beams with vertical stirrups.....	18
2.3.5 Behavior of beams failing in shear (Wight,j and Macgregor j ,2012).....	20
2.4 High Strength Concrete.....	22
2.4.1 Introduction.....	22
2.4.2 Definition (Gosh SMIE, S.K. Ghosh, 2004).....	23
2.4.1 Applications (Caldarone, Michael A., 2008).....	24
2.4.2 Material (Caldarone, Michael A., 2008).....	25

2.4.3 Properties of HSC (Caldarone, Michael A., 2008).....	27
2.5 Self-Compacting Concrete.....	31
2.5.1 Development of self-compacting.....	31
2.5.2 Self-Compacting Concrete laboratory study (SCC laboratory study, 2009).....	33
2.6 Previous Researches.....	36
2.6.1 Behavior of High-Strength Concrete I-Beams with Low Shear Reinforcement (Teoh B. K., etc., 2002).....	36
2.6.2 Shear Strength of Reinforced High-Strength Concrete Beams with Shear Span-to-Depth Ratios between 1.5 and 2.5(Sung-Woo Shin, etc., August 1999).....	38
2.6.3 Shear behaviour of high strength self-compacting concrete (Adham, 2006).....	40
CHAPTER 3: EXPERIMENTAL WORK.....	43
3.1 Introduction.....	44
3.2 Specimen Details.....	45
3.3 Materials.....	46
3.3.1 Coarse aggregate and Sand.....	46
3.3.2 Cement.....	46
3.3.3 Mixing Water.....	46
3.3.4 Steel Reinforcement.....	47
3.3.5 Silica Fume.....	47
3.3.6 Super plasticizer (Sika ViscoCrete [®] -20He).....	47
3.4 Concrete Mix.....	48
3.5 Preparation of test specimens.....	49
3.6 Material properties.....	52
3.7 Instrumentation and Testing Procedure.....	52
CHAPTER 4: EXPERIMENTAL RESULTS.....	57
4.1 Introduction.....	58
4.2 Experimental Results.....	59
4.2.1 Cracking Patterns.....	59
4.2.1.1 Effect of web reinforcement (Group 1)	60
4.2.1.2 Effect of shearing span to depth ratio (beams without web reinforcement) Group 2	64
4.2.1.3 Effect of shearing span to depth ratio (beams with web reinforcement) Group(3).....	66

4.2.1.4 Effect of web width (b_w) Group 4	68
4.2.2 Load-deflection relationship.....	71
4.2.2.1 Effect of web reinforcement (Group 1)	76
4.2.2.2 Effect of shearing span to depth ratio (beams without web reinforcement) Group 2	76
4.2.2.3 Effect of shearing Span to Depth ratio (beams with web reinforcement) Group 3	77
4.2.2.4 Effect of Web Width (b_w) Group 4	77
4.2.3 Beam failure modes.....	77
4.2.3.1 Effect of web reinforcement (Group 1)	79
4.2.3.2 Effect of shearing span to depth ratio (beams without web rft.) - Group 2.....	79
4.2.3.3 Effect of shearing span to depth ratio (beams with web rft.) - Group 3.....	79
4.2.3.4 Effect of web width (b_w) - Group 4.....	79
4.2.4 The Cracking and the Failure Loads	83
4.2.5 Strain measurements in steel reinforcement.....	84
4.2.6 Concrete strain measurements.....	96
CHAPTER 5: DISCUSSION OF TEST RESULTS	105
5.1 Introduction	106
5.2 Discussion of results of the tested beams.....	107
5.2.1 Effect of web reinforcement (Group 1):.....	107
5.2.1.1 Cracking Pattern	107
5.2.1.2 Load Deflection Relationship	107
5.2.1.3 Mode of failure.....	110
5.2.2 Shearing span to depth ratio – beams without web reinforcement group (2).....	111
5.2.2.1 Cracking Pattern.....	111
5.2.2.2 Load Deflection Relationship.....	111
5.2.2.3 Mode of failure.....	114
5.2.3 Shearing span to depth ratio – beams with web reinforcement group 3.....	114
5.2.3.1 Cracking Pattern.....	115
5.2.3.2 Load Deflection Relationship.....	115
5.2.3.3 Cracking and Ultimate loads.....	116
5.2.3.4 Mode of failure.....	117
5.2.4 Effect of web width b_w Group 4.....	117

