CONTENTS

1 INTRODUCTION 1
- 1.1 Motivation 3
- 1.2 Research objectives 4
- 1.3 Dissertation outline 5

2 STATE OF THE ART 7
- 2.1 The active bending principle 7
- 2.2 Required material properties 9
- 2.3 Determination of the configuration 10
  - 2.3.1 Models based on discrete mechanics 12
  - 2.3.2 Models based on finite-difference discretisations 13
  - 2.3.3 Models based on finite element discretisations 15
- 2.4 Previous works on the structural performance of bending-active structures 17

3 A FORM-FINDING METHOD BASED ON THE GEM FOR BENDING-ACTIVE STRUCTURES 19
- 3.1 Introduction 19
  - 3.1.1 Outline of the chapter 20
- 3.2 The geometrically exact rod model 20
  - 3.2.1 Basic kinematics 20
  - 3.2.2 Variation of the generalised strain measures 22
  - 3.2.3 Equations of static equlibrium 22
  - 3.2.4 Equations of dynamic equilibrium 23
  - 3.2.5 Constitutive equations 23
- 3.3 The dynamic relaxation method 24
- 3.4 Fundamentals of the method 24
  - 3.4.1 Application of D'Alembert's principle 24
  - 3.4.2 Determination of element end forces 25
  - 3.4.3 Strains associated to rotations 26
  - 3.4.4 Strains associated to translations 27
- 3.5 Numerical implementation 28
  - 3.5.1 Criterium for convergency 29
  - 3.5.2 Boundary conditions 29
- 3.6 Numerical tests 30
  - 3.6.1 The elastica and the circular beam 30
  - 3.6.2 Bathe and Bolourchi cantilever beam 32
  - 3.6.3 Combined bending and torsion 32
  - 3.6.4 Shear deformability test 36
- 3.7 Summary 37

4 THE BENDING-ACTIVE TIED ARCH 39
- 4.1 Introduction 39
  - 4.1.1 Outline of the chapter 41
- 4.2 A brief review of the inflexional elastica 41
  - 4.2.1 Configuration of the elastica 42
  - 4.2.2 Section forces 43

4.2.3 Scalability of the solution 43
4.3 Self-stress states in bending-active tied arches 44
4.3.1 Notation 44
4.3.2 Equilibrium and compatibility conditions at joints 45
4.4 Direct determination of self-stress configurations 47
4.4.1 Examples 49
4.5 Computation of self-stress configurations under additional constraints 53
4.6 Summary 57
5 EFFICIENCY-BASED DESIGN OF BENDING-ACTIVE TIED ARCHES 59
5.1 Introduction 59
5.1.1 Outline of the chapter 60
5.2 Stress levels after activation in elastica semi-waves 60
5.2.1 Evaluation of the utilisation ratio 60
5.3 Shape of the rod between deviators after activation 64
5.4 Numerical tests on bending-active tied arches with three deviators 66
5.4.1 Relationship between shape and activation forces 67
5.4.2 Stress levels in the rod after activation 67
5.4.3 Structural performance of cables 70
5.4.4 Performance for serviceability limit state (SLS) 72
5.4.5 Performance for ultimate limit state (ULS) 72
5.5 Example 73
5.6 Procedure to design bending-active tied arches with n deviators 74
5.7 Summary 76
6 DESIGN OF BENDING-ACTIVE TIED ARCHES BY USING A MOO METHOD 77
6.1 Introduction 77
6.1.1 Outline of the chapter 78
6.2 Problem description 78
6.3 The multi-objective optimisation problem 80
6.3.1 Fitness 82
6.3.2 Selection 84
6.3.3 Recombination and evolution 84
6.3.4 Sensitivity study 84
6.4 Results 85
6.5 Structural analysis and verification 90
6.6 Summary 93
7 EXPERIMENTAL FOOTBRIDGE BASED ON THE ACTIVE BENDING PRINCIPLE 95
7.1 Introduction 95
7.1.1 Outline of the chapter 95
7.2 Design 96
7.2.1 Specifications 96
7.2.2 Materials 96
7.2.3 Conceptual design 96
7.2.4 Determination of the structural configuration 99
7.3 Verification of limit states 102
7.3.1 Self-stress state 102
7.3.2 Dead load 105
7.3.3 Serviceability state 105
7.3.3.1 Symmetric load case 105

7.3.3.2 Non-symmetric load case 106
7.3.3.3 Torsional load case 107
7.4 Fabrication 108
7.4.1 Fabrication of the nodes 109
7.4.2 Assembling process 112
7.4.3 Future works 121
7.5 Summary 121
8 CONCLUSIONS AND FUTURE RESEARCH 123
8.1 Summary of results 123
8.2 Main conclusions 126
8.3 Future lines of research 127

APPENDIX

A NUMERICAL RESULTS FOR THE PROTOTYPE FE MODEL 131
A.1 Form-finding process 131
A.2 Load testing 135
A.2.1 Dead load (pallets) 135
A.2.2 Symmetric load case 137
A.2.3 Non-symmetric load case 139
A.2.4 Torsional load case 141
BIBLIOGRAPHY 147