



Cairo University

STRENGTHENING OF R.C. FLAT SLABS WITH CUT-OUT EDGE OPENINGS

By

FAISAL WALID HAFEZ

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
STRUCTURAL ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

STRENGTHENING OF R.C. FLAT SLABS WITH CUT-OUT EDGE OPENINGS

By
FAISAL WALID HAFEZ

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
STRUCTURAL ENGINEERING

Under the Supervision of

**Prof. Dr. HANY AHMED
ABDALLA**

.....
Professor of Concrete Structures
Structural Engineering
Department
Faculty of Engineering, Cairo
University

**Dr. KHALED FAROUK OMAR
EI-KASHIF**

.....
Assistant Professor
Structural Engineering Department
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

STRENGTHENING OF R.C. FLAT SLABS WITH CUT-OUT EDGE OPENINGS

By
FAISAL WALID HAFEZ

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
STRUCTURAL ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Hany Ahmed Ali Abdalla
Professor of Concrete Structures
Faculty of Engineering, Cairo University

(Thesis Main Advisor)

Prof. Dr. Akram Mohamed Torkey
Professor of Concrete Structures
Faculty of Engineering, Cairo University

(Internal Examiner)

Prof. Dr. Ahmed Ali Hasan Abdelwahab
Building Materials Research Institute
Housing & Building national research Center, Egypt

(External Examiner)

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

Engineer's Name: Faisal Walid Hafez
Date of Birth: 20/03/1992
Nationality: Syrian
E-mail: Faisalhz920@gmail.com

Phone: 01096645020
Address: 3 Central Street, 6 October City, Giza, Egypt
Registration Date: 01/10/2016
Awarding Date:/....../2019
Degree: Master of Science
Department: Structural Engineering



Supervisors:
Prof. Dr. Hany Ahmed Ali Abdalla
Dr. Khaled Farouk Omar El Kashif

Examiners:
Prof. Dr. Hany Ahmed Ali Abdalla
Prof. Dr. Akram Mohamed Torkey
Prof. Dr. Ahmed Ali Hasan Abdelwahab

Title of Thesis:

STRENGTHENING OF R.C. FLAT SLABS WITH CUT-OUT EDGE OPENINGS

Key Words:

Strengthening, R.C. Flat slab, Edge opening, Steel Bars, Steel Plates, CFRP Sheets, ECC.

Summary:

In this research different methods of strengthening of flat slabs with edge openings are studied theoretically and experimentally.

The experimental program consists of six square slabs with dimensions of (110*110*10) cm with cut-out edge opening of 30cm*30cm. Two slabs are considered as reference slabs with and without opening. The other four slabs were strengthened using various methods including additional steel bars, Carbon Fiber Reinforced Polymer (CFRP) strips, steel plates and bolts and near surface mounted Engineered Cementations Composite (ECC) steel mesh 10cm*10cm on the tensile face only. In addition, a numerical Finite element model is used to correlate and explore various conditions for strengthening techniques. The results showed that, the ultimate load carrying capacity increased for all the repaired slabs. Also, strengthening by steel bars was the most effective method of repair.

ACKNOWLEDGMENT

I would like to show my gratitude for my supervisors (**Prof. Dr. Hany Abdalla** and **Dr. Khaled El-Kashif**) for their guidance, advices, support and valuable discussions review during my Master, and their great efforts to achieve my objective.

I want also to thank my father, my mother, and all my friends who always help me for the success. I would not have to achieve this goal without their help and support.

DEDICATION

Dedicated to my parents, my sister and my brother with love

TABLE OF CONTENTS

ACKNOWLEDGMENT	I
DEDICATION	II
TABLE OF CONTENTS	III
LIST OF TABLES	VI
LIST OF FIGURES	VIII
ABSTRACT	XI
CHAPTER 1 : INTRODUCTION.....	1
1.1 General	1
1.2 Structural Statement.....	1
1.3 Objective	1
1.4 Thesis Outline	2
CHAPTER 2 : LITERATURE REVIEW.....	3
2.1 Introduction	3
2.2 Slabs with Opening	3
2.3 Strengthening Techniques	7
2.3.1 General.....	7
2.3.2 Types of FRP strengthening techniques.....	7
CHAPTER 3 : EXPERIMENTAL PROGRAM.....	28
3.1 Introduction.....	28
3.2 Material Properties.....	28
3.2.1 Coarse Aggregate.....	28
3.2.2 Fine Aggregate	28
3.2.3 Water	28
3.2.4 Cement	28
3.2.5 Reinforcing Steel	29
3.2.6 Concrete Mix	29
3.3 Test Program	30
3.4 properties of the tested specimens	30
3.4.1 Tested specimen (S1).....	30
3.4.2 Tested specimen (S2).....	31

