Slope Stability Analysis and Stabilization

New Methods and Insight Second Edition



Contents

	Prefa	ice		xi
1	Introduction			1
	1.1	Overview 1		
	1.2	Backg	round 2	
	1.3	Closed-form solutions 3		
	1.4	Engineering judgement 4		
	1.5	Groun	ed model 5	
	1.6	Status quo 5		
	1.7	Ground investigation 8		
	1.8	Design parameters 9		
	1.9			
	1.10	Design methodology 9		
	1.11	Case h	istories 10	
2	Basic	slope	stability analysis methods	17
	2.1	Introduction 17		
		2.1.1	Types of stability analyses 17	
		2.1.2	Definition of the factor of safety 17	
	2.2	Slope stability analysis: limit equilibrium method 20		
		2.2.1	Limit equilibrium formulation of	
			slope stability analysis methods 23	
			2.2.1.1 Force equilibrium 25	
			2.2.1.2 Moment equilibrium equation 27	
		2.2.2	Interslice force function 28	
		2.2.3	Reduction to various methods and discussion 30	
		2.2.4	Solution of non-linear factor of safety equation 35	
		2.2.5	Examples of slope stability analysis 38	

2.3	Miscellaneous considerations on slope stability analysis 41			
	2.3.1	Acceptability of the failure surfaces		
		and results of the analysis 41		
	2.3.2	Tension crack 42		
	2.3.3	Earthquake 42		
	2.3.4	Water 43		
	2.3.5	Saturated density of soil 45		
	2.3.6	Moment point 45		
	2.3.7	Use of soil nail/reinforcement 46		
		2.3.7.1 Advantages of soil nailing 46		
	2.3.8	Failure to converge 50		
	2.3.9	Location of the critical failure surface 51		
	2.3.10	Three-dimensional analysis 51		
2.4				
	2.4.1	Lower bound approach 53		
	2.4.2	Upper bound approach 54		
2.5	Rigid e	l element method 58		
	2.5.1	Displacements of the rigid elements 59		
	2.5.2	Contact stresses between rigid elements 61		
	2.5.3	Principle of virtual work 62		
	2.5.4	Governing equations 64		
	2.5.5	General procedure of REM computation 65		
2.6	Relation between the REM and the slice-based approach 6			
2.7	Uses of	es of design figures and tables for simple problems 70		
2.8 Finite element method 72		element method 72		
2.9	Distino	t element method 78		
	2.9.1	Force displacement law and the law of motion 82		
	2.9.2			
	2.9.3	Case studies for slope stability analysis using PFC 84		
	2.9.4	Three-dimensional model and distinct		
		element studies of a slope under a patch load 89		
		2.9.4.1 Laboratory test on a model slope 90		
		2942 Three-dimensional distinct numerical		

3 Location of critical failure surface, convergence and advanced formulations

3.1 Difficulties in locating the critical failure surface 99

modelling of slope under local surcharge 93

99

3.2 Generation of trial failure surface 103

3.3	Global optimization methods 108				
	3.3.1	Simulated annealing algorithm 108			
	3.3.2	Genetic algorithms 109			
	3.3.3	Particle swarm optimization algorithm 112			
	3.3.4	Simple harmony search algorithm 114			
	3.3.5	Modified harmony search algorithm 118			
	3.3.6	Tabu search algorithm 120			
	3.3.7	Ant colony algorithm 121			
	3.3.8	Hybrid optimization algorithm 124			
3.4	Verifica	ation of the global minimization algorithms 128			
3.5	Presence of Dirac function 131 Numerical studies of the efficiency and				
3.6	Numer	ical studies of the efficiency and			
	effectiv	eness of various optimization algorithms 132			
3.7	Sensitivity of global optimization parameters in the				
	perform	nance of the global optimization methods 140			
3.8	Convexity of critical failure surface 145				
3.9	Lateral earth pressure determination				
	from slope stability analysis 146				
3.10	Convergence problem due to iterative solution of FOS 148				
	3.10.1	Parametric study of convergence 153			
	3.10.2	Combined impact of optimization			
		and double QR analysis 158			
	3.10.3	Reasons for failure to converge 159			
3.11	Import	ance of the methods of analysis 162			
3.12	Solutio	n of the inter-slice force function			
	and fundamental investigation into				
	the problem of convergence 163				
	3.12.1	Determination of bounds on FOS and $f(x)$ 165			
	3.12.2	Numerical studies and comparisons			
		with classical methods of analysis 168			
	3.12.3	Study of convergence by varying $f(x)$ 171			
	3.12.4	Validation of maximum extremum principle 175			
3.13	Variable FOS formulation in LEM 177				
		Basic formulation for variable FOS formulation 178			
	3.13.2	Analysis of variable FOS approach 184			
	3.13.3	Discussion on variable FOS approach 185			
3.14	Use of	internal/external variables in slope			
	stabilit	y analysis and relation of slope stability			
	problem	m to other geotechnical problems 187			

