Sirindhorn International Institute of Technology
Thammasat University

Thesis CE-MS-2009-03

STRENGTHENING LAP SPLICE IN SUB-STANDARD REINFORCED CONCRETE COLUMN BY FRP WRAPPING

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A Thesis Presented

by

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Master of Science
School of Civil Engineering and Technology
Sirindhorn International Institute of Technology
Thammasat University

May 2010

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Submitted to

Sirindhorn International Institute of Technology

Thammasat University

In partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN ENGINEERING

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Dedication

This work is dedicated to my son “little Mốc”, my wife, and my family.

Acknowledgement

The author would like to express his appreciation of gratitude to his advisor, Dr. Amorn Pimanmas, for his enthusiastic guidance, valuable suggestions, constructive criticism, friendly discussion and persistent supervision, which are indispensable for completion of this thesis. The sincere appreciation is also due to Dr. Virote Boonyapinyo and Dr. Mongkut Piantanakulchai for their help, suggestions and serving as members of the examination committee.

In addition, the author would like to express his gratitude to the Japanese Government, Asian Development Bank (ADB) for granting the fully-funded scholarship to his study at Sirindhorn International Institute of Technology, Thammasat University.

A lot of thanks are also due to Mr. Joyklad, a Ph.D. student, for his persistent useful help during the author's study.

Last but not least, the author gratefully acknowledges the continuing patience, understanding, and vital sacrifices of his beloved mother and wife, whose love and supports are always a constant source of encouragement and guidance to him.

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Abstract

The old reinforced concrete (RC) building structures (pre 1970s or sub-standard) were brittle and susceptible to collapse under seismic actions. They have been addressed as the main reason to cause death and casualty in natural catastrophes, especially during earthquakes. In these columns, lap splice, or the zone in which two reinforcing (steel) bars overlap to form a continuous line, was relatively short and less than that is required in modern earthquake design standard. This causes the failure of lap splice to occur before the yielding of reinforcing bar, and no apparent ductility in column's and structure's behavior, as a consequence. To strengthen the sub-standard column, there are some methods that applied the jacketing around the lap spliced zone, for example, steel-plate jacketing, ferro-cement jacketing, and Fiber Reinforced Polymer (FRP) wrapping.

The application of FRP on confining the lap splice zone in sub-standard RC columns is the goal of this study. Firstly, the study proposed a tri-uniform bond stress distribution along starter bars at the critical state (lap splice failure state) since starter bar works in either elastic (pre-yield) or plastic (post-yield) range. Secondly, the parametric investigation was conducted to explore the effectiveness of FRP confinement on lap splice strength. Additionally, a dynamic analysis was also conducted to apply the proposed model on some existing experiments in order to verify the proposed tri-uniform bond stress model. Through this verification, a good agreement was found between the analytical and experimental results. Finally, an experiment was conducted to investigate the effectiveness of FRP confinement on improving the lap splice strength in reinforced concrete columns.

The experimental program consisted of 16 reinforced concrete beam specimens tested under static load. The beams were divided into 4 series with different lap splice lengths: $30d_b$, $25d_b$, $20d_b$, and $15d_b$ (where d_b is the bar diameter). It is found that the confinement by FRP significantly strengthens the lap splice zone and sub-standard RC column. The confined specimens show the great increase in strength and ductility in comparison to the unconfined ones. Especially by wrapping FRP, the short lap splice was protected from brittle pre-yield failure and the starter bar can finally reach yielding. Consequently, FRP confinement improves the lap splice strength from pre-yielding to post-yielding, and increase ductility from none to high ductility. The verification of the proposed tri-bond stress model was also good. The failure modes of specimens were predicted by the proposed tri-uniform bond stress distribution and verified in the experiment. The experimental results closely agree with the predicted ones. The slip measured in experiment also agreed well with the proposed ones. Strain values recorded by strain-gages along lap splice zone were laid around the predicted strain-distribution.