3.4.3 Tested specimen (S3).....	32
3.4.4 Tested specimen (S4).....	32
3.4.5 Tested specimen (S5).....	33
3.4.6 Tested specimen (S6).....	34
3.5 Specimens placing, curing and details.....	34
3.6 Cube Samples.....	45
3.7 Measuring Devices.....	48
3.7.1 Reinforcement Strain.....	48
3.7.2 Deflection Measurement.....	48
3.8 Test procedure.....	49
CHAPTER 4 : EXPERIMENTAL RESULTS.....	50
4.1 Introduction.....	50
4.2 Cracking of test slabs	50
4.2.1 Crack pattern of specimen (S1).....	50
4.2.2 Crack pattern of specimen (S2).....	51
4.2.3 Crack pattern of specimen (S3).....	52
4.2.4 Crack pattern of specimen (S4).....	53
4.2.5 Crack pattern of specimen (S5).....	54
4.2.6 Crack pattern of specimen (S6).....	55
4.3 Ultimate capacity and modes of Failure.....	56
4.4 Deflection of the test slabs.....	57
4.4.1 Load-Deflection Relations of specimen (S1).....	57
4.4.2 Load-Deflection Relations of specimen (S2).....	57
4.4.3 Load-Deflection Relations of specimen (S3).....	58
4.4.4 Load-Deflection Relations of specimen (S4).....	59
4.4.5 Load-Deflection Relations of specimen (S5).....	60
4.4.6 Load-Deflection Relations of specimen (S6).....	61
4.5 Analysis and discussion of test results.....	62
4.5.1 Introduction.....	62
4.5.2 Comparison of deflection for slabs.....	62

4.5.2.1 Effect of the cut-out opening	62
4.5.2.2 Effect of the strengthen technique	63
4.5.3 Cracking load and ultimate capacity.....	64
4.5.4 Ductility.....	65
4.5.5 Cost of strengthening materials for specimens.....	65
4.5.6 Comparisons for Cost of Specimens.....	68
CHAPTER 5 : FINITE ELEMENT ANALYSIS.....	69
5.1 Introduction.....	69
5.2 ANSYS Program.....	69
5.3 Three-Dimensional Modeling.....	69
5.4 Finite Element Modeling of Concrete slab	69
5.4.1 Solid 65 for concrete.....	70
5.4.2 Link 180 for steel	71
5.4.3 SOLID 185 for CFRP	72
5.4.4 Carbon fiber reinforced polymers (CFRP).....	73
5.4.5 Engineered cementations composite (ECC).....	74
5.4.6 Real constants for element models.....	74
5.4.7 Meshing of the slab	74
5.4.8 Loads and boundary conditions.....	76
5.4.9 Non-linear analysis and failure criteria.....	76
5.4.10 Specimens models.....	76
5.5 Verification of specimens using Finite Element Model.....	81
CHAPTER 6 : SUMMERY, CONCLUSION AND RECOMMENDATIONS.....	93
6.1 Summary.....	93
6.2 Conclusion.....	93
6.3 Recommendation for future work.....	94
REFERENCES	95

LIST OF TABLES

Table 3-1: Mechanical Properties of Steel Bars	29
Table 3-2: Weights of One Cubic Meter of Concrete	29
Table 3-3: Properties of the all slabs	30
Table 3-4: Mechanical Properties of Steel Plates	38
Table 3-5: Properties of ECC layer	43
Table 3-6: Concrete compressive strength	47
Table 4-1: Test results of the specimens	50
Table 4-2: Material Cost for Strengthening of Specimen (S3).....	66
Table 4-3: Material Cost for Strengthening of Specimen (S4).....	66
Table 4-4: Material Cost for Strengthening of Specimen (S5).....	67
Table 4-5: Material Cost for Strengthening of Specimen (S6).....	67
Table 5.1: Material properties of Epoxy	70
Table 5.2: Material properties of steel bars	71
Table 5-3: Material properties of concrete	73
Table 5-4: Material properties of CFRP sheets	73
Table 5-5: Material properties of ECC	74
Table 5-6: Test results of the specimens	81