		3.14.2	Inter-slice force function f(x) and thrust line for horizontal slope problem 190			
		3 14 3	Boundary forces in LEM 202			
		3.14.4				
		J.1 1. 1	extremum from limit equilibrium analysis 203			
4			nt methods for slope stability analysis and s with limit equilibrium analysis	209		
	4.1	Comba	risons between SRM and LEM 209			
	4.2	Stability analysis for a simple and homogeneous soil slope using LEM and SRM 210				
	4.3	Stability analysis of a slope with a soft band 217				
	4.4					
	4.5	Effect of water on slope stability analysis 227				
	4.6					
		4.6.1	Distribution of the nail tension force			
			and the critical slip surface by SRM 235			
	4.7	Stabilization of slope with piles using SRM 239				
	4.8	.8 Discussion and conclusion 251				
5	Thre	e-dime	nsional slope stability analysis	255		
	5.1	Limitar	tions of the classical three-			
		dimensional limit equilibrium methods 255				
	5.2					
		analysis in Bishop, Janbu and Morgenstern-				
		Price methods by Cheng and Yip 259				
		5.2.1	Basic formulation with consideration of			
			sliding direction 259			
		5.2.2	Reduction to 3D Bishop and Janbu			
			simplified methods 267			
		5.2.3	Numerical implementation of			
			Bishop, Janbu and MP methods 269			
		5.2.4	Numerical examples and verification 270			
		5.2.5	Comparison between Huang's method and the			
			present methods for transverse earthquake load	274		
		5.2.6	Relation of proposed 3D slope stability			
			method with classical 3D methods 278			
		5.2.7	Problem of cross-section force/moment equilibrium for MP method 278			
			and the second s			

3.14.1 Basic methods in formulation 187

333

	5.2.8	Discussi	on on λ_{xy} for MP analysis 284		
	5.2.9		on on 3D limit equilibrium		
		stability	formulation 284		
5.3	Three-	e-dimensional limit analysis 286			
	5.3.1		mensional bearing capacity		
		problem with an inclined slope 290			
		5.3.1.1	Failure mechanism of the		
			patched load acting on the top		
			surface of a slope $(D=0 m)$ 291		
		5.3.1.2	Work done rate produced		
			along load length L 291		
		5.3.1.3	Work done rate produced at the two		
			end-failure zones of the footing 295		
		5.3.1.4	Determining the value		
			of the safety factor 299		
		5.3.1.5	Failure mechanism of the patched load		
			acting at an embedded depth from		
			the top surface of slope $(D>0 m)$ 300		
		5.3.1.6	Work done rate produced		
			along footing length L 300		
		5.3.1.7	Work done rate produced at two		
			end failures of the buried load 302		
		5.3.1.8	Comparison of Cheng's method		
			with other analytical solutions 304		
5.4	, 0				
) failure surface 309		
			imensional NURBS surfaces 310		
	5.4.2 Spherical and ellipsoidal surface 313				
			of sliding surfaces 314		
2 2	5.4.4		ation analysis of NURBS surface 316		
5.5	Case studies in 3D limit equilibrium				
= 121	global optimization analysis 316				
5.6	[A. 1942] [A. 19				
5.7	I hree-	dimension	ial SRM analysis 325		
	500	85			
Imp	lementa	ition			

6

6.2

6.4

6.1 Introduction 333 FRP nail 335

Construction difficulties 340

6.3 Drainage 339

7	Routine assessment of feature and design of landslip preventive measures					
	7.1	Introduction 341				
	7.2					
	7.3					
	7.4					
	7.5	- B. (1) 전 전 전 전 전 전 전 전 전 전 전 전 전 전 전 전 전 전 전				
	7.6	Laboratory testing 345				
	7.7					
	7.8	1000 May 12 - 12 May 12 May 14 May 14 May 15 May 15 May 15 May 16 May				
	7.9 Groundwater regime 346 7.10 Stability assessment of the existing feature 347					
	Design of landslip preventive works 348					
		7.11.1 Design options for masonry retaining walls 348				
	7.11.2 Design options for fill slopes 349					
		7.11.3 Design options for cut slopes 351				
	7.12 Soil nailing 351					
	7.13 Soil nailing in loose fill 354					
7.14 Surface and sub-soil drainage 355						
7.15 Surface erosion control and landscaping 356						
	7.16 Site supervision during implementation 357					
	7.17	Corrosiveness assessment 357				
	7.18	Precautionary measures and other considerations 358				
	7.19	Long-term maintenance 358				
8		Numerical implementation of slope stability analysis methods 359				
	analysis methods					
	8.1	Numerical procedures for simplified				
	0.1	limit equilibrium methods 359				
	8.2					
		limit equilibrium methods 368				
		8.2.1 Spencer and Morgenstern-Price method 368				
		8.2.2 Janbu rigorous method 372				
		8.2.3 Sarma method 375				
	8.3	Three-dimensional analysis 381				
		1 mee-aimensionai anaiysis 301				
	Арре		387			
	10 10 10 10 10 10 10 10 10 10 10 10 10 1		399			
	Index					