

International Society for Rock Mechanics

## ISRM ISRM Book Series

## **Rock Dynamics**

Ömer Aydan



3

## Table of contents

	Abo	out the a	uthor	xi
	Ack	nowledg	gements	xiii
L	Intr	oduct	ion	I
	_		5.4.2 InSAR methods a second second second second	
2			ntal equations, constitutive laws and	
			methods	5
	2.1		mental equations	5
	2.2		itutive laws for rocks	6
			Linear constitutive laws	6
		2.2.2	Non-linear behaviour (elasto-plasticity and	-
	2.3	Const	elasto-visco-plasticity)	7 13
	2.3		itutive modeling of discontinuities	
	2.4		cterization of and constitutive modeling of rock mass rical methods	17
	2.5	Nume	rical methods	19
3	Tes	ts on d	lynamic responses of rocks and rock masses	25
	3.1		nic uniaxial compression, Brazilian, triaxial (Hopkinson bar)	2.0
		test	and the second sec	25
		3.1.1	Dynamic uniaxial compression test	27
		3.1.2	Dynamic tensile strength test (Brazilian, Notch, Slit)	27
		3.1.3	Dynamic triaxial compression test	29
		3.1.4	Rate dependency of deformation and strength	
			characteristics of rocks	30
	3.2	Cyclic	uniaxial compression, triaxial compression and shear tests	30
		3.2.1	Cyclic uniaxial compression test	31
		3.2.2	Cyclic tensile (Brazilian) test	32
		3.2.3	Cyclic triaxial compression test	33
			Cyclic shearing tests	34
		3.2.5	Dynamic shearing tests	34
	3.3	Conclu		42
		1015		
4			ameter responses and strong motions induced by	
			of geomaterials and slippage of discontinuities	
			ng model tests	45
	4.1		parameter responses and strong motions induced by	
		tractur	ring of rocks	45

vi T	<b>Fab</b>	le of	contents

	4.2	Strong motions induced in stick-slip tests	53					
	4.3	Strong motions induced in successip tests Strong motions induced in model faulting experiments	59					
	4.5	strong motions induced in model faulting experiments	39					
5	Gro	und motions due to earthquakes and estimation						
		procedures						
	5.1	Characteristics of earthquake faults	63					
	5.2	Observations on strong motions and permanent deformations	65					
		5.2.1 Observations on maximum ground accelerations	65					
		5.2.2 Permanent ground deformation	67					
	5.3	Strong motion estimations	69					
		5.3.1 Empirical approach	69					
		5.3.2 Green-function based empirical wave form estimation	73					
		5.3.3 Numerical approaches	74					
	5.4	Estimation of permanent surface deformation	76					
		5.4.1 Observational surface deformation by GPS and ground						
		surveying	79					
		5.4.2 InSAR method	79					
		5.4.3 EPS method	82					
		5.4.4 Okada's method	84					
		5.4.5 Numerical methods	86					
6	Dyn	amic responses and stability of rock foundations	87					
	6.1	Model experiments on foundations	87					
	6.2	Observations of damage to foundations by earthquakes	88					
		6.2.1 Roadways and railways	89					
		6.2.2 Bridges and viaducts	89					
		6.2.3 Dams	96					
		6.2.4 Power transmission lines	96					
		6.2.5 Tubular structures	98					
	6.3	Analytical and numerical studies on rock foundations	100					
		6.3.1 Simplified techniques	100					
		6.3.2 Pseudo-dynamic techniques	104					
		6.3.3 Pure dynamic techniques	106					
7		amic responses and stability of underground						
		avations in rock	109					
	7.1	Ground motions in underground structures	109					
	7.2	Model experiments on shallow underground openings	110					
	7.3	Tunnels	111					
	7.4	Observations on abandoned mines and quarries	115					
	7.5	Underground powerhouses	127					
	7.6	Empirical approaches	127					
	7.7	Limiting equilibrium methods	132					
		7.7.1 Shallow underground openings in discontinuous media	132					
		7.7.2 Shallow room and pillar mines and shallow karstic caves	132					
	7.8	Numerical methods	136					
0	Dur	amic reconnects and stability of real classes	147					
8	8.1	amic responses and stability of rock slopes Model tests	<b>147</b> 147					
	0.1	NIOUCI (CS15	14/					