LIST OF FIGURES

Figure (2-1): Opening in flat slabs According to ACI -318 (2014), CAN3-A23.3-M84 (2004).....	4
Figure (2-2): openings in flat slabs (British code BS8110, 1997).....	5
Figure (2-3): Opening in flat slabs According to (Egyptian Code, 2017).....	7
Figure (2-4): Details of tested specimens	8
Figure (2-5): Geometry and strip positioning.....	9
Figure (2-6): configurations of specimens.....	10
Figure (2-7): Depending failure of slab.....	11
Figure (2-8): Failure Modes of specimen.....	12
Figure (2-9): CFRP strengthening schemes.....	13
Figure (2-10): Dimensions and details of specimen.....	14
Figure (2-11): Failure mode of specimens.....	14
Figure (2-12): Cracks pattern for all slabs.....	15
Figure (2-13): Steel plates and bolts strengthened slab.....	16
Figure (2-14): Sketch of slab cross section a and b series.....	17
Figure (2-15): Different anchorage technique approaches.....	18
Figure (2-16): strengthening scheme by CFRP sheets.....	19
Figure (2-17): Concrete dimensions and reinforcement detailing for un-strengthened slabs and base slabs for strengthened slabs.....	20
Figure (2-18): Internal forces of slab cross-section including cut-out.....	20
Figure (2-19): Detailing of the FRP strengthening applied.....	21
Figure (2-20): Dimensions of specimens.....	22
Figure (2-21): Strengthening schemes of specimens.....	23
Figure (2-22): Detailing of the FRP strengthening applied.....	24
Figure (2-23): Vertical pre-stressed bolts as shear reinforcements.....	25
Figure (2-24): Detail of shear head.....	25
Figure (2-25): Strengthening scheme of specimen.....	26
Figure (2-26): Details of specimen.....	26

Figure (2-27): Test set-up and specimen.....	27
Figure (3-1): Details of tasted specimen (S1).....	31
Figure (3-2): Details of tasted specimen (S2).....	31
Figure (3-3): Details of tasted specimen (S3).....	32
Figure (3-4): Details of tasted specimen (S4).....	33
Figure (3-5): Details of tasted specimen (S5).....	33
Figure (3-6): Details of tasted specimen (S6).....	34
Figure (3-7): Wood forms before casting of concrete.....	35
Figure (3-8): Wood forms after casting of concrete.....	35
Figure (3-9): Wood forms before casting of concrete.....	36
Figure (3-10): Wood forms after casting of concrete.....	36
Figure (3-11): Cleaning the holes using Air Hose.....	37
Figure (3-12): Components of Epoxy A&B (Sika dur 31).....	37
Figure (3-13): planting for steel bars.....	37
Figure (3-14): Finishing of tasted specimen (S3).....	37
Figure (3-15): Tasted of steel plate for specimen (S4).....	38
Figure (3-16): Tasted of steel Bolt for specimen (S4).....	38
Figure (3-17): Smoothing of surface for specimen (S4).....	39
Figure (3-18): Steps of strengthening for specimen (S4).....	40
Figure (3-19): Cutting of CFRP sheet for specimen (S5).....	41
Figure (3-20): Smoothing of surface for specimen (S5).....	42
Figure (3-21): Painting Epoxy using a brushing for specimen (S5).....	42
Figure (3-22): CFRP installing for specimen (S5).....	42
Figure (3-23): Final installing for specimen (S5).....	42
Figure (3-24): Materials used for specimen (S6).....	43
Figure (3-25): Drilling for specimen (S6).....	44
Figure (3-26): Cleaning off by using air hose for specimen (S6).....	44

