ROCK Xia-Ting Feng & John A. Hudson ENGINEERING DESIGN



Contents

	Preface Acknowledgements About the authors		
i	Intro	duction	1
	1.1	The purpose of this book	1
	1.2	The structure of the book	2
	1.3	The 'long learning curve'	2 3
	1.4	Rock engineering design, related subjects and the future	3
	1.5	Chinese rock mechanics and Chinese rock engineering	6
	1.6	Examples of rock engineering projects in China	7
	1.7	Problems remaining to be solved	10
	1.8	Chapter summaries	13
2	The	ways ahead for rock engineering design methodologies	15
	2.1	Introduction	15
	2.2	Modelling and engineering design approaches	16
	2.3	The integrated design approach	19
	2.4	Modelling approaches which utilise computer networks	22
		2.4.1 Internet/Intranet/Local Area Network (LAN)-based	
		parallel computing	22
		2.4.2 Internet-neural network analogy	22
		2.4.3 Why do we need collaborative research on the internet?	23
	2.5	The idea of a Virtual Rock Mechanics Facility (VRMF)	25
	2.6	Development of the method D, level 2, methods: 'intelligent'	
	2.7	modelling	26
	2.7	The integrated methodology for rock slope design	27
		2.7.1 Determination of slope angle using neural network	
		models	29
		2.7.2 Recognition of failure modes using an expert system	34

		2,7.3	Estimation of the stability of slopes and their safety	
			factors using integrated intelligent methods	34
		2.7.4	Comprehensive integrated intelligent system for slope	
			design	39
	2.8	Case ex	cample using the rock slope integrated design	
		method		39
	2.9		r summary	44
3	Flowe	charts fo	or rock engineering modelling and design	47
	3.1	Introdu	action and summary of earlier work	47
	3.2	The roo	ck engineering modelling and design process	58
		3.2.1	Updated rock engineering flowchart	58
		3.2.2	Steps in the rock engineering design process	59
		3.2.3	Project purpose, constraints and key features of the site,	
			rock mass and project	60
		3.2.4	Establishing the design approach strategy via the	
			modelling options	61
		3.2.5	Utilising the principles of modelling and code	
			implementation	62
		3.2.6	Establishing and verifying/validating the design	64
	3.3		the procedure in three illustrative case examples	64
		3.3.1	Illustrative Example 1: The design of a conventional	
			tunnel—Design of the Qiaotou tunnel, Yuanmo	64
			Expressway, China	04
		3.3.2	Illustrative Example 2: The design of the powerhouse	66
			cavern for the Shuibuya project, Hubei Province, China	00
		3.3.3	Illustrative Example 3: The design of an underground	79
	2.4	O1 .	radioactive waste repository in crystalline rock	83
	3.4	Chapte	er summary	43
4	Spec	ifying th	ne information required for rock mechanics modelling	
			gineering design	85
	4.1	Introd	uction	85
	4.2		ifferent types of information required by the different	
			ling methods	86
		4.2.1	Forward analysis and the eight basic modelling methods	86
		4.2.2	Back analysis and the feedback information	90
	4.3	Obtair	ning the required information and problems associated	
			ite investigation and in situ monitoring	91
		4.3.1	The site investigation	91
		4.3.2	An information theory approach	91

		4.3.3	Potential lack of communication between designer, site investigation personnel, construction personnel	
			and monitoring—and the remedy	92
		4.3.4	Recommended procedure for establishing the required	
			information	93
	4.4	Illustra	tive case examples	94
		4.4.1	Basic rock slope: potential wedge failure, Rubha Mor,	
			Loch Lomond, Scotland, UK	94
		4.4.2	High rock slope at the Longtan Hydropower project,	
			China	97
	4.5	Chapte	er summary	108
5	Techi	nical au	diting of rock mechanics modelling and rock	
	engir	eering	design	109
	5.1	Introdu		109
		5.1.1	Purpose and principles of technical auditing	109
		5.1.2	Information supporting the technical audit	109
		5.1.3	'Soft', 'semi-hard' and 'hard' technical audits and	
			the audit evaluation	110
	5.2		nstration Example 1: The procedure for technically	
			g a site investigation measurement—in situ rock stress	
		(soft au		111
		5.2.1	Background	111
		5.2.2		112
		5.2.3	Discussion and conclusions relating to Demonstration	
	5.3	Б	Example 1	115
	5.3		enstration Example 2: Technical audit of modelling for	
			ign of hydropower caverns at the Laxiwa Yellow River	446
			China (Semi-Hard Audit)	116
		5.3.1	The Laxiwa hydropower project on the Yellow River	116
		5.3.2	Integrated intelligent recognition of model parameters	121
		5.3.3	for brittle rock masses in high stress fields	121
		5.3.4	Auditing the modelling for the Laxiwa project design	164
	5.4		Conclusions from the Laxiwa case example	166
	3.4	Chapte	er summary	176
6	Case	exampl	le of the design and construction of a rock slope	179
	6.1	Introdu	action	179
	6.2		and features of large rock slopes at hydropower stations	179
	6.3		nart for the design of large rock slopes for hydropower	
		station	S	179