สำนักหอสมุด

Table of Contents

Chapter **Title** **Page**

Signature Page i
Dedication ii
Acknowledgement iii
Abstract iv
Table of Contents v
List of Figures viii
List of Tables xv
List of Equations xvii
Nomenclature xviii

Chapter 1: Introduction 1
  1.1 Statement of Problem 1
  1.2 Objectives 3
  1.3 Scopes and limitations 3

Chapter 2: Literature Review 4
  2.1 Deficiencies of sub-standard reinforced concrete column 4
  2.2 Fiber reinforced polymer confinement impacts 5
    2.2.1 Uniaxial stress-strain model of confined concrete 6
    2.2.2 Bond stress-slip model for confined concrete 10
  2.3 Experiments of strengthening lap splice by FRP wrapping 14
  2.4 Nonlinear modeling of reinforced concrete column 15

Chapter 3: Tri-uniform Bond Stress Distribution 25
  3.1 Tri-uniform bond stress model 25
  3.2 Bond stress – slip model of lap splice confined by FRP 26
  3.3 Steel stress-strain model 28
  3.4 Equilibrium and strain-slip condition 29
    3.4.1 Splitting zone 29
    3.4.2 Post splitting zone 30
    3.4.3 Yielding zone 31
  3.5 Explicit equation for lap splice strength (both elastic and post-yield range) 32
  3.6 Calculation procedure for required FRP thickness to reach a desired stress 34
  3.7 Verification of proposed model 35
    3.7.1 Analytical verification 35
    3.7.2 Experimental verification 36
  3.8 Parametric investigation 36
    3.8.1 Strength of lap splice length Ls = 20db, 25db, 30db and 35db 36

3.8.2 Required number of FRP sheets to develop the a specified lap splice strength 38

Chapter 4: Experimental Program 41
4.1 Experiment design 41
4.1.1 A test for column in a beam-testing configuration 41
4.1.2 Series lapsplice length of 30db 43
4.1.3 Series lapsplice length of 25db 45
4.1.4 Series lapsplice length of 20db 48
4.1.5 Series lapsplice length of 15db 50
4.1.6 Series without lap splice 53
4.2 Materials 53
4.2.1 Concrete 53
4.2.2 Steel 57
4.2.3 Fiber Reinforced Polymer 58
4.3 Testing configuration 58
4.3.1 Strain-gage attachment 58
4.3.2 Transducer arrangement 59
4.3.3 Applied load 61
4.4 Experimental result and observation 62
4.4.1 Series 30db experiments 62
4.4.2 Series 25db experiments 72
4.4.3 Series 20db experiments 84
4.4.4 Series 15db experiments 99
4.4.5 Series without lap splice experiments 114
4.5 Experiment discussion 117
4.5.1 Series 30db experiments 117
4.5.2 Series 25db experiments 117
4.5.3 Series 20db experiments 118
4.5.4 Series 15db experiments 119
4.5.5 Average bond stress-entire slip relationship 119
4.5.6 Unconfined column's behaviors 131
4.5.7 Behavior of members confined by 2 layers confined ... 131
4.5.8 Behavior of members confined by 4 layers confined ... 132
4.5.9 Behavior of members confined by 6 layers confined ... 133
4.5.10 Effectiveness of FRP confinement on lap splice zone.. 133
4.6 Experiment conclusion 137

Chapter 5: Nonlinear Analysis 138
5.1 Nonlinear model of RC column with lap splice zone confined by FRP 138
5.1.1 Elastic frame element 138
5.1.2 Shear spring 139
5.1.3 Concrete spring 139
5.1.4 Reinforcement spring 143
5.2 Verification with existing experimental result 152

- 5.2.1 Response of columns subjected to cyclic load tested by Harajli and Dagher (2008) 152
- 5.2.2 Response of columns subjected to cyclic load tested by Xiao and Ma (1997) 161
- 5.2.3 Response of columns subjected to cyclic load tested by Bousias, Spathis et al. (2006) 166

Chapter 6: Conclusion and Recommendation for Further Study 173
- 6.1 Conclusion 173
- 6.2 Recommendation for Further Study 174

References 176

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สำนักหอสมุด

List of Figures

Fig 2.1: Typical FRP wrapping methods [Teng, Chen et al. (2002)] 16

Fig 2.2: Hydraulic pressure chamber Richart, Brandtzæg et al. (1928; 1929) 16

Fig 2.3: Effectively confined concrete area Mander, Priestley et al. (1988) 17

Fig 2.4: Stress-strain of confined concrete Saatcioglu and Razvi (1992) 17

Fig 2.5: Bilinear confinement model Samaan, Mirmiran et al. (1998) 17

Fig 2.6: Stress-strain response, Karbhari and Gao (1997) 18

Fig 2.7: Proposed stress–strain model for FRP-confined concrete Lam and Teng (2002) . 18

