
Contents

Photos and Attribution	xi
Preface.....	xiii
Foreword	xv
About the Authors.....	xvii
Chapter 1 Structural Vibration Control Using Passive Devices	1
1.1 Introduction	1
1.2 Control of Structural Vibrations.....	1
1.2.1 Response of Structures under Earthquake Excitations	4
1.2.2 Response of Structures under Wind Excitations	7
1.2.3 Response of Structures under Wave Excitations	10
1.2.4 Need for Structural Response Control	11
1.3 Classification of Structural Vibration Control Strategies.....	13
1.3.1 Passive Vibration Control Strategies	14
1.3.1.1 State-of-the-Art Review.....	14
1.3.1.2 Salient Features, Advantages, and Limitations	15
1.3.1.3 Base Isolation.....	16
1.3.1.4 Bracing System.....	17
1.3.1.5 Viscous Damper.....	17
1.3.1.6 Viscoelastic Damper.....	17
1.3.1.7 Mass Damper.....	18
1.3.1.8 Friction Damper.....	19
1.3.1.9 Metallic Damper.....	19
1.3.1.10 Re-Centering Devices.....	19
1.3.1.11 Wire Rope Isolator.....	20
1.3.2 Active Control Strategies	20
1.3.2.1 Salient Features of Active Control Strategies.....	20
1.3.2.2 Advantages of Active Control Strategies.....	21
1.3.2.3 Limitations of Active Control Strategies.....	21
1.3.2.4 Applications of Active Control Techniques.....	22
1.3.3 Semi-Active Control Strategies	23
1.3.3.1 Salient Features of Semi-Active Control Strategies	25
1.3.3.2 Advantages of Semi-Active Control Strategies	26
1.3.3.3 Limitations of Semi-Active Control Strategies.....	26
1.3.3.4 Applications of Semi-Active Control Techniques	26
1.3.4 Hybrid Control Strategies.....	28
1.3.4.1 Salient Features of Hybrid Control Strategies	29
1.3.4.2 Advantages of Hybrid Control Strategies	29
1.3.4.3 Limitations of Hybrid Control Strategies	29
1.3.4.4 Applications of Hybrid Control Techniques	29
Reference.....	32
Chapter 2 Dynamic Loading on Structures and Structural Response.....	33
2.1 Selection of Earthquake Ground Motion Records	33
2.1.1 Near-Fault Earthquake Ground Motions.....	36
2.1.1.1 Forward-Directivity	36
2.1.1.2 Fling-Step Effect.....	37

