



Investigation of Adaptive Base Isolation System Utilising Magnetorheological Elastomer

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To my dearest parents

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

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TABLE OF CONTENTS

CERTIFICATE OF AUTHORSHIP/ORIGINALITY	II
ACKNOWLEDGEMENT.....	III
LIST OF PUBLICATIONS RELATED TO THIS THESIS.....	IV
TABLE OF CONTENTS	VI
LIST OF FIGURES	XI
LIST OF TABLES	XVIII
ABSTRACT.....	XX
CHAPTER 1 INTRODUCTION.....	1
1.1 Background And Motivation Of This Research	1
1.2 Objective Of The Present Research	8
1.3 Organisation Of This Thesis	9
CHAPTER 2 LITERATURE REVIEW	12
2.1 Preface.....	12
2.2 State-Of-Art Of The Conventional Base Isolation.....	14
2.2.1 Working principle of base isolation	14
2.2.2 History and Development of Base Isolation	14
2.2.3 Contemporary Base Isolation Devices	17
2.2.4 Categorisation of conventional base isolation techniques.....	28
2.2.5 Issues Related to Conventional Base Isolation.....	28
2.3 Ideas Of “Smart” Isolation System	29

2.4	Present “Smart” Base Isolation	30
2.4.1	Active Base Isolation System	31
2.4.2	Semi-active Base Isolation System	32
2.4.3	Issues Related to Present Hybrid Base Isolation Systems	36
2.5	MRE Vibration Isolation.....	37
2.5.1	Brief Description of MRE Material	38
2.5.2	MRE vibration isolator in mechanical engineering.....	40
2.5.3	MRE base isolator in civil engineering.....	43
2.5.4	Control Application of MRE Isolators	50
2.6	Research Gaps And Challenges	55

CHAPTER 3 MRE BASE ISOLATION AND HYSTERESIS

MODELLING 58

3.1	Chapter Outline	58
3.2	Introduction and Background	59
3.2.1	MRE base isolator.....	59
3.3	Forward Model of MRE Base Isolator.....	61
3.3.1	Generalised Bouc-Wen Model.....	61
3.3.2	Strain-Stiffening Model	74
3.3.3	Comparison of Bouc-Wen Model and Strain-Stiffening Model	91
3.4	Inverse Model of MRE Base Isolator	92
3.4.1	Introduction.....	92
3.4.2	Experimental Setup and Training Data	94
3.4.3	Inverse Modelling of MRE Base Isolator	96
3.4.4	MRE Base Isolator Inverse Model Based on FOA-Optimised GRNN	100
3.5	Summary	103

CHAPTER 4 INVESTIGATION OF RESPONSE TIME OF MRE

ISOLATOR FOR REAL-TIME CONTROL 105

4.1	Chapter Outline.....	105
4.2	Background.....	106

4.3	Response Time Definition	108
4.4	Response Time Calibration Of MRE Base Isolator	110
4.4.1	Input Excitations	110
4.4.2	Experimental Setup	111
4.4.3	Measured Response Time	112
4.5	Approaches To Minimise Response Time	113
4.5.1	Optimal Controlled PWM Servo Current Source.....	113
4.5.2	Modification to The Solenoid Circuit	120
4.5.3	Field-Quenching Coil Configuration	122
4.6	Response Time Under Different Configurations	125
4.6.1	On Current and Force Responses	125
4.6.2	Performance evaluation for real-time control implementation	127
4.7	Summary	131
CHAPTER 5 SEMI-ACTIVE CONTROL OF MRE BASE		
ISOLATION SYSTEM		
		133
5.1	Chapter Outline	133
5.2	Design and Identification Of The MRE Base Isolation System	134
5.2.1	Three-storey Building Model Design.....	134
5.2.2	System Identification	137
5.3	Experimental Setup And System Description.....	146
5.4	Control Algorithms	150
5.4.1	LQR Control with GRNN Inverse Model	151
5.4.2	GA Optimised Fuzzy Logic Control	154
5.4.3	Lyapunov-Based Control	163
5.4.4	Frequency Control	171
5.5	Comparative Investigation Results And Discussion.....	175
5.5.1	Earthquake Records	176
5.5.2	Evaluative Indices	179
5.5.3	Comparison between Numerical and Experimental Results	181
5.5.4	Peak Responses	186
5.5.5	Evaluative indices comparison.....	201