Table	of	contents	vii
1 abie	<b>U</b> 1	concertes	

8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2.	<ul> <li>1999 Chi-Chi earthquake</li> <li>2004 Chuetsu earthquake</li> <li>2005 Kashmir earthquake</li> <li>2008 Wenchuan earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2010 and 2011 New Zealand earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2004 Chuetsu east Japan earthquake</li> <li>2011 Great east Japan earthquake</li> <li>2011 Discrete Element Method (DEM)</li> <li>2 Displacement Discontinuity Analyses (DDA)</li> <li>3 Discrete Finite Element Method (DFEM)</li> <li>anations of post failure motions of slopes</li> </ul>	157 159 169 163 164 167 168 168 169 170 171 171 171 174 174 177 179 179 182 <b>187</b>
8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2.	<ul> <li>1995 Dinar earthquake wedge failures</li> <li>1999 Chi-Chi earthquake</li> <li>2004 Chuetsu earthquake</li> <li>2005 Kashmir earthquake</li> <li>2008 Wenchuan earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2010 and 2011 New Zealand earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2004 Chuetsu east Japan earthquake</li> <li>M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>M9.0 2011 Great east Japan earthquake</li> <li>Mirical approaches for dynamic slope stability assessment</li> <li>Angenetical methods</li> <li>Discrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM)</li> <li>nations of post failure motions of slopes</li> </ul>	159 159 162 163 164 167 168 169 170 171 171 171 171 174 177 179 179 182
8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2.	<ul> <li>1999 Chi-Chi earthquake</li> <li>2004 Chuetsu earthquake</li> <li>2005 Kashmir earthquake</li> <li>2008 Wenchuan earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2010 and 2011 New Zealand earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2004 Chuetsu east Japan earthquake</li> <li>2011 Great east Japan earthquake</li> <li>2011 Discrete Element Method (DEM)</li> <li>2 Displacement Discontinuity Analyses (DDA)</li> <li>3 Discrete Finite Element Method (DFEM)</li> <li>anations of post failure motions of slopes</li> </ul>	159 162 163 164 167 168 169 170 171 171 171 174 177 179 179 182 <b>187</b>
8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.2.	<ul> <li>2004 Chuetsu earthquake</li> <li>2005 Kashmir earthquake</li> <li>2008 Wenchuan earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>2010 and 2011 New Zealand earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2009 Aceh (Off-Sumatra) earthquake</li> <li>M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>M9.0 2011 Great east Japan earthquake</li> <li>irical approaches for dynamic slope stability assessment</li> <li>iting equilibrium approaches</li> <li>merical methods</li> <li>Discrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM)</li> <li>nations of post failure motions of slopes</li> </ul>	162 163 164 167 168 169 170 171 171 171 174 174 177 179 179 182
8.2. 8.2. 8.2. 8.2. 8.2. 8.2. 8.3 Effe 8.3. 8.3 Effe 8.3. 8.4 Emp 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>4 2005 Kashmir earthquake</li> <li>5 2008 Wenchuan earthquake</li> <li>6 2008 Iwate-Miyagi intraplate earthquake</li> <li>7 Taşcılar wedge failure due to the 2007 Çameli earthquake</li> <li>8 2010 and 2011 New Zealand earthquakes</li> <li>9 2009 Padang-Pariaman earthquake</li> <li>10 2016 Kumamoto earthquakes</li> <li>10 2011 Great east Japan earthquake</li> <li>11 M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>12 M9.0 2011 Great east Japan earthquake</li> <li>13 irical approaches for dynamic slope stability assessment</li> <li>14 iting equilibrium approaches</li> <li>14 methods</li> <li>15 Discrete Element Method (DEM)</li> <li>2 Displacement Discontinuity Analyses (DDA)</li> <li>3 Discrete Finite Element Method (DFEM)</li> <li>15 mations of post failure motions of slopes</li> </ul>	163 164 167 168 169 170 171 171 171 174 174 177 179 179 182 <b>187</b>