	6.4	The fea	tures and constraints of the plunge pool slope	183	
		6.4.1	The features and constraints of the slope	183	
		6.4.2	The features and constraints of the rock mass	192	
	6.5		lesign of the plunge pool slope	195	
		6.5.1	Slope angle, height and width of bench, for the plunge		
			pool slope	195	
		6.5.2	Support design of the plunge pool slope	195	
		6.5.3	Water drainage system design for the plunge pool slope	196	
		6.5.4	The monitoring system design for the plunge pool slope	198	
		6.5.5	Safety control standard for the plunge pool slope	200	
		6.5.6	Stability analysis and failure mode recognition for the		
			plunge pool slope	204	
	6.6	Feedba	ck analysis and final design of the plunge pool slope	207	
		6.6.1	Back analysis of the deformation modulus of the plunge		
			pool slope	207	
		6.6.2	Establishment of dynamic warning system for the		
			plunge pool slope	213	
		6.6.3	Dynamic design of the excavation procedure and		
			support parameters for the plunge pool slope	226	
	6.7	Modell	ling methods and codes used for the design and stability		
			s of the plunge pool slope	232	
	6.8		er summary	232	
_	_				
7			le of the design and construction of a large	242	
	unde	rground	l hydroelectric powerhouse in a deep valley region	243	
	7.1	Introdu	uction	243	
	7.2				
	7.3				
		powerl	house	244	
		7.3.1	The features and constraints of the site	244	
		7.3.2	The features and constraints of the rock masses	252	
		7.3.3	The failure modes for large underground powerhouses	2.50	
			(cavern groups)	260	
	7.4	_	pproach used in the design and stability analysis for the	270	
			g II underground powerhouse	270	
	7.5		ling methods and computer codes used in the design and	274	
		ty analysis for the Jinping II underground powerhouse	271		
	7.6		ishment of the initial design	272	
		7.6.1	Selection of the orientation of the axis of the	272	
			underground powerhouse	272	
		7.6.2	Optimisation of the excavation procedure and bench		
			height for the underground powerhouse and transformer	~ - -	
			chamber	275	

		7.6.3	Determination of support parameters from experience	277
		7.6.4	Analysis of the deformation and failure characteristics	
			of the surrounding rock	278
		7.6.5	Optimisation of the surrounding rock support design	
			at key points	284
		7.6.6	Design of the monitoring sections and components for	
			the underground powerhouse and transformer chamber	286
		7.6.7	Safety evaluation of the rocks surrounding the large	
			cavern group	289
		7.6.8	Estimation of the entire safe factor for the underground	
			powerhouse using the over-loading method	292
	7.7		appraisal of the underground powerhouse after	
		excavat	ion of Layer II	294
		7.7.1	Prediction of the behaviour of the surrounding rock	
			during excavation of Layer III of the powerhouse and	
			Layer II of the transformer chamber	297
		7.7.2	Verification of the basic information and mechanical	
			behaviour after excavation of Stage 3	299
		7.7.3	Dynamic design of the underground powerhouse for the	
			excavation in Stage 4	332
		7 .7.4	Dynamic design for the control measures of the local	
			unstable surrounding rock induced by excavation of	
			the multi-layers	347
		7.7.5	Summary of dynamic feedback analysis and design	
			optimisation for the underground powerhouse	
			considering the entire excavation procedure	355
	7.8	Conclus	sions	364
8	Dunka	ocol She	-4-	367
0	Frott	ocoi Snec	ets	307
	8.1	Protoco	l Sheet 1: Objective and overall approach to the project	368
	8.2	Protoco	l Sheets 2: Geological setting and site investigation	369
		8.2.1	Protocol Sheet 2.1: Information on the Geological	
			Setting	370
		8.2.2	Protocol Sheet 2.2: In Situ Stress	371
		8.2.3	Protocol Sheet 2.3: Intact Rock	373
		8.2.4	Protocol Sheet 2.4: Fractures and Faults	374
		8.2.5	Protocol Sheet 2.5: Rock Mass Properties	37ϵ
		8.2.6	Protocol Sheet 2.6: Hydrogeological Properties	377
		8.2.7	Protocol Sheet 2.7: Other Special Parameters	378
	8.3		l Sheets 3: Modelling	379
		8.3.1	Protocol Sheet 3.1: Pre-existing Standard Methods	381
		8.3.2	Protocol Sheet 3.2: Precedent Type Analysis (PTA)	382
		8.3.3	Protocol Sheet 3.3: Analytical Methods	383