5.5.6	Time Histories.....	209
5.5.7	Control Force and Current Comparisons	224
5.5.8	Comparative Evaluation between Different Control Methods	233
5.6	Summary	234
CHAPTER 6 INNOVATIVE STOREY ISOLATION UTILISING		
SMART MRE ISOLATION SYSTEM 236		
6.1	Chapter Outline	236
6.2	Background And Introduction	237
6.3	System Description	240
6.4	Optimal Current Selection Of The MRE Isolator	243
6.4.1	Five-Storey Benchmark Building Model	243
6.4.2	Optimisation Problem Statement	244
6.4.3	Non-Dominated Sorting Genetic Algorithm-II (NSGA-II) with DCD	245
6.4.4	Parameter Identification Based on NSGA-II with DCD	247
6.5	Control Method.....	250
6.6	Numerical Investigation.....	251
6.7	Summary	268
CHAPTER 7 CONCLUSIONS AND FUTURE RESEARCH..... 269		
7.1	MRE Base Isolator Modelling	269
7.2	Response Time Of MRE Base Isolator Investigation	271
7.3	Control Algorithm For MRE Base Isolation System	271
7.4	Experimental Realisation Of MRE Base Isolation System	272
7.5	Storey MRE Isolation System.....	274
7.6	Suggestions For Future Work	275
7.6.1	Optimisation of Coil Configuration for Further Response Time Reduction	275
7.6.2	Further Development of Control Algorithm	276
7.6.3	Optimisation of MRE Isolator Placement in Storey Isolation System	277

7.6.4 Experimental Investigation of the MRE Base Isolation System on Full-Scaled Civil Infrastructures	277
REFERENCE.....	279
APPENDIX.....	293
Appendix A Peak Responses Under Four Earthquakes	293
Appendix B Evaluative Indices	296
Appendix C Selected Time History Responses	300
Appendix D Control Force And Corresponding Current.....	306

LIST OF FIGURES

Figure 2.1 Laminated rubber bearing: (a) composite and sectional details; (b) schematic diagram	17
Figure 2.2 Lead core rubber bearing (New Zealand rubber bearing): (a) composite and sectional details; (b) schematic diagram	20
Figure 2.3 Pure friction (PF) bearing: (a) composite and sectional details; (b) schematic diagram	21
Figure 2.4 EDF base isolation system: (a) composite and sectional details; (b) schematic diagram	22
Figure 2.5 Resilient friction base isolation (R-FBI) system: (a) composite and sectional details (Mostaghel 1987); (b) schematic diagram.....	23
Figure 2.6 Sliding resilient friction base isolation (S-RF) system: (a) composite and sectional details; (b) schematic diagram	24
Figure 2.7 Friction pendulum base isolator: (a) external view; (b) composite and sectional details; (c) schematic diagram	25
Figure 2.8 Categorisation of conventional base isolation techniques.....	27
Figure 2.9 Schematic diagram of (a) hybrid isolation system combining passive base isolation with supplementary dampers; (b) “smart” base isolation system with controllable isolators.....	30
Figure 2.10 Schematics of variable-orifice damper	34
Figure 2.11 Schematics of a controllable MRF damper	35
Figure 2.12 Shear stress-strain curves under different magnetic field (Li, Li & Samali 2012)	40
Figure 2.13 Design of the MRE vibration isolation mount (Kavlicoglu et al. 2011) ..	41
Figure 2.14 Sketch of the MRE-based vibration isolator (Liao et al. 2012).....	42
Figure 2.15 (a) Cross-section view of MRE isolator; (b) Vibration model of the MRE seat suspension system with human body.....	42
Figure 2.16 Structure model coupled with an MR elastomer-based base-isolation system (Jung et al. 2011)	43
Figure 2.17 Cross-section view and photo of variable stiffness and damping isolator (Behrooz, Wang & Gordaninejad 2014b).....	44
Figure 2.18(a) Phenomenological Bouc-Wen model of VSDI; (b) On-state and off-state shear force deformation characteristics of VSDIs (Behrooz, Wang & Gordaninejad 2014a)	45