2.1.2 Far-Fault Earthquake Ground Motions 37

2.1.3 Scaling of Earthquake Ground Motions 37

2.1.3.1 Scaling Based on ASCE 7-16 (2017) 37

2.1.3.2 Scaling Based on Conditional Mean Spectrum..... 38

2.1.3.3 Scaling Based on Uniform Design Method..... 38

2.1.4 Synthetic Earthquake Ground Motions..... 38

2.1.5 Structural Response under Near-Fault and Far-Fault Earthquakes 39

2.2 Wind Loading..... 40

2.2.1 Wind Loading on Buildings 42

2.2.1.1 Designing a Building for Wind..... 42

2.2.1.2 Mitigation of Wind Forces on Tall Buildings..... 43

2.2.2 Wind Loading on Bridges 43

2.2.2.1 Mitigation of Wind Effects on Bridges..... 44

2.2.2.2 Design Considerations 44

2.2.2.3 Construction Safety 44

2.2.2.4 Cable Vibrations 45

2.2.3 Wind Loading on Chimneys 45

2.2.4 Wind Loading on Towers 45

2.2.5 Wind Tunnel Test 46

2.2.5.1 Types of Wind Tunnel Tests 47

2.3 Wave Loading..... 49

2.3.1 Wave-induced Dynamic Forces 50

2.3.1.1 Computation of the Sea State 50

2.3.1.2 Computation of the Wave Forces..... 51

2.3.2 Dynamic Response of Offshore Structures..... 52

2.3.3 Morison’s Equation for Modeling of Wave Forces 52

2.3.4 Pierson-Moskowitz Wave Height Spectrum..... 52

2.3.5 Governing Equation of Motion for Wave Loading 53

2.3.6 Structural Response under Wave Loads..... 54

References 54

Chapter 3 Bracing Systems 55

3.1 Introduction 55

3.2 Buckling-Resistant Braces (BRBs)..... 55

3.3 Diagonal Bracing..... 72

3.4 Concentrically Braced Frames 73

3.5 Eccentrically Braced Frames 76

3.6 X-Type Brace 81

3.7 K-Type Brace 81

3.8 V Brace and Inverted V Brace (Chevron Brace) 82

3.9 Outrigger Braced System 82

3.10 Toggle Brace..... 82

3.11 Negative Stiffness Damper..... 84

3.12 Lead Rubber Shear Damper 85

3.13 Passive Tendon System 86

References 87

Chapter 4	Viscous and Viscoelastic Dampers	89
4.1	Introduction	89
4.2	Fluid Viscous Dampers	89
4.2.1	Linear Fluid Viscous Damper	92
4.2.2	Nonlinear Fluid Viscous Damper	92
4.2.3	GERB Fluid Viscous Damper	96
4.2.4	Viscous Damping Wall	98
4.3	Viscoelastic Damper	104
4.3.1	Viscoelastic Solid Damper	107
4.3.2	Viscoelastic Fluid Damper	112
4.4	Oil Damper	115
4.5	Orifice Fluid Damper	116
4.6	Lead Extrusion Damper	116
	References	131
Chapter 5	Tuned Dampers	133
5.1	Tuned Mass Damper	133
5.1.1	Simple Pendulum	134
5.1.2	Pendulum with Damper	137
5.1.3	Inverted Pendulum with Damper and Spring	139
5.1.4	Two-Mass Damper	140
5.1.5	Multistage Tuned Mass Damper	145
5.1.6	Mass on Rubber Bearing	147
5.1.7	Multiple and Distributed Tuned Mass Dampers	147
5.1.8	Tuned Mass Damper Inerter	152
5.1.9	Merits of Tuned Mass Dampers	153
5.1.10	Demerits of Tuned Mass Dampers	153
5.1.11	Worldwide Applications of Tuned Mass Dampers	153
5.2	Tuned Liquid Damper	161
5.2.1	Sloped Bottom Tuned Liquid Damper	162
5.2.2	Tuned Liquid Column Damper	168
5.2.3	Tuned Liquid Damper with Floats	171
5.2.4	Merits of Tuned Liquid Damper	172
5.2.5	Demerits of Tuned Liquid Damper	172
5.2.6	Worldwide Applications of Tuned Liquid Damper	173
	References	186
Chapter 6	Friction Dampers	187
6.1	Introduction	187
6.2	X-Braced Pall Friction Damper	187
6.3	Sumitomo Friction Damper	198
6.4	Constant and Proportional Friction Damper	198
6.5	Slotted Bolted Friction Damper	199
6.6	Energy Dissipating Restraint	202
6.7	Pseudo-Viscous Frictional Damper	204
6.8	Double-Face Frictional Damper	205
6.9	Multidirectional Torsional Damper	205
	References	218

