

624/16
S. A

AIN SHAMS UNIVERSITY
Faculty of Engineering

**Behaviour of the Reinforced Concrete Beams
Strengthened By Externally Bonded Plates**

By

Sami Akil Selim Fawzy
B.sc. (1990)



THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS OF THE DEGREE OF MASTER OF SCIENCE
IN STRUCTURAL ENGINEERING

51167

UNDER THE SUPERVISION OF

DR. OMAR ALI MOUSSA EL-NAWAWY.
PROF.DR. OF REINFORCED CONCRETE
AIN SHAMS UNIVERSITY

DR.ABD EL-SALAM AHMED MOKHTAR
ASSOC.PROF.OF THEORY OF STRUCTURE
AIN SHAMS UNIVERSITY



EXAMINERS COMMITTEE

Name, Title and Affiliation	Signature
1-Maj.Gen.Prof.Dr.Ahmed Nagy Sidky Prof. of Reinforced Concrete Dept. of civil Eng.Dept. Technical college	
2-Mostafa Zidan Theory of Structures Faculty of Engineering Ain Shams University	
3-Prof.Dr.Omar Ali Moussa El-Nawawy Prof. of Reinforced Concrete Faculty of Engineering Ain Shams University	
4-Dr.Abd El-Salam Ahmed Mokhtar Asso.Prof. of Theory of Structures Faculty of Engineering Ain Shams University	

Date / /1994



STATEMENT

THIS THESIS IS SUBMITTED TO AIN SHAMS UNIVERSITY FOR THE DEGREE OF MASTER OF SCIENCE IN THE STRUCTURAL ENGINEERING. NO PART OF THIS THESIS HAS BEEN PREVIOUSLY SUBMITTED FOR A DEGREE OR QUALIFICATION.

NAME: **Sami Akil Selim Fawzy**

DATE:

SIGNATURE: 

Thanks God

Acknowledgment

I would like to seize this opportunity to express my gratitude to all who have participated, helped and encouraged the presenting of this thesis.

Thanks to:

Prof.Dr.Omar Ali Moussa El-Nawawy for his supervision and guidance, valuable comments, interest, accurate time, respect, support and understanding and for all facilities that were made possible through him.

Assoc.Prof.Dr.Abd El-Salam Ahmed Mokhtar for his supervision, advice, assistance and contribution during the course of this study, and also for his valuable time passed in revising this thesis.

I would express my heartily thanks for my late father, always remembering his words, advice and education to me.

And send my devout appreciation to my brother Architectural Hany Fawzy for his invaluable effort during the preparation of most of the drawing and diagrams.

In addition, I'd like to thank Engineer Hossam Abdallah for his advice and useful notes, and also my gratitude to Engineer Amr Nafie.

Last but not least, no words can express my grateful for the ever lasting patience, encouragement and blessing of my mother.

Behaviour of Reinforced Concrete Beams Strengthened by Externally Bonded Plates

M. Sc Thesis by Sami Akil Fawzy

under supervision of:

Prof.Dr.Omar Ali Moussa El-Nawawy.

Dr.Abd El Salam Ahmed Mokhtar.

Abstract

The development of repair plated R.C. beams demanded the theoretical and experimental study for the main factors that affect the bonded beams.

The aim of this thesis is studying the behaviour of externally plated R.C. beams with the aid of a computer program, then verifying the results with the experimental works, then a parametric study is confirmed for studying the main factors influencing the strengthened beams, then modifying the program in order to handle the graphical representations.

The thesis consists of seven chapters and an appendix.

Chapter 1 :

Defining the strengthening of beams technique with its advantages and disadvantages, then a brief review and notes for the previous work pointing on the aim of this thesis.

Chapter 2:

Include a review for the theoretical and experimental works for steel and fiber plates, and a review for Finite element material models studying the effect of cracked and un-cracked concrete models in tension and compression, steel reinforcement representations, bond, shear modulus, dowel action, cracking and crushing criteria.

Chapter 3:

The adopted material models used in the program are discussed in this chapter

Chapter 4:

The computer program is presented in this chapter by a brief discussion for the flow chart and governing equations for each subroutine of the program, then the modified output files are explained to be used for graphical representations.

Chapter 5:

The computer program results are compared with the experimental works in the cases of steel and fiber plates, a good agreement of results is achieved with the use of steel plated R.C. beams.

Chapter 6:

The parametric study includes: the termination of plates, tensile strength of concrete, characteristic compressive strength, load distribution, area of plate, percentage ratio of steel reinforcement. Also there are some factors which affect in the accuracy of program as: tension stiffening, shear modulus, number of load increments, number of iterations, and tolerance.

Chapter 7:

The conclusions, recommendations and suggestions for future work in the case of bonded beams.

Appendix A:

Include a given input and output data files for an experimental test.