8.2. 8.2. 8.2. 8.2. 8.2. 8.3 Effe 8.3. 8.3 Effe 8.3. 8.4 Emp 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>5 2008 Wenchuan earthquake</li> <li>6 2008 Iwate-Miyagi intraplate earthquake</li> <li>7 Taşcılar wedge failure due to the 2007 Çameli earthquake</li> <li>8 2010 and 2011 New Zealand earthquakes</li> <li>9 2009 Padang-Pariaman earthquake</li> <li>10 2016 Kumamoto earthquakes</li> <li>10 2011 Great east Japan earthquake</li> <li>11 Discrete Element Method (DEM)</li> <li>21 Displacement Discontinuity Analyses (DDA)</li> <li>32 Discrete Finite Element Method (DFEM)</li> <li>11 mations of post failure motions of slopes</li> </ul>	164 167 168 169 170 171 171 171 174 174 177 179 179 182 <b>187</b>
8.2. 8.2. 8.2. 8.2. 8.3 Effe 8.3. 8.3 Effe 8.3. 8.4 Emp 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>2008 Iwate-Miyagi intraplate earthquake</li> <li>Taşcılar wedge failure due to the 2007 Çameli earthquake</li> <li>2010 and 2011 New Zealand earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2017 Great east Japan earthquake</li> <li>2010 2011 Great east Japan earthquake</li></ul>	167 168 168 169 170 171 171 171 174 174 177 179 179 182 187
8.2. 8.2. 8.2. 8.3 Effe 8.3. 8.3 Effe 8.3. 8.4 Emj 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>7 Taşcılar wedge failure due to the 2007 Çameli earthquake</li> <li>8 2010 and 2011 New Zealand earthquakes</li> <li>9 2009 Padang-Pariaman earthquake</li> <li>10 2016 Kumamoto earthquakes</li> <li>11 M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>21 M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>22 M9.0 2011 Great east Japan earthquake</li> <li>23 pircet east Japan earthquake</li> <li>24 M9.0 2011 Great east Japan earthquake</li> <li>25 merical approaches for dynamic slope stability assessment</li> <li>26 ting equilibrium approaches</li> <li>27 merical methods</li> <li>20 Displacement Method (DEM)</li> <li>20 Displacement Discontinuity Analyses (DDA)</li> <li>3 Discrete Finite Element Method (DFEM)</li> <li>27 mations of post failure motions of slopes</li> <li>28 responses and stability of historical structures</li> <li>29 ments</li> <li>20 ervations</li> </ul>	168 168 169 170 171 171 171 174 174 177 179 179 182 <b>187</b>
8.2. 8.2. 8.3 Effe 8.3. 8.4 Emj 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>2010 and 2011 New Zealand earthquakes</li> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2017 Great east Japan earthquake</li> <li>2010 2011 Great east Japan e</li></ul>	168 169 170 171 171 171 174 174 177 179 179 182 <b>187</b>
8.2. 8.3 Effe 8.3. 8.4 Emp 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>2009 Padang-Pariaman earthquake</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2016 Kumamoto earthquakes</li> <li>2017 Great east Japan earthquake</li> <li>2011 Great east Japan earthquake</li> <li>2010 Japan east Japan earthquake</li> <li>2010 Japan east Japa</li></ul>	169 170 171 171 171 174 174 177 179 179 182 187
8.2. 8.3 Effe 8.3. 8.3. 8.4 Emp 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>10 2016 Kumamoto earthquakes</li> <li>cts of tsunamis on rock slopes</li> <li>1 M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>2 M9.0 2011 Great east Japan earthquake</li> <li>cirical approaches for dynamic slope stability assessment</li> <li>iting equilibrium approaches</li> <li>merical methods</li> <li>1 Discrete Element Method (DEM)</li> <li>2 Displacement Discontinuity Analyses (DDA)</li> <li>3 Discrete Finite Element Method (DFEM)</li> <li>mations of post failure motions of slopes</li> <li>c responses and stability of historical structures</li> <li>ments</li> </ul>	170 171 171 174 174 174 177 179 179 182 182
<ul> <li>8.3 Effe</li> <li>8.3.</li> <li>8.4 Emp</li> <li>8.5 Lim</li> <li>8.6 Nun</li> <li>8.6 8.6.</li> <li>8.6</li> <li>8.7 Esti</li> <li>Dynamiand mon</li> <li>9.1 Obs</li> </ul>	<ul> <li>cts of tsunamis on rock slopes</li> <li>M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>M9.0 2011 Great east Japan earthquake</li> <li>birical approaches for dynamic slope stability assessment</li> <li>birical methods</li> <li>Discrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM)</li> <li>nations of post failure motions of slopes</li> </ul>	171 171 174 174 174 177 177 179 179 182 182
