****

**Shear Behavior of Self Compacting Concrete Deep Beams Reinforced with GFRP and Steel Rebars**

Submitted in partial fulfillment of the requirements for the Master of Science degree in the Department of Civil Engineering at the College of Engineering, King Saud University.

by

Saleh ……..

June 2020

**Shear Behavior of Self Compacting Concrete Deep Beams Reinforced with GFRP and Steel Rebars**

**سلوك القص في الكمرات الخرسانية العميقة ذاتية الدمك المسلحة بالحديد وقضبان الألياف الزجاجية**

**Prepared by:**

**Saleh ……..**

This thesis was discussed on, ……………………

corresponding to ……………..and was approved by the following:

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Prof.xxxxx Dr. xxxxxxx**

Advisor Co-advisor

Members of the Examination Committee

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Prof. xx Dr. xx**

# CONTENTS

[LIST OF FIGURES 6](#_Toc36218810)

[LIST OF TABLES 10](#_Toc36218811)

[ACKNOWLEDGEMENTS 11](#_Toc36218812)

[CHAPTER 1 15](#_Toc36218813)

[1. INTRODUCTION 15](#_Toc36218814)

[1.1 GENERAL 15](#_Toc36218815)

[1.2 RESEARCH OBJECTIVES 19](#_Toc36218816)

[1.3 THESIS LAYOUT 20](#_Toc36218817)

[CHAPTER 2 21](#_Toc36218818)

[2. LITERATURE REVIEW 21](#_Toc36218819)

[2.1 RC Deep beams 21](#_Toc36218820)

[2.2 Self-consolidating concrete in Deep Beams 30](#_Toc36218821)

[2.3 Deep beams reinforced with FRP rebars 35](#_Toc36218822)

[2.4 Deep beams with concrete having steel fibers 40](#_Toc36218823)

[CHAPTER 3 45](#_Toc36218824)

[3. EXPERIMENTAL PROGRAM 45](#_Toc36218825)

[3.1 Introduction 45](#_Toc36218826)

[3.2 Materials ……………………………………………………………………………………………………………………………………… 45](#_Toc36218827)

[3.2.1 Concrete……………………………………………………………………………………………………………………………………..45](#_Toc36218828)

[3.2.2 Steel bars ……………………………………………………………………………………………………………………………………48](#_Toc36218829)

[3.2.3 GFRP bars …………………………………………………………………………………………………………………………………49](#_Toc36218830)

[3.2.4 Steel fibers ………………………………………………………………………………………………………………………………...50](#_Toc36218831)

[3.3 Test Specimens 51](#_Toc36218832)

[3.4 Group I ………………………………………………………………………………………………………………………………………….55](#_Toc36218833)

[3.5 Group II …………………………………………………………………………………………………………………………………………57](#_Toc36218834)

[3.6 Group III ……………………………………………………………………………………………………………………………………….59](#_Toc36218835)

[3.7 Testing Setup 60](#_Toc36218836)

[CHAPTER 4 65](#_Toc36218837)

[4. RESULTS AND DISCUSSION 65](#_Toc36218838)

[4.1 Introduction.... 65](#_Toc36218839)

[4.2 Group I…………………………………………………………………………………………………………………………………………..65](#_Toc36218840)

[4.2.1 Deep Beam B1NS 66](#_Toc36218841)

[4.2.2 Deep Beam B2NG 68](#_Toc36218842)

[4.2.3 Deep Beam B3NG 71](#_Toc36218843)

[4.2.4 Deep Beam B4NH 74](#_Toc36218844)

[4.2.5 Deep Beam B5NH 77](#_Toc36218845)

[4.2.6 Deep Beam B6NH 80](#_Toc36218846)

[4.2.7 Deep Beam B1NG-NEW 83](#_Toc36218847)

[4.3 Group II…………………………………………………………………………………………………………………………………………86](#_Toc36218848)

[4.3.1 Deep Beam B1FG-1.2% 87](#_Toc36218849)

[4.3.2 Deep Beam B2FG-0.9% 90](#_Toc36218850)

