CONTENTS

VOLUME I

Declaration	2	
Acknowledgements		3
Abstract	5	
Table of contents	7	

1 INTRODUCTION 14

2 WEIGH IN MOTION 21

- 2.1 Introduction, 21
- 2.2 The Development of Weigh-In-Motion Technology, 22
- 2.3 Static Weighing Scales, 24
 - 2.3.1 Platform Scales, 24
 - 2.3.2 Portable Wheel Load Scales, 25
- 2.4 Pavement based Weigh-In-Motion systems, 26
 - 2.4.1 Low-Speed WIM systems, 27
 - 2.4.2 Bending Plate, 28
 - 2.4.3 Strip sensors, 28
 - 2.4.4 Calibration, 31
 - 2.4.5 Multiple-sensor WIM, 34

- 2.5 Accuracy of Weigh-In-Motion systems, 36
 - 2.5.1 Long Term Period Test on Urban Road (Zurich, 1993-1995), 37
 - 2.5.2 Alpine Tests (Switzerland, 1993-1995), 38
 - 2.5.3 Weigh In Motion Experience in Belgium (1994-1998), 38
 - 2.5.4 Portable and Multiple-Sensor WIM systems Trial (Trappes, 1996), 39
 - 2.5.5 European Test Program (1996-1998), 40
- 2.6 Applications of Weigh-In-Motion Data, 43
 - 2.6.1 Pavements, 44
 - 2.6.2 Bridges, 46
 - 2.6.3 Road and Traffic Management, 48
 - 2.6.4 Enforcement and Road Pricing, 49

3 BRIDGE WEIGH IN MOTION SYSTEMS 52

- 3.1 Introduction, 52
- 3.2 General Characteristics of Bridge Weigh In Motion Systems, 53
 - 3.2.1 Advantages, 54
 - 3.2.2 Disadvantages, 55
- 3.3 Moses' Algorithm, 57
 - 3.3.1 Ideal site, 58
 - 3.3.2 Principle, 58
 - 3.3.3 Removal of Dynamics, 61
- 3.4 Allied Static Algorithms for Calculation of Weights, 63
 - 3.4.1 AXWAY, 64
 - 3.4.2 CULWAY, 67
 - 3.4.3 Left Slope Alignment, 70
- 3.5 Further developments, 70
 - 3.5.1 Sources of Inaccuracy, 71

- 3.5.2 Artificial Neural Networks, 74
- 3.5.3 Extension to Orthotropic Bridges, 77
- 3.5.4 Multiple-Longitudinal Sensors, 79
- 3.5.5 Combined System, 82
- 3.6 Dynamic Algorithms, 83
 - 3.6.1 O'Connor & Chan, 84
 - 3.6.2 Ghosn & Xu, 87
 - 3.6.3 Dempsey, 89
- 3.7 Accuracy of Bridge Weigh In Motion Systems, 92
 - 3.7.1 American, Australian and European Bridge Systems, 92
 - 3.7.2 Slovenia tests on Slab Bridges, 93
 - 3.7.3 Autreville tests on Orthotropic Bridges, 96
 - 3.7.4 Luleå tests in Cold Environment, 96
- 3.8 Conclusions, 100

4 DATA COLLECTION AND PROCESSING 101

- 4.1 Introduction, 101
- 4.2 Strain Measurement, 102
 - 4.2.1 Strain Gauges, 102
 - 4.2.2 Strain Amplifiers, 105
- 4.3 Axle Detection Hardware, 107
 - 4.3.1 Road Sensors, 108
 - 4.3.2 Free of Axle Detection Systems, 112
- 4.4 Software, 121
 - 4.4.1 CULWAY, 121
 - 4.4.2 SiWIM, 122
 - 4.4.3 Irish B-WIM, 124

4.5 Summary, 134

5 DYNAMIC MODELLING OF TRUCK CROSSING BRIDGE 136

- 5.2 Planar Dynamic Models, 137
 - 5.2.1 Bridge, 137
 - 5.2.2 Truck, 139
- 5.3 Bridge Subjected to a Moving Constant Load, 146
 - 5.3.1 Single Load, 146
 - 5.3.2 Multiple Loads, 150
- 5.4 Road Profile, 151
 - 5.4.1 Definition of Road Roughness, 152
 - 5.4.2 Vehicle-Road Profile Interaction, 154
- 5.5 Bridge Subjected to a Moving Two-Axle Rigid Body, 155
 - 5.5.1 Effect of Bridge Characteristics, 158
 - 5.5.2 Effect of Truck Parameters, 160
- 5.6 Effect of Suspension Type and Road Roughness, 162