Fig 2.8: Analytical model for pull-out failure Abrishami and Mitchell (1996) 19

Fig 2.9: Analytical model for splitting failure Abrishami and Mitchell (1996) 19

Fig 2.10: Steel stress-strain and bond-stress distribution Alsiwat and Saatcioglu (1992) .. 20

Fig 2.11: Proposed Hysteretic Model for Anchorage Slip by Saatcioglu, Alsiwat et al. (1992) 21

Fig 2.12: Degradation of bond stress in lapsplice bar Xiao and Ma (1997) 21

Fig 2.13: Bi-uniform bond stress distribution by Sezen and Moehle (2003) 22

Fig 2.14: Bond stress–slip by Ayoub (2006) 22

Fig 2.15: Bond mechanisms in Bamonte and Gambarova (2007) 23

Fig 2.16: Bond stress-slip model proposed by Eligehausen, Popov et al. (1983) 23

Fig 2.17: Bond stress-slip model proposed by Lehman and Moehle (2000) 24

Fig 2.18:RC column model, Matrin (2007) 24

Fig 3.1: Tri-uniform bond stress model 26

Fig 3.2: Bond stress–slip model by Harajli (2006) 27

Fig 3.3: Free body diagram 28

Fig 3.4: Uniaxial stress-strain [Park and Paulay (1975)]. 28

Fig 3.5: Calculation of bond stress for a specific slip sA 30

Fig 3.6: Experimental result by Shima, Chou et al. (1987) 32

Fig 3.7: Free slip at the end of lap splice length 33

Fig 3.8: Calculation steps for lap splice strength 34

Fig 3.9: Calculation procedure for determining the required nftf 35

Fig 3.10: Column section used in parametrical investigation 36

Fig 3.11: Strength of lap splice $Ls/db = 20$ 37

Fig 3.12: Strength of lap splice ($Ls/db = 25$).......... 37

Fig 3.13: Strength of lap splice ($Ls/db = 30$).......... 38

Fig 3.14: Strength of lap splice ($Ls/db = 35$).......... 38

Fig 3.15: Required FRP sheets versus lap spliced length.......... 39

Fig 3.16: Required FRP sheets versus c/db 40

Fig 4.1: Normal column test configuration 41

Fig 4.2: Column's test in a beam-test's configuration.......... 42

Fig 4.3: A testing configuration for column by Harajli and Khalil (2008) 42

Fig 4.4: A testing configuration for column by Harajli and Rteil (2004).......... 43

Fig 4.5: Series 30db design 43

Fig 4.6: Strain-gages position and prediction of strain, stress, and bond stress in column 30F0. 44

Fig 4.7: Strain-gages position and prediction of strain, stress, and bond stress in column 30F1. 45

Fig 4.8: Strain-gages position and prediction of strain, stress, and bond stress in column 30F2. 45

Fig 4.9: Series 25db design 46

Fig 4.10: Strain-gages position and prediction of strain, stress, and bond stress in column 25F0. 47

Fig 4.11: Strain-gages position and prediction of strain, stress, and bond stress in column 25F2. 47

Fig 4.12: Strain-gages position and prediction of strain, stress, and bond stress in column 25F4. 47

Fig 4.13: Series 20db design 48

Fig 4.14: Strain-gages position and prediction of strain, stress, and bond stress in column 20F0. 49

Fig 4.15: Strain-gages position and prediction of strain, stress, and bond stress in column 20F2. 49

Fig 4.16: Strain-gages position and prediction of strain, stress, and bond stress in column 20F4. 50

Fig 4.17: Strain-gages position and prediction of strain, stress, and bond stress in column 20F6. 50

Fig 4.18: Series 15db design 51

Fig 4.19: Strain-gages position and prediction of strain, stress, and bond stress in column 15F0. 52

Fig 4.20: Strain-gages position and prediction of strain, stress, and bond stress in column 15F2. 52

Fig 4.21: Strain-gages position and prediction of strain, stress, and bond stress in column 15F4. 52

Fig 4.22: Strain-gages position and prediction of strain, stress, and bond stress in column 15F6. 53

