## Index

		Introduction	
1.		Conservation of the architectural heritage: structural, seismic	
		and geotechnical aspects	1
	1.1	Structural engineering and architectural heritage: national and	
		international deontological guidelines	1
		1.1.1 International and deontological guidelines	1
		1.1.2 The Italian scene	4
	1.2	The path of knowledge: historic, geometric, structural and geotechnical	5
		aspects	
		1.2.1 Geometric data gathering	5
		1.2.2 History of the structures	6
		1.2.3 Survey of constructive materials and state of conservation	7
		1.2.4 Mechanical characterisation of the materials	8
		1.2.5 Soil and foundation analysis	9
		1.2.6 Structural health monitoring	11
	1.3	Safety assessment of the architectural heritage	13
		1.3.1 Evolution of the safety levels	13
		1.3.2 Nominal life	14
		1.3.3 Modelling	14
2.	2.1	Seismic risk and safety assessment of the architectural heritage Seismic hazard and cultural heritage: geological, geomorphological and	17
		geotechnical aspects	17
		2.1.1 Local site effects and amplification	18
		2.1.2 Soil-structure interaction	19
		2.1.3 Liquefaction	21
	2.2	Seismic vulnerability of architectural heritage: experiences learned from	23
		past earthquakes	
		2.2.1 Earthquakes and architectural heritage in Europe and Middle East	23
		2.2.2 Earthquakes and architectural heritage in the Far East	28
	2.3	Performance-based approaches in structural engineering problems and	
		codes	32
		2.3.1 Performance-based approach for existing buildings	32
		2.3.2 Towards a performance-based assessment of historical buildings?	37
	2.4		40
	2.1	2.4.1 SHM technologies	41
3.		Experimental modal analysis of masonry buildings	47
	3.1	System identification	47

		3.1.1 Linear system identification and classification of methods	47
		3.1.2 Time domain methods	49
		3.1.3 Frequency domain methods	53
		3.1.4 Time-frequency domain methods	54
	3.2	Assimilating experimental results in numerical models (model updating)	70
		3.2.1 Model-driven approaches	70
		3.2.2 Direct methods and sensitivity analysis	71
		3.2.3 Parameterisation of the model	72
		$3.2.4$ Comparison between identified and analytical data: MAC and $\operatorname{COMAC}$	73
		3.2.5 Data-driven approaches	74
		3.2.6 Perspectives and remarks	74
		3.2.7 Stochastic model updating	75
	3.3	Examples of experimental modal analysis of masonry structures	76
		3.3.1 Experimental modal analysis in buildings	76
		3.3.2 SS. Annunziata Bell-Tower in Roccaverano	78
		3.3.3 Bell-Tower of Alba's Cathedral	82
		3.3.4 Dome of S.Gaudenzio in Novara	84
		3.3.5 Matilde's tower in San Miniato	88
4.		Analysis and monitoring of oval domes	101
	4.1	Geometry and structural peculiarities of oval domes	101
		4.1.1 Domes in historical architecture	101
		4.1.2 Oval geometry in historical architecture	105
		4.1.3 Structural monitoring of domes	107
	4.2	The oval dome of the Sanctuary of Vicoforte	113
		4.2.1 History of the building	113
		4.2.2 Geometry survey of the dome oval shape	114
		4.2.3 Structural monitoring and dynamic characterisation	117
	4.3	The oval dome of the church of Santa Caterina in Casale Monferrato	133
		4.3.1 Testing campaign	134
		4.3.2 Dynamic identification	137
		4.3.3 Model updating	139
	4.4	The oval dome of the church of Sant'Agostino in L'Aquila	141
		4.4.1 Technical history of the building	141
		4.4.2 Damages caused by the 2009 earthquake	141
		4.4.3 Dynamic analysis of the church	142
<b>5</b> .		Nonlinear and hysteretic models for masonry	151
	5.1	Constitutive models for static analysis	151
		5.1.1 Discrete models	151
		5.1.2 Continuous models	154
	5.2	Constitutive models for dynamic analysis	159
		5.2.1 Hysteretic models and operators	159
		5.2.1.1 Piecewise-linear hysteretic models	161
	5.3	Nonlinear models for multiple degrees of freedom systems: recent theories	181
		and extensions	