[4.3.3 Deep Beam B3FG-0.6% 93](#_Toc36218851)

[4.3.4 Deep Beam B4FH-1.2% 96](#_Toc36218852)

[4.3.5 Deep Beam B5FH-0.9% 100](#_Toc36218853)

[4.3.6 Deep Beam B6FH-0.6% 104](#_Toc36218854)

[4.4GroupIII………………………………………………………………………………………………………………………………………..107](#_Toc36218855)

[4.4.1 Deep Beam B1FG-2/3 108](#_Toc36218856)

[4.4.2 Deep Beam B3FG-2/3 110](#_Toc36218857)

[4.4.3 Deep Beam B4FH-2/3 113](#_Toc36218858)

[4.4.4 Deep Beam B6FH-2/3 115](#_Toc36218859)

[4.5 Dowel action in deep beams 123](#_Toc36218860)

[4.6 Effect of GFRP type 118](#_Toc36218861)

[4.7 Effect of the Hybrid system 119](#_Toc36218862)

[4.8 Effect of steel fibers 120](#_Toc36218863)

[4.9 Effect of using steel fibers in two-third of the beam height 121](#_Toc36218864)

[CHAPTER 5 127](#_Toc36218865)

[5.1 CONCLUSIONS 127](#_Toc36218866)

[REFERENCES 129](#_Toc36218867)

# ACKNOWLEDGEMENTS

First, I owe a huge debt of thanks to my supervisors, Prof…………………………………………………………………………………………………………………………………………………………………………………………………………

I also thank my colleagues and friends who supported me and have been kind enough to advise me when needed.

Finally, and certainly not least, I owe a great deal to my family; this thesis could not have been completed without the unlimited help and the support of my mother, brother and sisters.

# LIST OF FIGURES

[Figure 1 . 1:Stress-strain variation of reinforcement bars of different materials (Pinheiro et al. 2017) 17](#_Toc36218320)

[Figure 2 . 1:Schematic diagram of a deep beam (Lc/h ≤ 4, a/h ≤ 2) 21](#_Toc36218342)

[Figure 2 . 2:Cracking propagation in deep beams (Osman 2008) 24](#_Toc36218343)

[Figure 2 . 3:Stress distribution in deep beams (Mohamed 2019) 24](#_Toc36218344)

[Figure 2 . 4:Strut-and-tie in (a) simply-supported deep beam and (b) continuous deep beam (Mohamed 2019) 25](#_Toc36218345)

[Figure 2 . 5:DRAMIX RC steel fibers (Ambroise et al., 2001) 32](#_Toc36218346)

[Figure 2 . 6:General View of Perimeter Wall Used by Khayat et al. (2000) 34](#_Toc36218347)

[Figure 2 . 7:Tensile stress distribution in a FRP bar 36](#_Toc36218348)

[Figure 2 . 8:GFRP bars with (a) sand coated surface, (b) with a ripped exterior layer 38](#_Toc36218349)

[Figure 2 . 9:Classification of fibers used in concrete (Fanella and Naaman 1985) 42](#_Toc36218350)

[Figure 2 . 10:Classification of fibers based on fiber shape (Abdullah et al. 2018) 43](#_Toc36218351)

[Figure 3. 1: Ready mix truck delivering scc at casting location 46](#_Toc36218409)

[Figure 3. 2:Mixing SCC with steel fibers using a drum mixer 47](#_Toc36218410)

[Figure 3. 3:SCC slump flow test 48](#_Toc36218411)

[Figure 3. 4:First type of GFRP rebars used in this study 49](#_Toc36218412)

[Figure 3. 5:Second type of GFRP rebars used in this study 50](#_Toc36218413)

[Figure 3. 6:Steels fibers used in the study 50](#_Toc36218414)

[Figure 3. 7:Wooded molds used for casting the deep beam samples 52](#_Toc36218415)

[Figure 3. 8:Casting of deep beam samples without steel fibers 52](#_Toc36218416)