Figure (3-27): Preparation of wood forms before casting of concrete.....	45
Figure (3-28): Painting Epoxy using a brushing for specimen (S6).....	45
Figure (3-29): Installing steel grid after casted one layer of mix design.....	45
Figure (3-30): Final layer of mix design.....	45
Figure (3-31): Nine cubic samples of the concrete mix.....	46
Figure (3-32): New mix design to strengthen specimen (S6).....	46
Figure (3-33): Cubic sample of the new mix.....	46
Figure (3-34): Strain gauge positions.....	48
Figure (3-35): LVDTs placing.....	49
Figure (3-36): Test procedure for each specimen.....	49
Figure (4-1) Crack pattern of specimen (S1).....	51
Figure (4-2) Crack pattern of specimen (S2).....	52
Figure (4-3) Crack pattern of specimen (S3).....	53
Figure (4-4) Crack pattern of specimen (S4).....	54
Figure (4-5) Crack pattern of specimen (S5).....	55
Figure (4-6) Crack pattern of specimen (S6).....	56
Figure (4-7) Load-Deflection relationship of Specimen (S1).....	57
Figure (4-8) Load-Deflection relationship of Specimen (S2).....	58
Figure (4-9) Load-Deflection relationship of Specimen (S3).....	59
Figure (4-10) Load-Deflection relationship of Specimen (S4).....	60
Figure (4-11) Load-Deflection relationship of Specimen (S5).....	61
Figure (4-12) Load-Deflection relationship of Specimen (S6).....	62
Figure (4-13) Load-Deflection curves at point 3 for specimens (S1 and S2).....	63
Figure (4-14) Load-Deflection curves at point 3 for strengthen specimens.....	63
Figure (4-15) Ultimate Loads for Specimens.....	64
Figure (4-16) Ductility for Specimens.....	65
Figure (4-17) Cost of Strengthening Materials for Specimens.....	68

Figure (5-1): Solid65–3D reinforced concrete solid (ANSYS .v.19).....	70
Figure (5-2): Link180–3D spar, (ANSYS .v.19).....	71
Figure (5-3): Solid185–3D modeling for CFRP (ANSYS.v.19).....	72
Figure (5-4): Meshing of reinforcement.....	75
Figure (5-5): Meshing of typical slab.....	75
Figure (5-6): series loads applied to slabs.....	76
Figure (5-7) Reinforcement of two meshes for specimen (S1) in ANSYS.....	77
Figure (5-8) 3D model of specimen (S2) in ANSYS.....	77
Figure (5-9) Reinforcement of two meshes for specimen (S2) in ANSYS.....	78
Figure (5-10) Bottom mesh of two meshes for specimen (S3)	78
Figure (5-11) Lower chord of slab after strengthening for specimen (S4).....	79
Figure (5-12) Upper chord of slab after strengthening for specimen (S4).....	79
Figure (5-13) Lower chord of slab after strengthening for specimen (S5).....	80
Figure (5-14) Upper chord of slab after strengthening for specimen (S5).....	80
Figure (5-15) Strengthening by ECC layer for specimen (S6).....	81
Figure (5-16) Cracking of Specimen (S1).....	82
Figure (5-17) Deformed shape of Specimen (S1).....	83
Figure (5-18) Comparison between ANSYS results and experimental results for Specimen (S1).....	83
Figure (5-19) Cracking of Specimen (S2).....	84
Figure (5-20) Deformed shape of Specimen (S2).....	85
Figure (5-21) Comparison between ANSYS results and experimental results for Specimen (S2).....	85
Figure (5-22) Cracking of Specimen (S3).....	86
Figure (5-23) Deformed shape of Specimen (S3).....	87
Figure (5-24) Comparison between ANSYS results and experimental results for Specimen (S3).....	87

Figure (5-25) Cracking of Specimen (S4).....	88
Figure (5-26) Deformed shape of Specimen (S4).....	89
Figure (5-27) Comparison between ANSYS results and experimental results for Specimen (S4).....	89
Figure (5-28) Cracking of Specimen (S5).....	90
Figure (5-29) Deformed shape of Specimen (S5).....	91
Figure (5-30) Comparison between ANSYS results and experimental results for Specimen (S5).....	91
Figure (5-31) Cracking of Specimen (S6).....	92
Figure (5-32) Deformed shape of Specimen (S6).....	92
Figure (5-33) Comparison between ANSYS results and experimental results for Specimen (S6).....	92