Figure 2.19 Photo and cross-section view of the laminated MRE base isolator (Li, Li, Li, et al. 2013).....	47
Figure 2.20 Photo and cross-section view of the highly adjustable laminated MRE base isolator.....	47
Figure 2.21(a) Force-displacement relationships of the MRE base isolator at quasi-static testing ($f=0.1\text{Hz}$, $\Delta=8\text{mm}$); (b) force-displacement loops at different amplitudes (2mm, 4mm and 8mm) excitation at 0.1 Hz and 3A (Li, Li, Tian, et al. 2013).....	47
Figure 2.22 Laminated negative stiffness MRE isolator (Yang et al. 2014)	49
Figure 2.23 Different working modes of hybrid magnetic system (Yang et al. 2014)	50
Figure 2.24 Multiple short-type floating slab track magneto-rheological system model (Li et al. 2016).....	54
Figure 3.1 Experimental setup for training data acquisition and power equipment (Li, Li, Tian, et al. 2013).....	59
Figure 3.2 MRE isolator's stiffness and damping dynamics with different current input	60
Figure 3.3 Schematic diagram of the proposed Bouc-Wen model for MRE isolator..	62
Figure 3.4 Comparison between experimental data and forecast values from the proposed model with different excitation amplitudes (1Hz-3A).....	63
Figure 3.5. Comparison between experimental data and forecast values from the proposed model with different applied currents (1Hz-4mm)	64
Figure 3.6 Comparison between experimental data and forecast values from the proposed model with different excitation frequencies (4mm-1A).....	64
Figure 3.7 Parameter identification results: (a) k_0 vs current; (b) c_0 vs current; (c) α vs current; (d) A vs current; (e) β vs current; (a) γ vs current Based on the observations in Table 3.1 and Figure 3.4 to Figure 3.6, it can be assumed that the values of parameters are more affected by applied current rather than the excitation frequency and amplitude. Hence, an average of parameter values under different excitation scenarios when applied current is 0A, 1A, 2A and 3A, respectively, is taken as the parameter at the corresponding current level. Next, a curve fitting is conducted to explore the definitive correlation between the parameter of interest with applied current. Figure 3.7 shows the fitting curve of all six parameters, among which k_0 , c_0 , A , β , and γ have a linear relation with current while α and current have a quadratic relation. The fitted functions of parameters are expressed by Eq 3.2.....	67
Figure 3.8 k_0 dependent responses of the generalised Bouc-Wen model: (a) force-displacement loops; (b) force-velocity loops.....	69
Figure 3.9 c_0 dependent responses of the generalised Bouc-Wen model: (a) force-displacement loops; (b) force-velocity loops.....	69

Figure 3.10 α dependent responses of the generalised Bouc-Wen model: (a) force-displacement loops; (b) force-velocity loops.....	70
Figure 3.11 A dependent responses of the generalised Bouc-Wen model: (a) force-displacement loops; (b) force-velocity loops.....	71
Figure 3.12 β and γ dependent responses of the generalised Bouc-Wen model: (a) force-displacement loops of changing β ; (b) force-velocity loops of changing γ	71
Figure 3.13 Comparison between experimental force and predicted force by Bouc-Wen model with random displacement input.....	72
Figure 3.14 Comparison between experimental force and predicted force by Bouc-Wen model with El Centro earthquake displacement input.....	73
Figure 3.15 Break-down of the hysteresis of MRE base isolator.....	75
Figure 3.16 Schematic diagram of the proposed strain-stiffening model for MRE isolator.....	75
Figure 3.17 Comparison between experimental data and forecast values from the proposed model with different excitation amplitudes (1Hz-3A).....	77
Figure 3.18 Comparison between experimental data and forecast values from the proposed model with different applied current (2Hz-4mm).....	78
Figure 3.19 Comparison between experimental data and forecast values from the proposed model with different applied current (1A-4mm).....	79
Figure 3.20 k_0 dependent responses of the generalised strain-stiffening model: (a) force-displacement loops; (b) force-velocity loops.....	80
Figure 3.21 c_0 dependent responses of the generalised strain-stiffening model: (a) force-displacement loops; (b) force-velocity loops.....	80
Figure 3.22 α dependent responses of the generalised strain-stiffening model: (a) force-displacement loops; (b) force-velocity loops.....	83
Figure 3.23 F_0 dependent responses of the generalised strain-stiffening model: (a) force-displacement loops; (b) force-velocity loops.....	83
Figure 3.24 Correlations between parameter values and applied current with different excitation frequencies.....	84
Figure 3.25 Correlations between parameter values and excitation frequency with different applied current.....	85
Figure 3.26 Correlations between parameter values and applied current with different excitation amplitudes.....	86
Figure 3.27 Relationships between model parameters and applied current as well as absolute maximal displacement.....	87
Figure 3.28 Comparison between experimental force and predicted force by strain-stiffening model with random displacement input ($I = 0A$).....	89