[Figure 3. 9:Casting of deep beam samples with steel fibers 53](#_Toc36218417)

[Figure 3. 10:Finishing of deep beam samples 53](#_Toc36218418)

[Figure 3. 11:Deep beam samples after demolding 54](#_Toc36218419)

[Figure 3. 12:Deep beam samples after demoldin 54](#_Toc36218420)

[Figure 3. 13:Cross-section of deep beams tested in group I 55](#_Toc36218421)

[Figure 3. 14:Cross-section of deep beams tested in group II 57](#_Toc36218422)

[Figure 3. 15:Cross-section of deep beams tested in group III 59](#_Toc36218423)

[Figure 3. 16:Universal testing machine used in the testing of deep beams 61](#_Toc36218424)

[Figure 3. 17:The main controller of the Universal testing machine 62](#_Toc36218425)

[Figure 3. 18:Testing setup used and location of LVDT 62](#_Toc36218426)

[Figure 3. 19:Locations of strain gauges in deep beam samples containing two longitudinal reinforcement bars 63](#_Toc36218427)

[Figure 3. 20:Locations of strain gauges in deep beam samples containing three longitudinal reinforcement bars 63](#_Toc36218428)

[Figure 3. 21:Deep beam sample strengthed with CFRP sheet outside the testing span 64](#_Toc36218429)

[Figure 4. 1:Deep Beam B1NS before Testing 66](#_Toc36218448)

[Figure 4. 2:Cracking in Deep Beam B1NS during Testing 67](#_Toc36218449)

[Figure 4. 3:Deep Beam B1NS after Testing 67](#_Toc36218450)

[Figure 4. 4:Load versus Deflection of Deep Beam B1NS 68](#_Toc36218451)

[Figure 4. 5:Deep Beam B2NG before Testing 69](#_Toc36218452)

[Figure 4. 6:Cracking in Deep Beam B2NG during Testing 69](#_Toc36218453)

[Figure 4. 7:Deep Beam B2NG after Testing 70](#_Toc36218454)

[Figure 4. 8:Load versus Deflection of Deep Beam B2NG 70](#_Toc36218455)

[Figure 4. 9:Deep Beam B3NG before Testing 72](#_Toc36218456)

[Figure 4. 10:Cracking in Deep Beam B3NG during Testing 72](#_Toc36218457)

[Figure 4. 11:Deep Beam B3NG after Testing 73](#_Toc36218458)

[Figure 4. 12:Load versus Deflection of Deep Beam B3NG 73](#_Toc36218459)

[Figure 4. 13:Deep Beam B4NH before Testing 75](#_Toc36218460)

[Figure 4. 14:Cracking in Deep Beam B4NH during Testing 75](#_Toc36218461)

[Figure 4. 15:Deep Beam B4NH after Testing 76](#_Toc36218462)

[Figure 4. 16:Load versus Deflection of Deep Beam B4NH 76](#_Toc36218463)

[Figure 4. 17:Deep Beam B5NH before Testing 78](#_Toc36218464)

[Figure 4. 18:Cracking in Deep Beam B5NH during Testing 78](#_Toc36218465)

[Figure 4. 19:Deep Beam B5NH after Testing 79](#_Toc36218466)

[Figure 4. 20:Load versus Deflection of Deep Beam B5NH 79](#_Toc36218467)

[Figure 4. 21:Deep Beam B6NH before Testing 81](#_Toc36218468)

[Figure 4. 22:Cracking in Deep Beam B6NH during Testing 81](#_Toc36218469)

[Figure 4. 23:Deep Beam B6NH after Testing 82](#_Toc36218470)

[Figure 4. 24: Deep Beam B6NH after Testing 82](#_Toc36218471)

[Figure 4. 25: Load versus Deflection of Deep Beam B6NH 83](#_Toc36218472)

[Figure 4. 26:Deep Beam B1NG-NEW before Testing 84](#_Toc36218473)

[Figure 4. 27: Cracking in Deep Beam B1NG-NEW during Testing 84](#_Toc36218474)