Table of Contents

Acknowledgments.....	i
Abstract.....	ii
Table of contents.....	iv
list of Figures and Tables.....	vii
Nomenclature.....	xii
<u>Chapter 1 : Introduction.....</u>	<u>1</u>
1.1 General.....	1
1.2 Review of previous work.....	3
1.2.1 Notes Concerning the previous Analytical Models.....	7
1.3 Objectives of the thesis.....	9
1.4 scope and contents.....	10
<u>Chapter 2 : Literature Review.....</u>	<u>12</u>
2.1 General Review.....	12
2.2 Steel plate study Review.....	12
2.2.1 General.....	12
2.2.2 Review.....	13
2.3 Fiber plate study Review.....	19
2.3.1 General.....	19
2.3.2 Review.....	20
2.4 Analytical Study Review.....	23
2.5 Review of Models Representing Concrete and Steel.....	28
2.5.1 Concrete mesh representation.....	28
2.5.2 Concrete in compression.....	29
2.5.3 Concrete in tension.....	34
2.5.4 Representation of cracks.....	37
2.5.5 Cracking criteria.....	38
2.5.6 Crushing of concrete.....	39
2.5.7 Bond between concrete and steel.....	39
2.5.8 Shear retention factor.....	40
2.5.9 Dowel action.....	42
2.5.10 Steel representation.....	43
2.5.11 Stress Strain relationship for steel.....	43
<u>Chapter 3 : Material model.....</u>	<u>51</u>
3.1 General.....	51
3.2 The element used to represent concrete.....	51
3.3 Model used for un-cracked concrete in compression.....	51
3.4 Model used for cracked concrete in compression.....	51
3.5 Model used for un-cracked concrete in tension.....	54
3.6 Model used for cracked concrete in tension.....	54
3.7 Model used for representation of cracks.....	54
3.8 Model used for cracking criteria.....	55
3.9 Model used to represent crushing of concrete.....	55
3.10 Model used to represent bond between concrete and steel.....	56
3.11 Model used to represent shear modulus.....	56
3.12 Model used to represent dowel action.....	57
3.13 Model used for various steel types.....	57
3.14 Stress strain relationship used for steel.....	57

Chapter 4 : Program Construction	60
4.1 General.....	60
4.2.1 The 8-node isoparametric element.....	60
4.2.2 The 2-node bar element.....	61
4.2.3 The numerical technique for non linear analysis.....	61
4.2.4 The convergence criteria.....	62
4.2.5 Memory required for program.....	62
4.3 Computer Program.....	62
4.3.1 The main program.....	63
4.3.2 Subroutine Input.....	64
4.3.3 Subroutine Profile.....	65
4.3.4 Subroutine Deriva.....	66
4.3.5 Subroutine Tang.....	68
4.3.6 Subroutine Decompose.....	71
4.3.7 Subroutine Solve.....	72
4.3.8 Subroutine Unbalanced.....	74
4.3.9 Subroutine Results.....	79
4.4 How to write the input file ?.....	79
4.5 Output files.....	81
Chapter 5 : Verification of the proposed model	95
5.1 General.....	95
5.2 Test NO (1).....	95
5.3 Test NO (2).....	96
5.4 Test NO (3).....	97
5.5 Test NO (4).....	98
5.6 Test NO (5).....	99
5.7 Test NO (6).....	100
5.8 Test NO (7).....	101
5.9 Test NO (8).....	101
5.10 Test NO (9).....	102
5.11 conclusion.....	102
Chapter 6 : The parametric study	119
6.1 General.....	119
6.2 Effect of termination of the external plate.....	120
6.2.1 General.....	120
6.2.2 Load deflection curves.....	120
6.2.3 Stress contour lines.....	123
6.2.4 Crack pattern.....	124
6.2.5 stresses along the bar reinforced and steel plate.....	125
6.3 Effect of tensile stress of concrete.....	125
6.4 Effect of characteristic compressive strength of concrete... ..	127
6.5 Effect of load location.....	130
6.6 Effect of area of external plate.....	132
6.7 Effect of the Reinforcement ratio.....	136
6.8 Effect of tensions stiffening of concrete.....	138
6.9 Effect of the Shear modulus.....	141
6.10 Effect of load increment.....	143
6.11 Effect of the No of Iterations.....	144
6.12 Effect of Tolerance.....	145

<u>Chapter 7 : Conclusions and Recommendations</u>	227
7.1 General.....	227
7.2 Conclusions.....	227
7.3 Recommendations.....	230
7.4 Suggestion for future work.....	231
7.5 Guide lines for designing plated R.C beams.....	231

References

Appendix (A)