Fig 4.23: Series without lap splice design 53

Fig 4.24: Concrete strength versus ages 56

Fig 4.25: Reinforcing bar tensile test 57

Fig 4.26: Uniaxial stress-strain model use in calculation 58

Fig 4.27: Strain-gage attachment 59

Fig 4.28: Transducers arrangement 60

Fig 4.29: A slip measurement method 61

Fig 4.30: Member strength of series 30db 62

Fig 4.31: Cracks observation in member 30F0 64

Fig 4.32: Cracks observation in member 30F1 65

Fig 4.33: Cracks observation in member 30F2 66

Fig 4.34: Strain distribution along lap splice (Bar A) in member 30F0 69

Fig 4.35: Strain distribution along lap splice Bar A in member 30F1 69

Fig 4.36: Strain distribution along lap splice Bar B in member 30F1 70

Fig 4.37: Strain distribution along lap splice Bar A in member 30F2 71

Fig 4.38: Strain distribution along lap splice Bar B in member 30F2 71

Fig 4.39: Member strength of series 25db 72

Fig 4.40: Cracks observation in member 25F0 74

Fig 4.41: Cracks observation in member 25F2 75

Fig 4.42: Cracks observation in member 25F4 77

Fig 4.43: Strain distribution along lap splice (Bar A) in member 25F0 79

Fig 4.44: Strain distribution along lap splice (Bar B) in member 25F0 80

Fig 4.45: Strain distribution along lap splice (Bar A) in member 25F2 81

Fig 4.46: Strain distribution along lap splice (Bar B) in member 25F2 81

Fig 4.47: Strain distribution along lap splice (Bar A) in member 25F4 82

Fig 4.48: Strain distribution along lap splice (Bar B) in member 25F4 83

Fig 4.49: Lateral strength of series 20db 84

Fig 4.50: Cracks observation in member 20F0 86

Fig 4.51: Cracks observation in member 20F2 87

Fig 4.52: Cracks observation in member 20F4 89

Fig 4.53: Cracks observation in member 20F6 91

Fig 4.54: Strain distribution along lap splice (Bar A) in member 20F0 93

Fig 4.55: Strain distribution along lap splice (Bar B) in member 20F0 94

Fig 4.56: Strain distribution along lap splice (Bar A) in member 20F2 95

Fig 4.57: Strain distribution along lap splice (Bar B) in member 20F2 95

Fig 4.58: Strain distribution along lap splice (Bar A) in member 20F4 96

Fig 4.59: Strain distribution along lap splice (Bar B) in member 20F4 97

Fig 4.60: Strain distribution along lap splice (Bar A) in member 20F6 98

Fig 4.61: Strain distribution along lap splice (Bar B) in member 20F6 98

Fig 4.62: Lateral strength of series 15db 99

Fig 4.63: Cracks observation in member 15F0 101

Fig 4.64: Cracks observation in member 15F2 102

Fig 4.65: Cracks observation in member 15F4 104

Fig 4.66: Cracks observation in member 15F6 106

Fig 4.67: Strain distribution along lap splice (Bar A) in member 15F0 109

Fig 4.68: Strain distribution along lap splice (Bar B) in member 15F0 110

Fig 4.69: Strain distribution along lap splice (Bar A) in member 15F2 111

Fig 4.70: Strain distribution along lap splice (Bar B) in member 15F2 111

Fig 4.71: Strain distribution along lap splice (Bar B) in member 15F4 112

Fig 4.72: Strain distribution along lap splice (Bar A) in member 15F6 113

Fig 4.73: Lateral strength of series without lap splice 114

Fig 4.74: Cracks observation in member 00C1 115

Fig 4.75: Cracks observation in member 00C2 116

Fig 4.76: Analytical average bond stress-entire slip relationship 120

Fig 4.77: Average bond stress versus entire slip in member 30F0 121
Fig 4.78: Average bond stress versus entire slip in member 30F1 122
Fig 4.79: Average bond stress versus entire slip in member 30F2 123
Fig 4.80: Average bond stress versus entire slip in member 25F0 123
Fig 4.81: Average bond stress versus entire slip in member 25F2 124
Fig 4.82: Average bond stress versus entire slip in member 25F4 125
Fig 4.83: Average bond stress versus entire slip in member 20F0 126
Fig 4.84: Average bond stress versus entire slip in member 20F2 126
Fig 4.85: Average bond stress versus entire slip in member 20F4 127