Figure 3.29 Comparison between experimental force and predicted force by strain-stiffening model with random displacement input ($I = 3A$)	90
Figure 3.30 Experimental setup for MRE inverse model identification	95
Figure 3.31 Training data for GRNN inverse model	96
Figure 3.32 Schematic diagram of inverse model based on GRNN	101
Figure 3.33 Performance of the GRNN inverse model (a) comparison between measured current and GRNN output; (b) regression analysis of results.....	103
Figure 4.1 Circuit diagram of the solenoid with current and voltage sources	108
Figure 4.2 Definition of response time at rise edge and fall edge	110
Figure 4.3 Illustration of input displacement and current excitations	111
Figure 4.4 Experimental setup of current and force response testing.....	112
Figure 4.5 Original current and force response of MRE isolator	113
Figure 4.6 Schematics of a typical servo system	114
Figure 4.7 Definition of duty cycle.....	114
Figure 4.8 PWM signal governed current source: (a) schematic diagram; (b) transfer function block diagram	116
Figure 4.9 Working principle of a PWM servo current drive responding under a step command.....	118
Figure 4.10 Circuit description of isolated IGBT drive driven by PWM signal.....	119
Figure 4.11 Circuit description of power supplies used in IGBT switch system	119
Figure 4.12 Schematic diagram of MRE isolator with multi coils	122
Figure 4.13 Circuit description of split coil system.....	124
Figure 4.14 Circuit diagram of split coil system.....	124
Figure 4.15 Current response curves under different coil configurations	125
Figure 4.16 Current and force response time under different displacements	126
Figure 4.17 Final current and force responses with field-quenching coil configuration	127
Figure 4.18 Response time comparison under El-centro earthquake	129
Figure 4.19 Response time comparison under Kobe earthquake.....	129
Figure 4.20 Response time comparison under Hachinohe earthquake	130
Figure 4.21 Response time comparison under Northridge earthquake.....	130
Figure 5.1 Schematic diagram and dimensioning drawing of the three-storey shear building model	135
Figure 5.2 Photos of three-storey shear building model and connections in the structure	136
Figure 5.3 Modal testing experimental setups of fixed base building and base isolated structure.....	138

Figure 5.4 Flowchart of experimental modal analysis / statistical modal analysis module in DIAMOND (Doebling, Farrar & Cornwell 1997)..... 139

Figure 5.5 Experimental dynamic mode shapes (along softer direction): (a) first mode shape; (b) second mode shape; (c) third mode shape 141

Figure 5.6 Comparison between experimental and predicted top floor displacement in fixed base building..... 142

Figure 5.7 Comparison between experimental and predicted top floor displacement in base isolated building..... 146

Figure 5.8 Experimental setup schematics of comparative testing of proposed MRE base isolation system..... 146

Figure 5.9 Photo of experimental setup: (a) front view; (b) side view 148

Figure 5.10 Laser sensor and sensor adapter 148

Figure 5.11 Power supplies and data acquisition system with dSPACE 149

Figure 5.12 Block diagram of a general semi-active structural control problem 151

Figure 5.13 Semi-active control strategy of MRE base isolation system with GRNN inverse model..... 152