Arabic summary

List of Figures

Figure	Page
(2.1) Flexural peeling stresses across interface.....	26
(2.2) End Anchorages.....	26
(2.3) Variation of failure pattern for bonded beams.....	27
(2.4) Hand stress strain curve.....	44
(2.5) Nilson stress strain curve.....	44
(2.6) Compression stress strain relationship.....	44
(2.7) Cracked & un-cracked concrete in tension.....	44
(2.8) Stress distribution in a cracked R.C. member.....	45
(2.9) Tension stiffening curves suggested by Bhide	45
(2.10) Concrete models in tension.....	46
(2.11) Failure surface.....	47
(2.12) Crushed surface.....	47
(2.13) Bond slip curves (Nilson and Haude relation).....	48
(2.14) Bond linkage spring.....	48
(2.15) Aggregate interlock and dowel action mechanism.....	49
(2.16) Idealized bilinear curve.....	50
(2.17) Elastic perfectly plastic curve.	50
(2.18) Stress strain relation for steel (B.C.P.).....	50
(3.1) Model for un-cracked concrete in compression.....	58
(3.2) Model for cracked concrete in compression.....	58
(3.3) Model for concrete in tension.....	59
(3.4) Shear modulus model.....	59
(3.5) The cracking criteria for concrete.....	59
(4.1) The 2-node bar element.....	83
(4.2) The force displacement relation for steel.....	83
(4.3) Modified Newton Raphson method.....	83
(4.4) The Main subroutine flow chart.....	85
(4.5) Input subroutine flow chart.....	86
(4.6) Profile subroutine flow chart.....	87
(4.7) Deriva Subroutine flow chart.....	88
(4.8) Tang Subroutine flow chart.....	89
(4.9) Decompose Subroutine flow chart.....	90
(4.10) Solve Subroutine flow chart.....	90
(4.11) Unbalanced Subroutine flow chart.....	91
(4.12) Result Subroutine flow chart.....	88
(4.13) Profile matrix.....	92
(4.14.a) The structure of the file "Input".....	93
(4.14.b) The structure of the file "Input".....	94
(5.1) Data for Test No (1).....	103
(5.2) Test No(1)	104
(5.3) Data for Test No (2).....	105
(5.4) Test No(2)	106
(5.5) Data for Test No (3).....	107
(5.6) Test No(3)	108
(5.7) Data for Test No (4).....	109
(5.8) Test No(4)	110

(5.9) Data for Test No (5).....	111
(5.10) Test No(5)	112
(5.11) Data for Test No (6).....	113
(5.12) Test No(6).....	114
(5.13) Test No(7).....	115
(5.14) Test No(8).....	116
(5.15) Data for Test No (9).....	117
(5.16) Test No(9).....	118
(6.1) R.C. beam used in the parametric study.....	146
(6.2) Variable plate length.....	147
(6.3) Load deflection curves for diffeent plate lengths.....	148
(6.4) Load deflection curves for different plate length with tensile stress $F_t=25$ kg/cm ²	149
(6.5) Load deflection curves for different plate length with tensile stress $F_t=20$ kg/cm ²	150
(6.6) Load deflection curves for different plate length with compressive stress $F_{cu}=150$ kg/cm ²	151
(6.7) Load deflection curves for different plate length with compressive stress $F_{cu}=350$ kg/cm ²	152
(6.8) Load deflection curves for different plawe length with mid load.....	153
(6.9) Load deflection curves for different plate length with plate area $A=3.5$ cm ²	154
(6.10) Load deflection curves for different plate length with plate area $A=5.0$ cm ²	155
(6.11) Load deflection curves for different plate length with half the reinforced steel area.....	156
(6.12) Load deflection curves for different plate length with double the reinforced steel area.....	157
(6.13) Load deflection curves for different plate length with number of load increment =50.....	158
(6.14) Load deflection curves for different plate length with number of iterations=500.....	159
(6.15) Load deflection curves for different plate length with number of iterations=1000.....	160
(6.16) Load deflection curves for different plate length with Tolerance=0.1.....	161
(6.17) Load deflection curves for different plate length with Tolerance=0.01.....	162
(6.18) Deflection of beam P11 at different load levels.....	163
(6.19) Deflection of beam P12 at different load levels.....	164
(6.20) Deflection of beam P13 at different load levels.....	165
(6.21) Deflection of beam P13 at different load levels.....	166
(6.22)Contour lines for σ_{max} at various load increment(p11).167	
(6.23)Contour lines for T_{xy} at various load increment(p11)....	168
(6.24)Contour lines for σ_{max} at various load increment(p12).169	
(6.25)Contour lines for T_{xy} at various load increment(p12)....	170
(6.26)Contour lines for σ_{max} at various load increment(p13).171	
(6.27)Contour lines for T_{xy} at various load increment(p13)....	172
(6.28) Crack pattern for P11 at various load levels.....	173
(6.29) Crack pattern for P12 at various load levels.....	174
(6.30) Crack pattern for P13 at various load levels.....	175