Fig 4.86: Average bond stress versus entire slip in member 20F6 127
Fig 4.87: Average bond stress versus entire slip in member 15F0 128
Fig 4.88: Average bond stress versus entire slip in member 15F2 129
Fig 4.89: Average bond stress versus entire slip in member 15F4 129
Fig 4.90: Average bond stress versus entire slip in member 15F6 130
Fig 4.91: unconfined column's behaviors 131
Fig 4.92: 2 layers confined column's behaviors 131
Fig 4.93: 4 layers confined column's behaviors 132
Fig 4.94: Behavior of members confined by 6 layers confined 133
Fig 4.95: Effectiveness of FRP confinement on lap splice zone in series 30db 133
Fig 4.96: Effectiveness of FRP confinement on lap splice zone in series 25db 134
Fig 4.97: Effectiveness of FRP confinement on lap splice zone in series 20db 135
Fig 4.98: Effectiveness of FRP confinement on lap splice zone in series 15db 135
Fig 5.1: Confinement effectiveness coefficients Harajli, Hantouche et al. (2006) 142
Fig 5.2: RC column model Matrin (2007) 145
Fig 5.3: discretization of an RC section Matrin (2007) 145
Fig 5.4: fiber-section element Matrin (2007) 145
Fig 5.5: Degrading coefficient k, Sezen (2000) 146
Fig 5.6: Monotonic envelope curve governing response of nonlinear shear springs 146
Fig 5.7: Hysteretic model SINA degrading Carr (2005) for nonlinear shear springs 147
Fig 5.8: Monotonic envelope curve governing response of nonlinear concrete springs ... 147

Fig 5.9: Hysteretic model Bi-linear with Slackness Carr (2005) for concrete springs...... 148
Fig 5.10: Proposed stress–strain relationship for FRP confined concrete Harajli (2006). 148
Fig 5.11: Bond problem for spliced reinforcement Lowes, Mitra et al. (2003) 149
Fig 5.12: Monotonic envelope curve for splice springs Matrin (2007)............................ 150
Fig 5.13: Monotonic envelope curve for reinforcement springs Matrin (2007)............... 150
Fig 5.14: Modified Takeda Degrading hysteresis for reinforcement springs Carr (2005) 151
Fig 5.15: Column specimen used by Harajli and Dagher (2008) 153
Fig 5.16: Test setup by Harajli and Dagher (2008) 153
Fig 5.17: Lateral load history of column specimens Harajli and Dagher (2008) 154
Fig 5.18: Force – slip relation for the lap splice spring in columns C14FP1 and C14FP2 154
Fig 5.19: Force – slip relation for the lap splice spring C16FP1 and C16FP2................. 154
Fig 5.20: Force – slip relation for the lap splice spring C20FP1 and C20FP2................. 155
Fig 5.21: Response of columns C14E 156
Fig 5.22: Response of columns C14FP1 156
Fig 5.23: Response of columns C14FP2 157
Fig 5.24: Response of columns C16E 157
Fig 5.25: Response of columns C16FP1 158
Fig 5.26: Response of columns C16FP2 158
Fig 5.27: Response of columns C20E 159
Fig 5.28: Response of columns C20FP1 159
Fig 5.29: Response of columns C20FP2 160
Fig 5.30: Xiao and Ma (1997)'s columns details (length in mm) 161
Fig 5.31: Steel stress – slip relation of the lap splice spring 162
Fig 5.32: Response of columns C1-A.. 162
Fig 5.33: Response of columns C2-RT4 163
Fig 5.34: Response of columns C3-RT5 163
Fig 5.35: Response of hypothetical columns C1-H (Excluding lap splice springs).......... 164
Fig 5.36: Response of hypothetical columns C2-H (Excluding lap splice springs).......... 164
Fig 5.37: Response of hypothetical columns C3-H (Excluding lap splice springs).......... 165
Fig 5.38: Section details in Bousias, Spathis et al. (2006)'s columns.............................. 166

Fig 5.39: Response of columns R-0L0 167

Fig 5.40: Force – slip relation for the lap splice in columns R-0L1, R-P2L1 and R-P5L1 167

Fig 5.41: Response of columns R-0L1 168

Fig 5.42: Response of columns R-P2L1 169

Fig 5.43: Response of columns R-P5L1 169

Fig 5.44: Force – slip relation for the lap splice in columns R-0L3, R-P2L3 and R-P5L3 170

