

Contents

Acknowledgements.....	v
Abstract.....	vii
Résumé.....	ix
1. Introduction.....	1
1.1. Background and motivation.....	1
1.2. Objectives and scope.....	2
1.3. Research methodology.....	3
1.4. Thesis scenario and outline.....	5
1.5. State of the art.....	8
References.....	8
2. Development of PUR and PBR systems.....	11
2.1. Development of prestressed unbonded and bonded CFRP strengthening solutions for tensile metallic members.....	13
1. Introduction.....	14
2. Analytical solution.....	15
2.1. Prestressed unbonded reinforcement (PUR).....	15
2.2. Prestressed bonded reinforcement (PBR).....	15
3. Development of mechanical clamping system.....	18
3.1. Design Basis.....	18
3.2. Finite element simulation.....	19
4. Experimental verification.....	21
4.1. Test specimens.....	21
4.2. Material properties.....	22
4.3. CFRP strengthening procedure.....	23
4.4. Static and fatigue test setup.....	25
5. Results and discussion.....	26
5.1. Static and fatigue tests on the proposed mechanical clamping system.....	26
5.2. Static tests on CFRP-strengthened steel plates.....	27
6. Conclusions and recommendations.....	30
References.....	31
2.2. Short-term bond behavior and debonding capacity of prestressed CFRP composites to steel substrate.....	35
1. Introduction.....	35
2. Prestressed partially bonded reinforcement technique.....	36
3. Experimental program.....	37
3.1. Test setup.....	37

3.2. Adhesive curing conditions.....	39
3.3. Test layout.....	40
3.4. Material properties.....	40
3.5. Specimen preparation.....	41
3.6. Digital image correlation (DIC).....	42
4. Results and discussions.....	42
4.1. Bond strength.....	42
4.2. Failure mode.....	45
4.3. Investigation of bond behavior using 3D DIC.....	46
5. Summary and concluding remarks.....	52
References.....	53
3. Mode I fatigue crack arrest in tensile steel members.....	57
3.1. Mode I fatigue crack arrest in tensile steel members using prestressed CFRP plates.....	59
1. Introduction.....	59
2. Analytical solution for crack arrest.....	61
3. Experimental program.....	63
3.1. Test layout and specimen details.....	63
3.2. Material properties.....	64
3.3. Fatigue precracking.....	66
3.4. Strengthening techniques.....	66
3.5. Instrumentation, test setup, and test procedure.....	68
4. Experimental results and discussions.....	70
4.1. Fatigue life extension and crack arrest.....	70
4.2. Crack closure phenomenon.....	76
4.3. State of holes in PUR system.....	79
5. Finite element (FE) modeling.....	81
5.1. Geometry, mesh, and boundary conditions.....	81
5.2. Material behavior, interactions, and CFRP prestressing.....	82
5.3. FE results.....	83
6. Design recommendations.....	84
6.1. Threshold stress intensity factor (SIF) range.....	84
6.2. Crack closure effect.....	84
6.3. Special considerations regarding PUR system.....	85
7. Conclusions.....	85
References.....	87
3.2. Prestressed unbonded reinforcement system with multiple CFRP plates for fatigue strengthening of steel members.....	91
1. Introduction.....	91
2. Finite element simulation.....	92
2.1. Model description.....	92

2.2. Finite element results.....	94
3. Experimental program.....	95
3.1. Test specimens.....	95
3.2. Prestressed unbonded reinforcement (PUR) system.....	96
3.3. Material properties.....	98
3.4. Static and fatigue test setup.....	98
4. Results and discussions.....	98
4.1. Static and fatigue tests on the proposed mechanical clamping system.....	98
4.2. Performance of the proposed PUR system for fatigue strengthening of cracked steel members.....	100
5. Summary and conclusions.....	102
References.....	103
4. Mixed mode I/II fatigue crack arrest in steel members.....	107
4.1. Mixed mode I/II fatigue crack arrest in steel members using prestressed CFRP reinforcement.....	109
1. Introduction.....	110
2. Strengthening design approach for mixed mode I/II fatigue crack arrest.....	111
2.1. The proportional mixed mode I/II fatigue problem in mild steel.....	111
2.2. Design model for mixed mode I/II fatigue crack arrest in steel members.....	112
2.3. Strengthening design flowchart for mixed mode I/II fatigue crack arrest in steel members.....	116
3. Experimental verification.....	118
3.1. Test layout and specimens' specifications.....	118
3.2. Mode I fatigue precracking.....	119
3.3. CFRP-strengthening using prestressed unbonded retrofit (PUR) system.....	120
3.4. Material properties.....	121
3.5. Fatigue test setup and procedure.....	122
4. Experimental results and discussions.....	123
4.1. Effect of the rolling direction on the fatigue characteristics of grade S355J2+N steel.....	123
4.2. Mixed mode I/II fatigue failure mechanism map and performance of the proposed strengthening approach.....	125
4.3. Kink angle in the mixed mode I/II fatigue loading condition.....	128
5. Design recommendations.....	130
5.1. Design value for mode I threshold SIF range.....	130
5.2. Crack closure effect in mixed mode I/II fatigue condition.....	131
5.3. Maximum allowable prestress level in CFRP materials.....	131
6. Conclusions.....	131
Appendix A. Determination of mode I fatigue precrack loading through finite element simulation.....	133
Appendix B. Supplementary material.....	136
References.....	136

5. Flat prestressed unbonded retrofit system.....	141
5.1. Flat prestressed unbonded retrofit system for strengthening of existing metallic I-girders	143
1. Introduction.....	144
2. Concept and overall view of the proposed strengthening system.....	145
3. Finite element simulation.....	147
3.1. Model description.....	147
3.2. FE results.....	149
4. Experimental program.....	150
4.1. Pull-off test.....	150
4.2. Static and fatigue four-point bending tests.....	151
4.3. Material properties.....	152
5. Experimental results and discussion.....	153
5.1. Pull-off tests.....	153
5.2. Static tests.....	154
5.3. Fatigue test.....	157
6. Determination of the stress state in a metallic I-girder strengthened with the proposed FPUR system.....	159
6.1. Analytical modeling.....	159
6.2. Verification of the proposed model with the experimental test results.....	162
7. Field application of the proposed FPUR system.....	163
8. Design recommendations.....	164
8.1. Static/fatigue strengthening of existing metallic girders using the proposed FPUR system.....	164
8.2. Maximum prestressing level in the CFRP reinforcements.....	164
9. Summary and conclusions.....	164
Appendix A. Detailed dimensions of the mechanical components and test setups.....	165
References.....	168
5.2. Mixed mode I/II fatigue crack arrest in metallic I-girders using FPUR system.....	173
6. Conclusions and future research.....	177
6.1. Conclusions.....	177
6.2. Original contribution.....	180
6.3. Recommendations for future research.....	181
References.....	184
Appendix A: The existing experimental literature on the mixed mode I/II fatigue threshold of mild steel.....	187
Appendix B: Supplementary fatigue test results.....	193
Appendix C: Matlab scripts.....	203
Curriculum vitae.....	213