



Earth Pressure and Earth-retaining Structures

Second Edition

by

C.R.I. CLAYTON
Professor in Geotechnical Engineering
University of Surrey

J. MILITITSKY
Professor of Civil Engineering
UFRGS
Porto Alegre
Brazil

and

R.I. WOODS
Lecturer in Civil Engineering
University of Surrey



BLACKIE ACADEMIC & PROFESSIONAL

An Imprint of Chapman & Hall

London · Weinheim · New York · Tokyo · Melbourne · Madras

Contents

PART I: MECHANISMS

1	Soil behaviour	3
1.1	Introduction	3
1.2	Soil strength and compressibility—the importance of effective stress	4
1.3	Consequences for engineering design	12
2	Wall placement, construction and movement	13
3	The development of earth-pressure theory	21
3.1	Classical solutions and effective stress	37
4	Graphical techniques	40
4.1	Graphical techniques for the active case	44
4.2	Determination of line of thrust for complex geometries	48
4.3	Graphical techniques for the passive case	49
5	Lateral pressures due to external loads	56
5.1	Elastic solutions for horizontal stress increase	58
5.2	Calculation based on vertical elastic stress distributions	60
5.3	Empirical approaches	60
6	Compaction pressures	63
6.1	Compaction of granular fill	63
6.2	Compaction pressures from cohesive soil	71
7	From theory to practice	81
7.1	Inadequacies of classical solutions	81
7.2	Strain softening and progressive failure	85
7.3	Acceptable wall deformations	87
7.4	Wall flexibility	88
7.5	<i>In-situ</i> earth pressures and installation effects	91

PART II: DESIGN

8	Introduction to design	99
8.1	Limit states for earth-retaining structures	99
8.2	Factors to consider in choosing a retaining structure	101

8.3	Types of structure	102
8.3.1	Gravity and reinforced concrete cantilever walls	103
8.3.2	Sheet-pile walls	108
8.3.3	Diaphragm and bored-pile walls	114
8.3.4	Multiple-anchored and braced walls	120
8.3.5	Soil reinforcement and anchoring	123
8.4	Selection and acquisition of soil parameters	132
8.4.1	Introduction	132
8.4.2	Selecting relevant soil parameters for design	133
8.4.3	Methods of investigation	134
8.4.4	Required soil parameters	139
8.5	Types of analysis	148
8.5.1	Limit equilibrium analysis	148
8.5.2	Computer analysis	153
9	Backfilled walls	155
9.1	External stability	156
9.1.1	Preliminary estimates of backfill forces	156
9.1.2	Earth-pressure calculations	159
9.1.3	Overturning	166
9.1.4	Sliding	171
9.1.5	Bearing capacity	175
9.1.6	Overall stability	180
9.1.7	Settlement and tilt	181
9.2	Internal stability	181
9.2.1	Masonry, gravity block and gabion walls	181
9.2.2	Crib walls	183
9.2.3	Reinforced-concrete cantilever walls	185
9.2.4	Design of bridge abutments for earth pressure	187
10	Sheet-pile walls	191
10.1	Groundwater conditions	191
10.2	Definitions of factor of safety	194
10.3	Cantilever sheet-pile walls	199
10.3.1	Preliminary design	199
10.3.2	Determination of depth of embedment and maximum bending moment	202
10.4	Design of anchored sheet-pile walls	212
10.4.1	Free earth support method	213
10.4.2	Fixed earth support method	225
10.4.3	Design of anchor systems	238
11	Excavation support	243
11.1	Influence of construction methods	245
11.2	Methods of supporting excavations	246
11.3	Required analysis	249
11.3.1	Groundwater considerations	249
11.3.2	Stresses applied to the wall	251
11.3.3	Base stability	253
11.3.4	Bending moment and shear force distribution	258
11.3.5	Strut, prop and anchor loads	260
11.3.6	Displacements around and below excavations	263
11.3.7	Overall stability	272
11.4	Numerical modelling of excavation support systems	272

11.4.1	Issues in modelling	274
11.4.2	Analysis with Winkler spring models	276
11.4.3	Finite element analysis	278
11.4.4	Finite difference analysis	282
11.4.5	Boundary element analysis	283
11.4.6	Some available computer packages	285

12 Soil reinforcement and anchoring 289

12.1	Mechanics of reinforced soil	289
12.1.1	Enhancement of shear strength	289
12.1.2	Available reinforcement force	290
12.1.3	Stress-strain behaviour	291
12.2	Components of reinforced-soil walls	292
12.2.1	Reinforcement	292
12.2.2	Facing	295
12.2.3	Backfill	296
12.3	Principles of design	297
12.3.1	General	297
12.3.2	Preliminary dimensions	297
12.3.3	Factors of safety	297
12.4	External stability	298
12.4.1	Outward sliding	299
12.4.2	Overturning	299
12.4.3	Bearing failure	300
12.4.4	Deep-seated failure	300
12.5	Internal stability	300
12.5.1	Tension failure	302
12.5.2	Pullout failure	305
12.6	Pullout capacity of reinforcement	307
12.6.1	Strip reinforcement	307
12.6.2	Bar reinforcement (soil nails)	308
12.6.3	Sheet/fabric reinforcement	309
12.6.4	Wire-mesh reinforcement	310
12.6.5	Polymer-grid reinforcement	310
12.6.6	Bar-anchor reinforcement	311
12.6.7	Hybrid-anchoring systems	312
12.7	Ground anchors	317
12.7.1	Types of ground anchor	317
12.7.2	Design of ground anchors	319
12.7.3	Durability	319
12.8	Pullout capacity of ground anchors	320
12.8.1	Type A anchors	320
12.8.2	Type B anchors	320
12.8.3	Type C anchors	321
12.8.4	Type D anchors	321
12.8.5	Other anchor types	323
12.8.6	Preliminary estimate	323
12.8.7	Factors of safety	323
12.9	Stability of anchored walls	323
12.9.1	Overall equilibrium	324
12.9.2	Local equilibrium	325

F. 13 Slope-stability and seepage analysis 326

13.1	Slope stability applied to earth-retaining structures	326
13.1.1	Method of slices	327
13.1.2	Short-term stability analysis	328

13.1.3	Long-term stability analysis—circular slips	329
13.1.4	Long-term stability analysis—non-circular slips	333
13.1.5	Parameters and mechanisms	338
13.2	Groundwater and retaining structures	339
13.2.1	Introduction	339
13.2.2	Horizontal water-table with no flow	339
13.2.3	Groundwater flow	340
13.2.4	Seepage analysis	341
13.2.5	Instability of the bottom of excavation	345
13.2.6	Water flow due to heavy rainfall	350
13.2.7	Erosion control	351
Appendix A: Sarma slope-stability analysis		354
A.1	Data input program	354
A.2	Stability analysis program	356
A.3	Typical output from Sarma slope stability program	359
Appendix B: Earth pressure coefficients		360
References		387
Index		395

Publisher's note

'Reinforced Earth' is the trademark of the licensees of the patents of Henri Vidal and is the trading name of those companies. Use of the term Reinforced Earth without reference to the trade-mark ownership by the Reinforced Earth Companies constitutes an unauthorized use of the Reinforced Earth trademark rights.