Figure 5.14 Schematic diagram of inverse model based on GRNN 153

Figure 5.15 Schematic diagram of the RBF based NFLC 156

Figure 5.16 Fuzzy rule base matrix at hidden layer..... 157

Figure 5.17 Schematic diagram of one chromosome with encoded NFLC parameters 160

Figure 5.18 Flow chart of NSGA-II with DCD 161

Figure 5.19 NSGA-II optimised membership function for top acceleration and base displacement 162

Figure 5.20 Schematics of the dynamic system..... 164

Figure 5.21 Stiffness ON-OFF control (Liao et al. 2012)..... 169

Figure 5.22 Flow chart of the feed-forward frequency control system (Gu et al. 2016) 172

Figure 5.23 Time histories of evaluative indices and corresponding control command 174

Figure 5.24 Earthquake time histories and pseudo-acceleration spectra (damping ratio=5%) 177

Figure 5.25 Experimental and numerical relative displacement responses of Passive-on system (0.15 Hachinohe) 181

Figure 5.26 Experimental and numerical absolute acceleration responses of Passive-on system (0.15 Hachinohe) 183

Figure 5.27 Peak responses with four different earthquake magnitudes of El-Centro earthquake 187

Figure 5.28 Peak responses with four different earthquake magnitudes of Kobe earthquake	188
Figure 5.29 Peak responses under four earthquakes (scaling factor = 15%)	189
Figure 5.30 Peak inter-storey drift ratio under four earthquakes (inter-storey drift ratio = inter-storey drift/floor height (0.04m); earthquake scaling factor= 15%)	191
Figure 5.31 Peak floor acceleration under four earthquakes (earthquake scaling factor = 15%).....	194
Figure 5.32 Peak relative displacement under four earthquakes (earthquake scaling factor = 15%)	196
Figure 5.33 Peak floor shear/Seismic weight W under four earthquakes ($W = 912.57N$ (fixed base building)/ $1402.58N$ (base-isolated building) ; earthquake scaling factor = 15%).....	198
Figure 5.34 Evaluative indices $J_1 \sim J_6$ under four earthquakes (earthquake scaling factor = 15%).....	202
Figure 5.35 Evaluative indices $J_7 \sim J_9$ at worst case scenario (earthquake scaling factor = 15%).....	203
Figure 5.36 Time history of top floor acceleration with different control algorithms (0.15 El-Centro)	212
Figure 5.37 Time history of top floor acceleration with different control algorithms (0.15 Kobe)	213
Figure 5.38 Time history of top floor acceleration with different control algorithms (0.15 Hachinohe).....	214
Figure 5.39 Time history of top floor acceleration with different control algorithms (0.15 Northridge)	215
Figure 5.40 Time history of base displacement with different control algorithms (0.15 El-Centro)	216
Figure 5.41 Time history of base displacement with different control algorithms (0.15 Kobe).....	217
Figure 5.42 Time history of base displacement with different control algorithms (0.15 Hachinohe).....	218
Figure 5.43 Time history of base displacement with different control algorithms (0.15 Northridge).....	219
Figure 5.44 Time history of base acceleration with different control algorithms (0.15 El-Centro)	220
Figure 5.45 Time history of base acceleration with different control algorithms (0.15 Kobe).....	221
Figure 5.46 Time history of base acceleration with different control algorithms (0.15 Hachinohe).....	222