8.3. 8.4 Emj 8.5 Lim 8.6 Nun 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ol> <li>M9.3 2004 Aceh (Off-Sumatra) earthquake</li> <li>M9.0 2011 Great east Japan earthquake</li> <li>irical approaches for dynamic slope stability assessment</li> <li>iting equilibrium approaches</li> <li>merical methods</li> <li>Discrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM)</li> <li>nations of post failure motions of slopes</li> <li>responses and stability of historical structures</li> <li>ments</li> </ol>	171 174 174 174 177 177 179 179 182 182
8.4 Emp 8.5 Lim 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>M9.0 2011 Great east Japan earthquake</li> <li>irical approaches for dynamic slope stability assessment</li> <li>iting equilibrium approaches</li> <li>merical methods</li> <li>Discrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM)</li> <li>mations of post failure motions of slopes</li> <li>responses and stability of historical structures</li> <li>ments</li> <li>ervations</li> </ul>	171 174 174 177 177 179 179 182 182
8.4 Emp 8.5 Lim 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti <b>Dynami</b> and mon 9.1 Obs	<ul> <li>approaches for dynamic slope stability assessment</li> <li>approaches</li> <li>approaches</li> <li>approaches</li> <li>biscrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM)</li> <li>a Discrete Finite Element Method (DFEM)</li> <li>anations of post failure motions of slopes</li> <li>c responses and stability of historical structures</li> <li>buments</li> <li>ervations</li> </ul>	174 174 177 177 179 179 182 182
8.5 Lim 8.6 Nun 8.6. 8.6. 8.6. 8.7 Esti Dynami and mon 9.1 Obs	<ul> <li>atting equilibrium approaches</li> <li>anerical methods</li> <li>a Discrete Element Method (DEM)</li> <li>bisplacement Discontinuity Analyses (DDA)</li> <li>biscrete Finite Element Method (DFEM)</li> <li>anations of post failure motions of slopes</li> <li>c responses and stability of historical structures</li> <li>buments</li> <li>ervations</li> </ul>	174 177 177 179 179 182
<ul> <li>8.6 Nun 8.6. 8.6.</li> <li>8.7 Esti</li> <li>Dynami and mon 9.1 Obs</li> </ul>	nerical methods 1 Discrete Element Method (DEM) 2 Displacement Discontinuity Analyses (DDA) 3 Discrete Finite Element Method (DFEM) nations of post failure motions of slopes <b>c responses and stability of historical structures</b> <b>buments</b> ervations	177 177 179 179 182
8.6. 8.6. 8.7 Esti Dynami and mou 9.1 Obs	<ol> <li>Discrete Element Method (DEM)</li> <li>Displacement Discontinuity Analyses (DDA)</li> <li>Discrete Finite Element Method (DFEM) nations of post failure motions of slopes</li> <li>responses and stability of historical structures numents</li> </ol>	177 179 179 182
8.6. 8.7 Esti Dynami and mou 9.1 Obs	<ul> <li>2 Displacement Discontinuity Analyses (DDA)</li> <li>3 Discrete Finite Element Method (DFEM)</li> <li>mations of post failure motions of slopes</li> <li>c responses and stability of historical structures</li> <li>numents</li> <li>ervations</li> </ul>	179 179 182 <b>187</b>
8.7 Esti Dynami and mo 9.1 Obs	<ul> <li>B Discrete Finite Element Method (DFEM)</li> <li>mations of post failure motions of slopes</li> <li>responses and stability of historical structures</li> <li>numents</li> <li>ervations</li> </ul>	179 182 187
8.7 Esti Dynami and mo 9.1 Obs	nations of post failure motions of slopes <b>responses and stability of historical structures</b> <b>numents</b> ervations	182 187
Dynami and mor 9.1 Obs	<b>responses and stability of historical structures</b> <b>numents</b> ervations	187
		187
9.1. 9.1.		187
9.1.	1 51	196
9.1.		202
9.1.	1 071	205
9.1.		207 208
9.1.		208
9.1.	1 0	208
	lel experiments on masonry structures	210
9.2		210
9.2.	1	211
9.2.		212
9.2.	· · · · · · · · · · · · · · · · · · ·	213
9.2.	1	213
9.2.		217
	it equilibrium approaches	219
9.3.		220
9.3.	0	225
9.3.		227
	nerical methods	230
9.4.		230
9.4.		233