Fig 5.45:Responses of columns R-0L3 170

Fig 5.46:Responses of columns R-P2L3 171

Fig 5.47:Responses of columns R-P5L3 171

List of Tables

Table 4.1: Strain-gages arrangement in series 30db 44

Table 4.2: Strain-gages arrangement in series 25db 46

Table 4.3: Strain-gages arrangement in series 20db 49

Table 4.4: Strain-gages arrangement in series 15db 51

Table 4.5: Compressive strength at 3 days old 54

Table 4.6: Compressive strength at 5 days old 54

Table 4.7: Compressive strength at 7 days old 54

Table 4.8: Compressive test at 14 days old 55

Table 4.9: Compressive test at 20 days old 55

Table 4.10: Compressive test at 28 days old 56

Table 4.11: Steel properties 57

Table 4.12: FRP sheet Properties 58

Table 4.13 Member strength of series 30db 63

Table 4.14: Lapsplice strength of series 30db 63

Table 4.15: Entire slip in member 30F0 67

Table 4.16: Entire slip in members 30F1 and 30F2 68

Table 4.17: Strain-gages measurement and prediction in member 30F0 68

Table 4.18: Strain-gages measurement and prediction in member 30F1 70

Table 4.19: Strain-gages measurement and prediction in member 30F2 72

Table 4.20 Member strength of series 25db 73

Table 4.21: Lapsplice strength of series 25db 73

Table 4.22: Entire slip in member 25F0 78

Table 4.23: Entire slip in members 25F2 and 25F4 78

Table 4.24: Strain-gages measurement and prediction in member 25F0 79

Table 4.25: Strain-gages measurement and prediction in member 25F2 80

Table 4.26: Strain-gages measurement and prediction in member 25F4 83

Table 4.27: Member strength of series 20db 84

Table 4.28: Lapsplice strength of series 20db 85

Table 4.29: Entire slip in unconfined member 20F0 92

Table 4.30: Entire slip in confined members 20F2, 20F4 and 20F6 92

Table 4.31: Strain-gages measurement and prediction in member 20F0 94

Table 4.32: Strain-gages measurement and prediction in member 20F2 96

Table 4.33: Strain-gages measurement and prediction in member 20F4 97

Table 4.34: Strain-gages measurement and prediction in member 20F6 99

Table 4.35: Member strength of series 15db 100

Table 4.36: Lapsplice strength of series 15db 100

Table 4.37: Entire slip in members 15F0 and 15F2 107

Table 4.38: Entire slip in confined members 15F4 and 15F6 107

Table 4.39: Free slip in members 15F0 and 15F2 108

Table 4.40: Strain-gages measurement and prediction in member 15F0 110

Table 4.41: Strain-gages measurement and prediction in member 15F2 112

Table 4.42: Strain-gages measurement and prediction in member 15F4 113

Table 4.43: Strain-gages measurement and prediction in member 15F6 114

Table 4.44: Member strength of series without lap splice.. 115

Table 5.1: Harajli and Dagher (2008)'s columns results... 160

Table 5.2: Xiao's columns results 166

Table 5.3: Bousias's columns results 172

List of Equations

Equation **Pages**

(2.1a)............................4
(2.2)..............................6
(2.3)..............................6
(2.4)..............................7
(2.5)..............................7
(2.6)..............................7
(2.7)..............................7
(2.8)..............................7
(2.9)..............................7
(2.10)............................7
(2.11)............................8
(2.12)............................8
(2.13)............................8
(2.14)............................8
(2.15)............................8
(2.16)............................8
(2.17)............................9
(2.18)............................9
(2.19)............................9
(2.20)..........................10
(2.21)..........................10
(2.22)..........................12
(2.23)..........................12
(2.24)..........................12
(2.25)..........................13
(2.26)..........................13
(3.1)............................25
(3.2)............................27
(3.3)............................27
(3.4)............................27