Figure 5.47 Time history of base acceleration with different control algorithms (0.15 Northridge).....	223
Figure 5.48 Time history of control force with different control algorithms (0.15 El Centro)	226
Figure 5.49 Time history of control force with different control algorithms (0.15 Kobe)	227
Figure 5.50 Time history of control force with different control algorithms (0.15 Hachinohe).....	228
Figure 5.51 Time history of control force with different control algorithms (0.15 Northridge).....	229
Figure 5.52 Control force and corresponding control current with NSGA-NFLC (Earthquake scaling factor = 15%)	230
Figure 5.53 Control force and corresponding control current with Lyapunov control (Earthquake scaling factor = 15%)	231
Figure 5.54 Control force and corresponding control current with frequency control (Earthquake scaling factor = 15%)	232
Figure 6.1 Sketches of: (a) fixed base building; (b) base-isolated building; (c) storey isolated building.....	240
Figure 6.2 Schematic diagrams of: (a) fixed base building model; (b) storey-isolated building model	242
Figure 6.3 Photo and typical floor plan of the 5-storey benchmark building model (Wu & Samali 2002).....	243
Figure 6.4 Illustration of Pareto frontier (Barraza et al. 2017)	246
Figure 6.5 Time history of top floor acceleration under El Centro earthquake.....	252
Figure 6.6 Time history of top floor acceleration under Kobe earthquake.....	253
Figure 6.7 Time history of top floor acceleration under Hachinohe earthquake.....	254
Figure 6.8 Time history of top floor acceleration under Northridge earthquake.....	255
Figure 6.9 Comparison of top floor acceleration between optimised SI and controlled SI.....	256
Figure 6.10 Peak floor acceleration response under four earthquakes	257
Figure 6.11 Peak inter-storey drift ratio response under four earthquakes (drift ratio = inter-storey drift/floor height; floor height = 600mm).....	258
Figure 6.12 Peak relative displacement response under four earthquakes	259
Figure 6.13 Control current of different storey under El Centro earthquake.....	261
Figure 6.14 Control current of different storey under Kobe earthquake	262
Figure 6.15 Control current of different storey under Hachinohe earthquake.....	263
Figure 6.16 Control current of different storey under Northridge earthquake	264

LIST OF TABLES

Table 2.1 Inference rule of the fuzzy logic control algorithm (Yang et al. 2016).....	54
Table 3.1 Identified parameter values for Bouc-Wen model under different excitation scenarios.....	65
Table 3.2 Identified parameter values for strain-stiffening model under different excitation scenarios.....	81
Table 3.3 Final identified parameter values of strain-stiffening model.....	88
Table 3.4 Comparison results between Bouc-Wen model and strain-stiffening model.....	91
Table 4.1 Original current and force response time (4mm displacement).....	112
Table 4.2 Final current and force response time (4mm displacement, field-quenching configuration).....	127
Table 5.1 Detailed designated parameters of each component.....	136
Table 5.2 Comparison of natural frequency and damping ratio between numerically predicted and modal analysis results.....	140
Table 5.3 Mode shape vectors from modal analysis results.....	140
Table 5.4 Parameter values of MRE base isolator’s Bouc-Wen model.....	143
Table 5.5 Identified structural parameters of the base isolated building model.....	145
Table 5.6 Evaluative indices for NSGA II.....	162
Table 5.7 NSGA-II optimised weights for NFLC.....	163
Table 5.8 Benchmark earthquakes information.....	178
Table 5.9 Evaluative indices description.....	180
Table 5.10 Comparative peak responses of experimental and numerical results (0.15 El Centro).....	184
Table 5.11 Comparative peak responses of experimental and numerical results (0.15 Kobe).....	184
Table 5.12 Comparative peak responses of experimental and numerical results (0.15 Hachinohe).....	185
Table 5.13 Comparative peak responses of experimental and numerical results (0.15 Northridge).....	185
Table 5.14 Reduction of peak floor responses of different isolation scenarios.....	199
Table 5.15 Evaluative indices value.....	204
Table 5.16 Comparison of five controllers.....	233
Table 6.1 Parameter values of MRE isolator model.....	241

Table 6.2 Structural parameters of the 5-storey model.....	243
Table 6.3 Optimisation current solutions and corresponding objective values	249
Table 6.4 Evaluative indices description	265
Table 6.5 Values of evaluative indices $J_1 \sim J_6$ under four earthquakes with different isolation scenarios	266
Table 6.6 Values of evaluative indices $J_1 \sim J_6$ under four earthquakes with different isolation scenarios (Cont'd)	267