5.2.4.1 Cracking Pattern.....	117
5.2.4.2 Load Deflection Relationship.....	118
5.2.4.3 Mode of failure.....	120
CHAPTER 6: THEORETICAL ANALYSIS	121
6.1 Introduction	122
6.2 Methods to calculate ultimate shear strength of concrete beams	122
6.2.1 Code methods.....	122
6.2.1.1 Egyptian Code of Practice (ECP 203-2007)	123
6.2.1.2 American Concrete Institute ACI 318 (2011)	124
6.2.1.3 British Standard Code of Practice (BS 8110-97)	125
6.2.1.4 Eurocode 2 (2004).....	126
6.3 Experimental Results vs. Theoretical Results	127
6.4 Comparison with computer software (Response 2000)	132
CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS.....	137
7.1 Summary	139
7.2 Conclusions	140
7.3 Recommendations for Future Work	142
CHAPTER 8: REFERENCES.....	143

LIST OF FIGURES

Figure (2.1) Shear in homogeneous rectangular beams.....	9
Figure (2.2) Stress trajectories in a homogenous rectangular beam adapted	11
Figure (2.3) Beam action and arch action.....	12
Figure (2.4) Typical locations of critical combinations of shear and moment.....	14
Figure (2.5) Diagonal tension cracking in reinforced concrete beams.....	15
Figure (2.6) Forces at a diagonal crack in a beam without web reinforcement.....	16
Figure (2.7) Types of web reinforcement.....	18
Figure (2.8) Forces at a diagonal crack in a beam with vertical stirrups.....	19
Figure (2.9) Modes of failure.....	20
Figure (2.10) Applications on using high strength concrete.....	24
Figure (2.11) Typical stress-strain relation for high, Moderate and conventional strength concrete.....	28
Figure (2.12) equipment used in scc study.....	33
Figure (2.13) specimen dimension.....	36
Figure (2.14) specimen dimension.....	38
Figure (2.15) specimen dimension.....	41
Figure (3.1) Concrete dimensions of beam specimens (mm).....	45
Figure (3.2) Preparing beam specimens.....	50
Figure (3.3) Finishing preparations of beam reinforcement and formwork.....	50
Figure (3.4) Performing slump test and measuring slump diameter.....	51
Figure (3.5) Pouring concrete in beams.....	51
Figure (3.6) Beam specimen (B1).....	53
Figure (3.7) Beam specimen (B2).....	53
Figure (3.8) Beam specimen (B3).....	53
Figure (3.9) Beam specimen (B4).....	54
Figure (3.10) Beam specimen (B5).....	54

Figure (3.11) Beam specimen (B6).....	54
Figure (3.12) Beam specimen (B7).....	55
Figure (3.13) Beam specimen (B8).....	55
Figure (3.14) Location of dimic points and LVDT in a typical beam.....	56
Figure (3.15) Testing of concrete specimen.....	56
Figure (4.1) The cracking and failure pattern for group (1): B4, B2, B6 and B5.....	63
Figure (4.2) The cracking and failure pattern for group (2): B1 and B4.....	65
Figure (4.3) The cracking and failure pattern for group (3):B3 and B5.....	67
Figure (4.4) The cracking and failure pattern for group (4):B2, B7 and B8.....	70
Figure (4.5) Location of dimic points and LVDT in a typical beam.....	71
Figure (4.6) Load deflection curves for beam B1.....	72
Figure (4.7) Load deflection curves for beam B2.....	72
Figure (4.8) Load deflection curves for beam B3.....	73
Figure (4.9) Load deflection curves for beam B4.....	73
Figure (4.10) Load deflection curves for beam B5.....	74
Figure (4.11) Load deflection curves for beam B6.....	74
Figure (4.12) Load deflection curves for beam B7.....	75
Figure (4.13) Load deflection curves for beam B8.....	75
Figure (4.14) cracks propagated through the aggregates.....	78
Figure (4.15) Failure of beam (B1).....	80
Figure (4.16) Failure of beam (B2).....	80
Figure (4.17) Failure of beam (B3).....	81
Figure (4.18) Failure of beam (B4).....	81
Figure (4.19) Failure of beam (B5).....	82
Figure (4.20) Failure of beam (B6).....	82
Figure (4.21) Failure of beam (B7).....	83
Figure (4.22) Failure of beam (B8).....	83
Figure (4.23) Comparison between the cracking and failure loads of tested beams.....	84
Figure (4.24) Location of strain gages on stirrups, lower and upper reinforcement.....	85
Figure (4.25) Load versus longitudinal steel strain for beam (B1).....	86