[Figure 4. 28: Deep Beam B1NG-NEW after Testing 85](#_Toc36218475)

[Figure 4. 29: Deep Beam B1NG-NEW after Testing 85](#_Toc36218476)

[Figure 4. 30: Load versus Deflection of Deep Beam B1NG-NEW 86](#_Toc36218477)

[Figure 4. 31: Deep Beam B1FG-1.2% before Testing 88](#_Toc36218478)

[Figure 4. 32: Cracking in Deep Beam B1FG-1.2% during Testing 88](#_Toc36218479)

[Figure 4. 33: Deep Beam B1FG-1.2% after Testing 89](#_Toc36218480)

[Figure 4. 34: Deep Beam B1FG-1.2% after Testing 89](#_Toc36218481)

[Figure 4. 35: Load versus Deflection of Deep Beam B1FG-1.2% Compared to B3NG 90](#_Toc36218482)

[Figure 4. 36: Deep Beam B2FG-0.9% before Testing 92](#_Toc36218483)

[Figure 4. 37: Cracking in Deep Beam B2FG-0.9% during Testing 92](#_Toc36218484)

[Figure 4. 38: Deep Beam B2FG-0.9% after Testing 93](#_Toc36218485)

[Figure 4. 39: Load versus Deflection of Deep Beam B2FG-0.9% Compared to B3NG 93](#_Toc36218486)

[Figure 4. 40: Cracking in Deep Beam B3FG-0.6% during Testing 95](#_Toc36218487)

[Figure 4. 41: Deep Beam B3FG-0.6% after Testing 95](#_Toc36218488)

[Figure 4. 42: Load versus Deflection of Deep Beam B3FG-0.6% Compared to B3NG 96](#_Toc36218489)

[Figure 4. 43: Deep Beam B4FH-1.2% before Testing 98](#_Toc36218490)

[Figure 4. 44: Cracking in Deep Beam B4FH-1.2% during Testing 98](#_Toc36218491)

[Figure 4. 45: Deep Beam B4FH-1.2% after Testing 99](#_Toc36218492)

[Figure 4. 46: Deep Beam B4FH-1.2% after Testing 99](#_Toc36218493)

[Figure 4. 47: Load versus Deflection of Deep Beam B4FH-1.2% Compared to B5NG 100](#_Toc36218494)

[Figure 4. 48: Deep Beam B5FH-0.9% before Testing 102](#_Toc36218495)

[Figure 4. 49: Cracking in Deep Beam B5FH-0.9% during Testing 102](#_Toc36218496)

[Figure 4. 50: Deep Beam B5FH-0.9% after Testing 103](#_Toc36218497)

[Figure 4. 51: Deep Beam B5FH-0.9% after Testing 103](#_Toc36218498)

[Figure 4. 52: Load versus Deflection of Deep Beam B5FH-0.9% Compared to B5NG 104](#_Toc36218499)

[Figure 4. 53: Cracking in Deep Beam B6FH-0.6% during Testing 105](#_Toc36218500)

[Figure 4. 54: Deep Beam B6FH-0.6% after Testing 106](#_Toc36218501)

[Figure 4. 55: Load versus Deflection of Deep Beam B6FH-0.6% Compared to B5NG 106](#_Toc36218502)

[Figure 4. 56: Cracking in Deep Beam B1FG-2/3 during Testing 109](#_Toc36218503)

[Figure 4. 57: Deep Beam B1FG-2/3 after Testing 109](#_Toc36218504)

[Figure 4. 58: : Load versus Deflection of Deep Beam B1FG-2/3 Compared to B3NG and B1FG-1.2% 110](#_Toc36218505)

[Figure 4. 59: Cracking in Deep Beam B3FG-2/3 during Testing 111](#_Toc36218506)

[Figure 4. 60: Deep Beam B3FG-2/3 after Testing 112](#_Toc36218507)

[Figure 4. 61: Load versus Deflection of Deep Beam B3FG-2/3 Compared to B3NG AND B3FG-0.6% 112](#_Toc36218508)