6.		Identification of nonlinear and hysteretic systems	193
	6.1	Identification of nonlinear and evolving systems	193
	6.2	Models and methods for the identification of nonlinear and evolving	400
		systems	196
		6.2.1 Direct Parameter Estimation	196
		6.2.2 Restoring Force Surface method (RFS)	198
		6.2.3 NARMAX modelling	199
		6.2.4 Reverse Path method and Conditioned Reverse Path method	201
		6.2.5 Nonlinear identification through feedback and output (NIFO)	203
		6.2.6 Volterra series and higher order frequency response functions	205
		6.2.7 Neural Networks	207
	6.3	Instantaneous and on-line methods for nonlinear identification	208
		6.3.1 Hilbert transform	210
		6.3.2 Instantaneous identification with time-frequency estimators	213
		6.3.2.1 Polynomial identification in the time-frequency domain	214
		6.3.2.2 Instantaneous identification of a polynomial form	219
		6.3.2.3 Parametric identification in the time-frequency domain	227
		6.3.3 Kalman filter and its application to nonlinear systems	233
		6.3.3.1 The Extended Kalman Filter (EKF)	234
		6.3.3.2 The Unscented Kalman Filter (UKF)	235
		6.3.3.3 The Iterated Unscented Kalman Filter (UKF)	240
7.		Experimental identification of non-linear and hysteretic models	
		for masonry structures	
		for masoning structures	251
	7.1	Scaled model of a masonry twin-arch bridge	$\frac{251}{251}$
	7.1		
	7.1	Scaled model of a masonry twin-arch bridge	251
	7.1	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests	$251 \\ 253$
	7.1 7.2	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models	$251 \\ 253 \\ 254$
		Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests	251 253 254 254
		Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests	251 253 254 254 255
		Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program	251 253 254 254 255 255
		Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers	251 253 254 254 255 255 257
		Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges	251 253 254 254 255 255 257 258
		Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage	251 253 254 254 255 255 257 258 258
	7.2	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign	251 253 254 254 255 255 257 258 258 259
	7.2	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign 7.3.1 Data analysis and assimilation	251 253 254 254 255 255 257 258 258 259 259
	7.2	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign 7.3.1 Data analysis and assimilation 7.3.1.1 Modal parameters and symptoms evolution	251 253 254 254 255 255 257 258 258 259 259
	7.2 7.3	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign 7.3.1 Data analysis and assimilation 7.3.1.1 Modal parameters and symptoms evolution 7.3.2 Study of the transient after the application of settlements	251 253 254 254 255 257 258 258 259 259 259
	7.2 7.3	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign 7.3.1 Data analysis and assimilation 7.3.1.1 Modal parameters and symptoms evolution 7.3.2 Study of the transient after the application of settlements Dynamic monitoring of the parameters at different damage levels	251 253 254 254 255 255 257 258 258 259 259 259 261
	7.2 7.3	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign 7.3.1 Data analysis and assimilation 7.3.1.1 Modal parameters and symptoms evolution 7.3.2 Study of the transient after the application of settlements Dynamic monitoring of the parameters at different damage levels	251 253 254 254 255 257 258 258 259 259 259 261 262
	7.2 7.3	Scaled model of a masonry twin-arch bridge 7.1.1 Material characterisation tests 7.1.2 Flume tests 7.1.3 Numerical models Dynamic experimental tests 7.2.1 Experimental test program 7.2.2 Experimental setups 7.2.3 Accelerometers 7.2.4 Strain gauges 7.2.5 Visually detectable damage Identification campaign 7.3.1 Data analysis and assimilation 7.3.1.1 Modal parameters and symptoms evolution 7.3.2 Study of the transient after the application of settlements Dynamic monitoring of the parameters at different damage levels 7.4.1 Non-linear identification in principal coordinates	251 253 254 254 255 257 258 258 259 259 259 261 262