Figure (4.26) Load versus longitudinal steel strain for beam (B2).....	86
Figure (4.27) Load versus stirrups steel strain for beam (B2).....	87
Figure (4.28) Load versus longitudinal and stirrups steel strain for beam (B2).....	87
Figure (4.29) Load versus longitudinal steel strain for beam (B3).....	88
Figure (4.30) Load versus stirrups steel strain for beam (B3).....	88
Figure (4.31) Load versus longitudinal and stirrups steel strain for beam (B3).....	89
Figure (4.32) Load versus longitudinal steel strain for beam (B4).....	89
Figure (4.33) Load versus longitudinal steel strain for beam (B5).....	90
Figure (4.34) Load versus stirrups steel strain for beam (B5).....	90
Figure (4.35) Load versus longitudinal and stirrups steel strain for beam (B5).....	91
Figure (4.36) Load versus longitudinal steel strain for beam (B6).....	91
Figure (4.37) Load versus stirrups steel strain for beam (B6).....	92
Figure (4.38) Load versus longitudinal and stirrups steel strain for beam (B6).....	92
Figure (4.39) Load versus longitudinal steel strain for beam (B7).....	93
Figure (4.40) Load versus stirrups steel strain for beam (B7).....	93
Figure (4.41) Load versus longitudinal and stirrups steel strain for beam (B7).....	94
Figure (4.42) Load versus longitudinal steel strain for beam (B8).....	94
Figure (4.43) Load versus stirrups steel strain for beam (B8).....	95
Figure (4.44) Load versus longitudinal and stirrups steel strain for beam (B8).....	95
Figure (4.45) Locations of dimic points for a typical beam specimen.....	96
Figure (4.34) Load versus concrete strain curves for beam B1 – left side.....	97
Figure (4.35) Load versus concrete strain curves for beam B2 – right side.....	97
Figure (4.36) Load versus concrete strain curves for beam B2 – left side.....	98
Figure (4.37) Load versus concrete strain curves for beam B3 – right side.....	98
Figure (4.38) Load versus concrete strain curves for beam B3 – left side.....	99
Figure (4.39) Load versus concrete strain curves for beam B4 – right side.....	99
Figure (4.40) Load versus concrete strain curves for beam B4 – left side.....	100
Figure (4.41) Load versus concrete strain curves for beam B5 – right part.....	100
Figure (4.42) Load versus concrete strain curves for beam B5 – left side.....	101
Figure (4.43) Load versus concrete strain curves for beam B6 – right side.....	101

Figure (4.44) Load versus concrete strain curves for beam B6 – left side.....	102
Figure (4.45) Load versus concrete strain curves for beam B7 – right side.....	102
Figure (4.46) Load versus concrete strain curves for beam B7 – left side.....	103
Figure (4.47) Load versus concrete strain curves for beam B8 – right part.....	103
Figure (4.48) Load versus concrete strain curves for beam B8 – left side.....	104
Figure (5.1) Load – deflection curves for group 1.....	108
Figure (5.2) Load – stiffness curves for group 1.....	109
Figure (5.3) Relation between loads and shear reinforcement for beams in group 1.....	110
Figure (5.4) Load deflection curves for group 2.....	112
Figure (5.5) Load-Stiffness curves for group 2.....	113
Figure (5.6) Relation between loads and shearing span to depth ratios for beams in group 2.....	114
Figure (5.7) Load deflection curves for group 3.....	115
Figure (5.8) Load-Stiffness curves for group 3.....	116
Figure (5.9) Relation between loads and shearing span to depth ratios for beams in group 3.....	117
Figure (5.10) Load deflection curves for group 4.....	118
Figure (5.11) Load-stiffness curves for group 4.....	119
Figure (5.12) Relation between loads and increase in web width for beams in group 4.....	120
Figure (6.1) Values of the experimental and predicted ultimate shear values for ECP 203-2007.....	130
Figure (6.2) Values of the experimental and predicted ultimate shear values for ACI 318-2011.....	130
Figure (6.3) Values of the experimental and predicted ultimate shear values for BS 8110-97.....	131
Figure (6.4) Values of the experimental and predicted ultimate shear values for Euro code 2 [2004].....	131
Figure (6.5) Values of the experimental and predicted ultimate shear values for the studied code equations together.....	132

Figure (6.6) Inputs for beam (B5) in Response 2000 program.....	133
Figure (6.7) Outputs for beam (B5) in Response 2000 program.....	134
Figure (6.8) Values of the experimental and predicted ultimate shear values for Response 2000 program.....	136
Figure (6.9) Values of the experimental and predicted ultimate shear values for the studied codes and Response 2000 program.....	136