		8.3.4	Protocol Sheet 3.4: Rock Mass Classification	384
		8.3.5	Protocol Sheet 3.5: Basic Numerical Models	386
		8.3.6	Protocol Sheet 3.6: Database and Systems Approaches	387
		8.3.7	Protocol Sheet 3.7: Extended Numerical Models	388
		8.3.8	Protocol Sheet 3.8: Advanced Systems Approaches	390
		8.3.9	Protocol Sheet 3.9: Alternative Type(s) of Modelling	391
		8.3.10	Protocol Sheet 3.10: Use of Different Modelling	
			Methods in Combination or Sequence	392
	8.4	Protoco	l Sheets 4: Design	393
		8.4.1	Protocol Sheet 4.1: Initial Design	394
		8.4.2	Protocol Sheet 4.2: Final Design	395
	8.5	Protoco	l Sheet 5: Auditing evaluation	396
	8.6	Chapte	r summary	398
9	Illust	rative ex	cample of the Protocol Sheets use	399
•	9.1		le completion of Protocol Sheet 1	399
	9.2		le completion of Protocol Sheets 2	401
	, <u>, , , , , , , , , , , , , , , , , , </u>	9.2.1	Example completion of Protocol Sheet 2.1	403
		9.2.2	Example completion of Protocol Sheet 2.2	404
		9.2.3	Example completion of Protocol Sheet 2.3	405
		9.2.4	Example completion of Protocol Sheet 2.4	407
		9.2.5	Example completion of Protocol Sheet 2.5	409
		9.2.6	Example completion of Protocol Sheet 2.6	410
		9.2.7	Example completion of Protocol Sheet 2.7	411
	9.3		le completion of Protocol Sheets 3	412
	•	9.3.1	Example completion of Protocol Sheet 3.1	414
		9.3.2	Example completion of Protocol Sheet 3.2	415
		9.3.3	Example completion of Protocol Sheet 3.3	416
		9.3.4	Example completion of Protocol Sheet 3.4	417
		9.3.5	Example completion of Protocol Sheet 3.5	418
		9.3.6	Example completion of Protocol Sheet 3.6	420
		9.3.7	Example completion of Protocol Sheet 3.7	421
		9.3.8	Example completion of Protocol Sheet 3.8	422
		9.3.9	Example completion of Protocol Sheet 3.9	424
		9.3.10	Example completion of Protocol Sheet 3.10	425
	9.4		le completion of Protocol Sheets 4	426
		9.4.1	Example completion of Protocol Sheet 4.1	426
		9.4.2	Example completion of Protocol Sheet 4.2	427
	9.5		le completion of Protocol Sheet 5	428
	9.6	Chapte	r summary	429

) Con	cludin	g remarks	431		
ppendi	ppendix A List of all the ISRM suggested methods (in chronological order)		433		
nnendi	ppendix B The Chinese 'Basic Quality' (BQ) system				
ppendi		for rock mass classification	437		
B1		oduction			
B2		ninology and symbols	437		
DΔ	B2.1	- · · · · · · · · · · · · · · · · · · ·	437		
	B2.3	- 07	437		
В3	-	ssification parameters for the rock mass basic quality	438		
ВЭ	B3.1		438		
	D3.1	determination	438		
	В3.2	· 	438		
	B3.3		441		
	B3.4		441		
B4		sification of rock mass basic quality	442		
	B4.1		442		
	B4.2		112		
		basic quality index	442		
B5	Engi	ineering classification for a rock mass	443		
	B5.1		443		
	B5.2	Engineering rock mass classification	444		
В6	Esta	blishing the K_v and J_v indices	445		
	B6.1		445		
	B6.2	The J_{V} index	445		
B7	Preli	minary assessment of the rock stress field	446		
B8	,				
	and	discontinuities	447		
	B8.1	Rock mass parameters	4 47		
	B8.2	Discontinuity parameters	447		
В9	Cori	ected value of the rock mass basic quality index	448		
B10		d-up time for an underground rock mass	450		
B11	Ackı	nowledgements	450		
Refer	ences	and bibliography	451		
-	ct ind	- · ·	459		
	ur plai		461		