Equation **Pages**

(3.5)........................... 27
(3.6)........................... 28
(3.7)........................... 28
(3.8)........................... 28
(3.9)........................... 29
(3.10)......................... 29
(3.11)......................... 29
(3.12)......................... 29
(3.13)......................... 29
(3.14)......................... 30
(3.15a)....................... 30
(3.16)......................... 30
(3.17)......................... 31
(3.18a)....................... 31
(3.19)......................... 31
(3.20)......................... 31
(3.21)......................... 31
(3.22)......................... 32
(3.23)......................... 32
(3.24)......................... 33
(3.25)......................... 33
(3.26)......................... 33
(3.27)......................... 34
(4.1)........................... 59
(4.2)......................... 120
(4.3)......................... 120
(4.4)......................... 120
(4.5)......................... 120
(4.6)......................... 121
(5.1)......................... 139

Equation **Pages**

(5.2)......................... 139
(5.3)......................... 139
(5.4)......................... 139
(5.5)......................... 139
(5.6)......................... 139
(5.7)......................... 140
(5.8)......................... 140
(5.9)......................... 140
(5.10)....................... 141
(5.11)....................... 141
(5.12)....................... 141
(5.13)....................... 141
(5.14)....................... 141
(5.15)....................... 141
(5.16)....................... 142
(5.17)....................... 142
(5.18)....................... 142
(5.19)....................... 143
(5.20)....................... 143
(5.21)....................... 143
(5.22)....................... 143
(5.23)....................... 143
(5.24)....................... 143
(5.25)....................... 143
(5.26)....................... 144
(5.27)....................... 144
(5.28)....................... 144

Nomenclature

A_{fap}	Area of transverse FRP reinforcement
A_{fa}	Area of longitudinal FRP reinforcement
A_g	Gross area of section
A_{cc}	Area of concrete core
A_e	Area of effectively confined concrete
A_s	Area of column longitudinal reinforcement
A_{st}	Area of column transverse reinforcement
b	Section width
b_f	Width of discrete bands of FRP
c	Minimum concrete cover
D	Diameter of circular section
d	effective depth of column section
d_s	Diameter of spiral or hoop
d_b	Diameter of reinforced bar
E_c	Modulus of elasticity of concrete
E_f	Modulus of elasticity of transverse FRP
E_{fa}	Modulus of elasticity of longitudinal FRP
E_{lf}	Lateral modulus of elasticity of FRP
E_{ls}	Lateral modulus of elasticity of steel
E_s	Modulus of elasticity of steel
f_c	Concrete stress
f_c'	Compressive strength of unconfined concrete
f_{cc}	Stress in confined concrete
f_{cc}'	Compression strength of confined concrete
f_{co}	Stress at the intersection point between the 1st and 2nd stage of the stress–strain curve
f_{cu}	Stress corresponding to a limiting strain ε_{cu}
f_l	Effective lateral confining pressure
f_l'	Hydrostatic confining pressure
f_s	Steel stress
f_y	Yield stress of longitudinal column reinforcement
f_{yt}	Yield stress of transverse steel ties or hoops
h	Section depth
K	confined strength ratio
k_1	Confinement effectiveness coefficient
k_e, k_v	Confinement effectiveness parameters
n_f	Number of transverse FRP layers
N_f	Number of equally spaced discrete bands
P	Applied axial load
r	Corner radius
s'	Clear spacing between transverse hoops or spirals
t_f	Thickness of one FRP layer
w	Clear distance between adjacent longitudinal bars
w_{xi}, w_{yi}	The i^{th} clear distance between adjacent longitudinal bars along the horizontal x and y dimensions respectively
x, y	Concrete core dimensions to center line of peripheral hoop
ε_c	Concrete strain
ε_{cc}	Concrete strain for confined concrete
ε_{co}	Concrete strain at the intersection point between the 1st and 2nd stage of the stress–strain curve
ε_{cu}	Limiting concrete strain
ε_{fu}	Fracture strain of the FRP
ε_l	Lateral concrete strain
ε_{lo}	Lateral concrete strain at intersection point between the 1st and 2nd stage of the stress strain curve
ε_o	Strain at maximum stress for unconfined concrete
ε_{yt}	Yield strain of transverse hoops
ρ_{cc}	Steel ratio relative to the concrete core section
ρ_f	Volumetric ratio of FRP reinforcement
ρ_s	Ratio of column longitudinal reinforcement
ρ_{st}	Volumetric ratio of hoop reinforcement
L	Height of column
L_p	Length of plastic hinge zone
L_s	Length of lapsplice
a	Shear span of column
V_s	Shear strength of column
V_r	Residual shear strength of column