9

## viii Table of contents

10		amics of loading and excavation in rocks	239
	10.1	Dynamics of loading	239
		10.1.1 Uniaxial tensile loading experiment	239
		10.1.2 Uniaxial compression loading	240
	10.2	Dynamics of excavations	245
		10.2.1 Loading of inclined semi-infinite slabs	245
		10.2.2 Excavation of circular underground openings	251
П		sting	257
	11.1	Background	257
	11.2	Blasting agents	257
		11.2.1 Dynamite	257
		11.2.2 Ammonium Nitrate/Fuel Oil (ANFO)	258
		11.2.3 Blasting pressure for rock breakage	258
	11.3	Measurement of blasting vibrations in open-pit mines and quarries	258
		11.3.1 Orhaneli open-pit lignite mine	259
		11.3.2 Demirbilek open-pit lignite mine	262
		11.3.3 ELI Işıkdere open-pit mine	264
		11.3.4 Motobu quarry	269
	11.4	Measurements at underground openings	270
		11.4.1 Kuriko tunnel	270
		11.4.2 Taru-Toge tunnel	273
		11.4.3 Zonguldak tunnels	277
	11.5	Multi-parameter monitoring during blasting	280
	11.6	The positive and negative effects of blasting	284
		11.6.1 In-situ stress inference	285
		11.6.2 Rock mass property estimation from wave velocity using blasting induced waves	288
		11.6.3 Instability problems	288
		11.6.4 Vibration effects on buildings	200
		11.6.5 Air pressure due to blasting	292
		11.6.6 Flyrock distance	292
12	Dyna	amics of rockburst and possible countermeasures	301
	12.1	Mechanics of rockbursts	301
	12.2	Stress changes in the vicinity of tunnel face	304
		12.2.1 Static stress changes	304
		12.2.2 Dynamic stress changes	307
	12.3	Examples of rockbursts	307
		12.3.1 Major rockburst examples in civil engineering	307
		12.3.2 Major rockburst examples in mining	317
	12.4	Laboratory tests on rockburst phenomenon	318
		12.4.1 Sandstone block from Shizuoka Third Tunnel	318
		12.4.2 Sandstone sample from Tarutoge Tunnel	321
	12.5	Prediction of rockburst potential	323
		12.5.1 Energy method	323