[Figure 4. 62: Cracking in Deep Beam B4FH-2/3 during Testing 114](#_Toc36218509)

[Figure 4. 63: Deep Beam B4FH-2/3 after Testing 114](#_Toc36218510)

[Figure 4. 64: Load versus Deflection of Deep Beam B4FH-2/3 Compared to B5NG and B4FH-1.2% 115](#_Toc36218511)

[Figure 4. 65: Cracking in Deep Beam B6FH-2/3 during Testing 116](#_Toc36218512)

[Figure 4. 66:Deep Beam B6FH-2/3 after Testing 117](#_Toc36218513)

[Figure 4. 67: Load versus Deflection of Deep Beam B6FH-2/3 Compared to B5NG and B6FH-0.6% 117](#_Toc36218514)

Figure 4. 1: Prediction of shear strength of concrete deep beams………..…….112

# LIST OF TABLES

[Table 1.1: Mechanical properties of steel and FRP 17](#_Toc35992322)

[Table 2.1: Properties of steel fiber SCC (Ambroise et al., 2001) 33](#_Toc35992323)

[Table 3. 1:Concrete mix design 47](#_Toc35992297)

[Table 3. 2:Properties of steel fibers used in this study 51](#_Toc35992298)

[Table 3. 3:Reinforcement details of deep beam samples tested in Group I 55](#_Toc35992299)

[Table 3. 4:Reinforcement details of deep beam samples tested in Group II 58](#_Toc35992300)

[Table 3. 5:Reinforcement details of deep beam samples tested in Group III 60](#_Toc35992301)

[Table 4. 1:Flexure strength test results of deep beams in Group I 65](#_Toc52100441)

[Table 4. 2:Flexure strength test results of deep beams in Group II 86](#_Toc52100442)

[Table 4. 3:Flexure strength test results of deep beams in Group III 107](#_Toc52100443)

[Table 4. 5:Effect of using steel fibers 120](#_Toc52100444)

[Table 4. 6:Effect of using steel fibers in two-third of the beam height………….122](#_Toc52100445)

# ABSTRACT

Reinforced Concrete (RC) deep beams are often required in structures for the transfer of heavy loads to columns/shear walls at relatively close spacing. The span to depth ratio of these beams being small, their behavior is different from normal beams. The requirement of heavy flexural and shear reinforcement in RC deep beams causes rebar congestion, which makes the concreting difficult. The use of steel fibers in concrete further enhances the difficulties in concreting due to considerable reduction in the workability of fiber reinforced concrete (FRC). These difficulties can

# الملخص

غالبا ما يتم اللجوء إلى استخدام الكمرات الخرسانية العميقة المسلحة في المنشآت لنقل الأحمال الثقيلة إلى الأعمدة /جدران القص في التباعد القريب نسبيا، حيث تكون نسبة المجاز (الطول) إلى العمق لهذه الكمرات صغيرة، وسلوكها مختلفا عن سلوك الكمرات العادية.

# CHAPTER 1

# INTRODUCTION

## GENERAL

Reinforced concrete (RC) deep beams are members loaded on one face and supported on the opposite face so that compression struts can develop between the loads and the supports, and have either a clear spans equal to or less than four times the overall member depth or have regions with concentrated loads within twice the member depth from the face of the support (ACI 318-14 sec 9.9 and SBC 304 sec 10.7). Based on the literature, reinforced concrete beams could be classified based on the span-to-depth ratio. Deep beams typically have a shear span-to-depth ratio of less

REFERENCES

1. Abadel, A. A. (2021). Experimental investigation for shear strengthening of reinforced self-compacting concrete beams using different strengthening schemes. *Journal of Materials Research and Technology*, *15*, 1815-1829.
2. Almusallam, T. H., Abadel, A. A., Al-Salloum, Y. A., Siddiqui, N. A., & Abbas, H. (2015). Effectiveness of hybrid-fibers in improving the impact resistance of RC slabs. *International Journal of Impact Engineering*, *81*, 61-73.