6 SIMULATIONS USING FINITE ELEMENT ANALYSIS 170

- 6.1 Introduction, 170
- 6.2 Technique for Determination of Bridge-Vehicle Dynamic Interaction, 171
 - 6.2.1 Equations of Motion and Compatibility, 171
 - 6.2.2 Derivation of NASTRAN input code, 178
- 6.3 Implementation in NASTRAN, 192
- 6.4 Truck Models, 200

6.5 Bridge Models, 205

- 6.5.1 Single Span Isotropic Slab, 206
- 6.5.2 Two-Span Isotropic Slab, 216
- 6.5.3 Slab with Edge Cantilever, 222
- 6.5.4 Voided Slab Deck, 226
- 6.5.5 Beam and Slab, 230
- 6.5.6 Skew, 235
- 6.5.7 Cellular, 239
- 6.6 Conclusions, 245

VOLUME II

Table of contents

2

7 THE DEVELOPMENT OF A DYNAMIC ALGORITHM

- 7.1 Introduction, 5
- 7.2 An algorithm based on Spectrum Analysis, 6
 - 7.2.1 Principle, 7
 - 7.2.2 Calibration, 8
 - 7.2.3 Weight Calculation, 10
 - 7.2.4 Theoretical Testing, 11
 - 7.2.5 Advantages and Disadvantages, 15
- 7.3 An algorithm based on a Bridge Dynamic Model, 16
- 7.4 An algorithm based on a Truck Dynamic Model, 24
 - 7.4.1 Optimisation Process, 24
 - 7.4.2 Objective Function, 28
- 7.5 One-Dimensional Multiple-sensor Algorithms, 31

5

- 7.5.1 Dynamic Multiple-sensor Algorithm, 31
- 7.5.2 A Least Square Fitting Multiple-sensor Algorithm, 38
- 7.5.3 An Algorithm based on Modal decoupling, 52
- 7.6 Two-Dimensional Multiple-sensor Algorithms, 57
- 7.7 Summary, 61

8 EXPERIMENTAL TESTING 64

- 8.1 Introduction, 64
- 8.2 Delgany, Skewed Short Span (15 m) Simply Supported Bridge, 65
 - 8.2.1 Installation, 66
 - 8.2.2 Testing, 68
 - 8.2.3 Traffic Statistics, 79
 - 8.2.4 Influence of Braking Forces on Accuracy, 81
- 8.3 Luleå, Two-span (15 m each) Integral Bridge, 82
 - 8.3.1 Installation, 83
 - 8.3.2 Testing, 86
- 8.4 Belleville, Two-span (50 m each) Continuous Bridge, 92
 - 8.4.1 Installation, 93
 - 8.4.2 Testing, 96
- 8.5 Slovenia, Medium span (32 m) Simply Supported Bridge, 104
 - 8.5.1 Testing of the Northbound Carriageway, 104
 - 8.5.2 Testing of the Southbound Carriageway, 108
- 8.6 Conclusions, 110

9 NUMERICAL TESTING OF ALGORITHM 112

- 9.1 Introduction, 112
- 9.2 Testing with Green's one dimensional dynamic interaction model, 113
 - 9.2.1 Calibration, 113
 - 9.2.2 Check of Accuracy, 124
- 9.3 Testing with finite element models, 134
 - 9.3.1 Isotropic Single Span Slab, 135
 - 9.3.2 Two-Span Isotropic Slab, 143
 - 9.3.3 Slab with Edge Cantilever, 145
 - 9.3.4 Voided Slab Deck, 148
 - 9.3.5 Beam and Slab, 150
 - 9.3.6 Skew, 154
 - 9.3.7 Cellular, 156
- 9.4 Summary, 159

10 CONCLUSIONS 165

- 10.1 Introduction, 165
- 10.2 Results, 166
 - 10.2.1 Experimental Results, 167
 - 10.2.2 Theoretical Results, 168
- 10.3 Discussion, 170
- 10.4 Suggestions for future research, 172

APPENDICES 175

- A. Weigh In Motion Terms, 175
- B. Statistical Issues (COST 323 Specification), 186
- C. Data Acquisition Hardware, 194
- D. Bridge Weigh In Motion Program, 201
- E. Runge-Kutta Method, 209
- F. Bridge-truck Dynamic Interaction using MSC/NASTRAN, 213
- G. Analysis of Objective Function, 227
- H. Contents of CD-ROM, 233

REFERENCES 234