4

	Table of contents	ix
1.0	2	24

		12.5.2	Extensional strain method	324
		12.5.3	Elasto-plastic method	324
		12.5.4	Empirical methods	324
		12.5.5	A unified method by Aydan <i>et al.</i> (2001, 2004)	324
		12.5.6	Application of rockburst prediction methods to tunnels	524
		12.3.0		325
		12.5.7	under hydrostatic stress condition	525
		12.3./	Application of rockburst prediction methods to tunnels	220
	12 (	N	under non-hydrostatic stress condition	330
	12.6		ring of rockburst	334
		12.6.1	Multi-parameter monitoring results during July 20–26,	
		10.10	2014	337
		12.6.2	Multi-parameter monitoring results during September	
			20–26, 2014	338
		12.6.3	Acoustic emission responses at the tunnel face	340
		12.6.4	Infrared monitoring system	340
	12.7		rmeasures against rockburst	341
		12.7.1	Allowing rockburst to occur	341
		12.7.2	De-stressing or pre-conditioning	342
		12.7.3	Flexible and deformable support	343
	12.8	Conclus	sions	344
13	Dun		f needshelts and needs an shows and their	
13			f rockbolts and rock anchors and their	245
			ctive testing	345
	13.1		e-induced vibrations in an underground power house	345
	13.2		ic behaviour of rockbolts and rock anchors subjected	247
		to shaki		347
		13.2.1	Model tests on rock anchors restraining potentially	2.40
		1222	unstable rock-block	348
		13.2.2	Model tests on fully grouted rockbolts restraining a	
			potentially unstable rock-block against sliding	351
		13.2.3	A theoretical approach for evaluating axial forces in	
			rock anchors subjected to shaking and its applications	
			to model tests	353
		13.2.4	Application of the theoretical approach to rock anchors	
			of an underground power house subjected to	
			turbine-induced shaking	358
	13.3		structive testing for soundness evaluation	360
		13.3.1	Impact waves for non-destructive testing of rockbolts	
			and rock anchors	361
			13.3.1.1 Mechanical models	361
			13.3.1.2 Analytical solutions	362
			13.3.1.3 Finite element formulation	363
			13.3.1.4 Properties of rockbolts/rock anchors,	
			grouting material and interfaces	364
			13.3.1.5 Evaluation of corrosion of rockbolts and	Referen
			rock anchors	366
			13.3.1.6 Numerical analyses	367
			13.3.1.0 INUMERICAL analyses	507

	x	<b>Tab</b>	le of	contents
--	---	------------	-------	----------

			13.3.1.7		
				records	370
			13.3.1.8	Applications to actual measurements under	274
			12210	laboratory conditions	374
			13.3.1.9	Some applications to rockbolts and rock	270
			122110	anchors in-situ	378
			15.5.1.10	The utilization of wavelet data processing technique and some issues	380
		13.3.2	Cuided ul	trasonic wave method	381
		13.3.2		elastic sensor method	382
		13.3.4		sting technique	382
		13.3.4		Elastic behaviour	383
			13.3.4.2	Elasto-plastic behaviour of rock anchor	505
			13.3.7.2	system	384
	13.4	Estimat	ion of failur	e time of tendons	387
	13.5			on of support system	389
	13.6	Conclus		in or support system	391
	13.0	Concius	510115		371
14	Dyn	amics o	f impacts		393
	14.1			y meteorites and its environmental effects	394
	1	14.1.1		of crater formation by meteorites	394
			Effects of		397
	14.2			y projectiles in rocks	398
	14.3			ations caused by meteorites	398
	14.4		l (drop) exp		400
	1	14.4.1		lling onto dry sand layer or a mixture of	100
		1 11 11 1	,	nO and Vaseline oil	401
		14.4.2		falling onto hard-base	406
		14.4.3	-	back-hoe impact test at a bridge foundation	
		1.1.1.0	site		409
	14.5	Impact	of slope fail	ures	411
	14.6	*	*	actor penetration and its applications	413
				al modeling	413
			Solution p		415
			Examples	and a second providence of the state of the	416
	14.7			ges due to impactors	416
		14.7.1		occurrence by meteorite impacts	416
		14.7.2		nts on water-level variations due to impactor	
				water bodies	418
		14.7.3		al modeling on water-level variations due to	
				in closed water bodies and its applications	421
15	Con	clusions			425
D		and the			121
	erences				431
SUD	ject inc	iex			455