(6.31) Variation of stress in bar Rft.with distance at failure.....	176
(6.32) Variation of stress in steel plate with distance at failure.....	177
(6.33) Variation of stress in bar Rfm. with distance at failure.....	178
(6.34) Variation of stress in steel plate with distance at failure.....	179
(6.35) Variation of stress in bar Rft.with distance at failure.....	180
(6.36) Variation of stress in steel plate with distance at failure.....	181
(6.37) Load deflection curves for beam P11 with different values of tensile stress of concrete.....	182
(6.38) Load deflection curves for beam P12 with different values of tensile stress of concrete.....	183
(6.39) Load deflection curves for beam P13 with different values of tensile stress of concrete.....	184
(6.40) Load deflection curves for beam P11 with different values of compressive strength of concrete (FCU kg/cm ²).....	185
(6.41) Load deflection curves for beam P12 with different values of compressive strength of concrete (FCU kg/cm ²).....	186
(6.42) Load deflection curves for beam P13 with different values of compressive strength of concrete (FCU kg/cm ²).....	187
(6.43) contour lines for sigmax at failure for different plate lengths.....	188
(6.44) contour lines for Txy at failure for different plate lengths.....	189
(6.45) Load deflection curves for beam P11 with different load positions.....	190
(6.46) Load deflection curves for beam P12 with different load positions.....	191
(6.47) Load deflection curves for beam P13 with different load positions.....	192
(6.48) crack pattern for beam P11 at various load increments..	193
(6.49) crack pattern for beam P12 at various load increments..	194
(6.50) crack pattern for beam P13 at various load increments..	195
(6.51) Load deflection curves for beam P11 with different plate area.....	196
(6.52) Load deflection curves for beam P12 with different plate area.....	197
(6.53) Load deflection curves for beam P13 with different plate area.....	198
(6.54) Crack pattern for beam P12 with plate Area=5.0 cm ²	199
(6.55.a)Variation of stress in bar Rft. with distance at failure for P12 beam using Area=5.0 cm ²	200
(6.55.b) Variation of stress in plate with distance at failure for P12 beam using Area=5.0 cm ²	201
(6.56) Load deflection curves for beam P11 with different area of steel reinforced ratio.....	202
(6.57) Load deflection curves for beam P12 with different area of steel reinforced ratio.....	203

(6.58) Load deflection curves for beam P13 with different area of steel reinforced ratio.....	204
(6.59) Tension stiffening.....	205
(6.60) Shear modulus.....	205
(6.61) Load deflection curves for different Alpha factors with P11 beam.....	206
(6.62) Load deflection curves for different Alpha factor with P12 beam.....	207
(6.63) Load deflection curves for different Alpha factor with P13 beam.....	208
(6.64) Load deflection curves for different Beta factor with P11 beam.....	209
(6.65) Load deflection curves for different Beta factor with P12 beam.....	210
(6.66) Load deflection curves for different Beta factor with P13 beam.....	211
(6.67) Load deflection curves for different Gamma factor with P11 beam.....	212
(6.68) Load deflection curves for different Gamma factor with P12 beam.....	213
(6.69) Load deflection curves for different Gamma factor with P13 beam.....	214
(6.70) Load deflection curves for different Delta factor with P11 beam.....	215
(6.71) Load deflection curves for different Delta factor with P12 beam.....	216
(6.72) Load deflection curves for different Delta factor with P13 beam.....	217
(6.73) Load deflection curves for different load increment with P11 beam.....	218
(6.74) Load deflection curves for different load increment with P12 beam.....	219
(6.75) Load deflection curves for different load increment with P13 beam.....	220
(6.76) Load deflection curves for different iterations with beam P11.....	221
(6.77) Load deflection curves for different iterations with beam P12.....	222
(6.78) Load deflection curves for different iterations with beam P13.....	223
(6.79) Load deflection curves for different Tolerance with beam P11.....	224
(6.80) Load deflection curves for different Tolerance with beam P12.....	225
(6.81) Load deflection curves for different Tolerance with beam P13.....	226

List of Tables

Table	Page
(4.1) Conditions of Gauss point.....	74
(4.2) Triangular decomposition of K	83
(5.1) Properties of concrete after 28 days for test no	98
(5.2) Properties of Rft.bars and steel plate for test no.....	98
(6.1) Percentage increase in ultimate load for different plate lengths.....	121
(6.2) percentage increase in ultimate load for tensile stress of concrete with different plate lengths.....	126
(6.3) Percentage increase in ultimate load for compressive strength of concrete with different plate lengths.....	129
(6.4) Percentage increase in ultimate load in the case of mid load with different plate lengths.....	132
(6.5) percentage increase in ultimate load for external plate area with different plate lengths	135
(6.6) Percentage increase in ultimate load for variable steel reinforcement ratio with different plate lengths.....	138