ABSTRACT

Most of current researches on controllable or “smart” base isolation systems have been based on the hybrid of conventional base isolation system with active or semi-active dampers. Although supplementary dampers may help to reduce maximum displacement of base isolation systems and provide adjustable damping to suppress vibrations of the protected structure, it suffers some setbacks such as introduction of undesirable acceleration, limited performance due to the passive nature of base isolation, etc. Moreover, those “smart” supplementary dampers failed to add “smartness” or controllability toward working mechanism of isolation systems, i.e. decoupling ground motion from superstructures. In recent years, the development of adaptive base isolator utilising magnetorheological elastomer (MRE) shed light on “truly” smart base isolation systems in which isolators’ lateral stiffness can be controlled in real time by varying applied current. To this end, the MRE base isolation system exhibits a promising potential for ultimate seismic protection of civil infrastructures due to its ability to maximise, in real time, level of decoupling between ground motion and the superstructure. However, there have been only limited researches reported in this area. In addition, there is lack of throughout investigations, especially experimental investigation, on critical issues and feasibility related design and implementation of such MRE-based smart base isolated system, which is much needed for future development and application.

This thesis is aimed at filling aforementioned research gap in development and application of MRE-based smart base isolated system by contributing new knowledge in the fields in terms of: i) modelling of the MRE isolator to capture its forward and inverse dynamic characteristics; ii) comprehensive investigation on the response time of MRE isolator and exploration of approaches to minimise the lag; iii) overcome

obstacles in experimental realisation of smart base isolation system; iv) other innovations in seismic protection of civil infrastructures employing MRE isolator.

First, the modelling of the MRE isolator is conducted for dynamic response prediction of the device. Two forward models of the isolator are proposed and compared, namely, a phenomenological model based on hysteresis Bouc-Wen model and innovative strain-stiffening model identified by least square (LS) function. Performance evaluation of the model has been conducted based on the experimental testing data from MRE isolator. Furthermore, due to the inherent nonlinearity and hysteretic characteristics of the devices, it is challenging to obtain a less complicated mathematical model to describe the inverse dynamics of MRE base isolators and hence to perform control synthesis of the MRE base isolation system. Therefore, an optimal general regression neural network (GRNN) inverse model has been proposed to depict the inverse dynamics of the isolator. With the inverse model, the nonlinearity and phenomenological hysteresis brought into control system by the MRE isolator can be neutralised for the classic control algorithm like LQR to be feasible.

Real-time control of the MRE isolators holds the key to unlock MRE materials' unique characteristics, i.e. instantly changeable shear modulus in continuous and reverse fashion. However, one of the critical issues for the applications of real-time control is the response time delay of MRE vibration isolators, which has not yet been fully addressed and studied. Therefore, the next topic of this thesis is to identify the inherent response time of the MRE isolator and explore feasible approaches to minimise the response time delay. The definition and experimental measurement of the response time of MRE isolator is presented, followed by three response time reduction approaches, i.e. PWM servo current drive, modification of isolator's solenoid and innovative configuration of solenoid excitation.

A three-storey shear building model is then designed as the testing bed of proposed MRE base isolation system. Various control algorithms are proposed, developed and formulated to explore the capability of the smart isolation system, including non-

dominated sorting genetic algorithm optimised neural fuzzy logic control (NSGA-NFLC), Bang-Bang control, LQR control with GRNN inverse model, frequency control and Lyapunov-based current selection control. Comprehensive investigation of seismic protection performance of the MRE isolation system has been conducted numerically and experimentally. Promising vibration suppression performance has been observed in most controlled solution scenarios, particularly in NSGA-NFLC and Lyapunov controller.

Finally, an innovative storey isolation system utilising MRE isolator has been proposed and numerically evaluated. The advantage of storey isolation system lies in that it can distribute the deformation of base isolation system into different levels, leading to effective solution of extensive base displacement issue faced by conventional base isolation system. The NSGA-II is utilised to seek for the optimal placement of isolators and current input of each device. The Lyapunov-based current selection control is employed for the control of the storey isolation system. A comprehensive numerical testing compares the seismic responses of bare building, building with passive controlled MRE base isolation system, building with optimal MRE storey isolation system and controlled storey isolation system. Simulation results indicate that the controlled storey isolation system is capable of significantly mitigating the floor acceleration and base displacement as well as avoiding whipping effect problem in passive storey isolation system.