Chapter 7 Metallic Dampers..... 219

7.1 Introduction 219

7.2 X-Shaped Metallic Damper (ADAS Device) 219

7.3 Tyler’s Yielding Steel Bracing System 222

7.4 Steel Damper 224

7.4.1 Bar-Type Steel Damper 224

7.4.2 Loop-Type Steel Damper 225

7.4.3 Portal-Type Steel Damper 225

7.4.4 Ring-Type Steel Damper 226

7.4.5 Plate-Type Steel Damper 229

7.5 Dual-Pipe Damper and Infilled-Pipe Damper..... 229

7.6 Triangular Metallic Damper..... 230

7.7 Dual Function Metallic Damper 233

7.7.1 Strip Metallic Damper..... 233

7.7.2 Round-Hole Metallic Damper..... 233

7.7.3 Double X-Shaped Metallic Damper..... 234

7.8 Metallic Yielding-Friction Damper..... 234

References 236

Chapter 8 Re-centering Devices 239

8.1 Introduction 239

8.2 Pressurized Fluid Damper..... 239

8.3 Preloaded Spring Friction Damper..... 241

8.3.1 Mathematical Model of Preloaded Spring Friction Damper..... 241

8.4 Self-Centering Seismic-Resistant System 242

8.4.1 Applications of Self-Centering System 243

8.5 Shape Memory Alloy Devices..... 247

8.5.1 Mathematical Model of SMA-Based Device 248

References 253

Chapter 9 Miscellaneous Response Control Devices 255

9.1 Wire Rope Isolators 255

9.2 Bretelle Damper..... 260

9.3 Spacer Damper 260

References 262

Chapter 10 Advances in Passive Control Strategies: *Hybrid Control* 263

10.1 Introduction 263

10.2 Passive Control Systems 263

10.3 Hybrid Control Systems 264

10.4 Hybrid Base Isolation System for Buildings and Bridges 264

References 318

Chapter 11 Introduction to Benchmark Control Problems 319

11.1 Introduction 319

11.2 Seismically Excited 8-Story Base-Isolated Benchmark Building..... 319

11.2.1 Model of 8-Story Benchmark Building 319

11.2.2	Governing Equations of Motion	321
11.2.3	Evaluation Criteria.....	323
11.2.4	Peak Response	324
11.2.5	RMS Response	325
11.2.6	Earthquake Ground Excitations	326
11.2.7	Numerical Study	326
11.3	Seismically Excited 20-Story Steel Benchmark Building	327
11.3.1	Model of the Seismically Excited 20-Story Steel Benchmark Building.....	328
11.3.2	Evaluation Model for 20-Story Benchmark Building	330
11.3.3	Governing Equations of Motion	331
11.3.4	Earthquake Ground Motions	332
11.3.5	Evaluation Criteria.....	333
11.3.6	Numerical Study	336
11.3.6.1	Application of SMA Dampers	338
11.3.6.2	Application of Viscous Damping Walls	339
11.3.6.3	Application of Friction Dampers	339
11.3.6.4	Application of d-TMDs.....	351
11.4	Wind Excited 76-Story Benchmark Building	355
11.4.1	Model of the Wind Excited 76-Story Benchmark Building.....	355
11.4.2	Performance Criteria	357
11.4.3	RMS Response	357
11.4.4	Peak Response	358
11.4.4.1	Application of Tuned Liquid Column Dampers (TLCD).....	359
11.4.4.2	Application of Friction Dampers	359
11.4.4.3	Application of Fluid Viscous Dampers	360
11.4.4.4	Application of TMD	360
11.5	Seismically Excited Benchmark Highway Bridge	361
11.5.1	Evaluation Model	362
11.5.2	Finite Element Model	363
11.5.3	Reduced-Order Controller Design Model	364
11.5.4	Governing Equations of Motion	364
11.5.5	Evaluation Criteria.....	365
11.5.6	Peak Response	365
11.5.7	Normed Response.....	366
11.5.8	Control Requirement	367
11.5.9	Earthquake Ground Excitations	368
11.5.10	Phase I and Phase II of the Benchmark Highway Bridge	369
11.5.11	Sample Controllers for the Benchmark Highway Bridge	369
11.5.11.1	Application of Sliding Isolators	371
11.5.12	Numerical Study	372
11.5.13	Seismic Response Control of Benchmark Highway Bridge: Phase II.....	373
11.5.14	Evaluation Criteria.....	373
11.6	Seismically Excited Benchmark Cable-Stayed Bridge	373
11.6.1	Evaluation Model	376
11.6.2	Finite Element Model	382

11.6.3	Nonlinear Static Analysis	382
11.6.4	Reduced-Order Controller Design Model	384
11.6.5	Evaluation Criteria.....	384
11.6.6	Peak Response	384
11.6.7	Normed Response.....	385
11.6.8	Control Requirement	386
11.6.9	Earthquake Ground Excitations	388
11.6.10	Numerical Study.....	388
	References	392
Index.....		393