GROUND ANCHORS AND ANCHORED STRUCTURES

PETROS P. XANTHAKOS

Consulting Engineer Washington, D.C.



A Wiley-Interscience Publication JOHN WILEY & SONS, INC.

New York / Chichester / Brisbane / Toronto / Singapore

gapore D.S

CONTENTS

1 STATE OF THE ART

- 1-1 Function Of Ground Anchors / 1
- 1-2 Origin And First Applications / 2
- 1-3 Current Demand For Anchorages / 4
- 1-4 Tiebacks And Tied-Back Walls / 6
- 1-5 Compatibility With Ground Engineering Problems / 7
- 1-6 Constructional Feasibility And Requirements / 15

1-7 Statistical And Regional Data: Brief Review / 19 References / 30

2 THE ANCHOR SYSTEM: COMPONENTS AND INSTALLATION

- 2-1 Basic Considerations / 33
- 2-2 Anchor Grouping And Classification / 34
- 2-3 Anchor Assembly And Parts / 39
- 2-4 Anchor Tendon / 41
- 2-5 Tendon Characteristics / 45
- 2-6 Anchor Head / 50
- 2-7 Anchor Hole Drilling / 52
- 2-8 Water Testing And Waterproofing By Pregrouting / 64

33

- 2-9 Tendon Preparation And Installation / 66
- 2-10 Grouting / 71
- 2-11 Anchor Stressing And Jacking / 81
- 2-12 Construction Limitations / 82
- 2-13 Examples Of Anchor Systems Used In North America / 85

References / 92

3 SPECIAL ANCHOR SYSTEMS

- 3-1 Removable And Extractable Anchors / 97
- 3-2 Compression, Compressed Bond And Compressed Tube Anchors / 103
- 3-3 Multibell (Underreamed) Anchors / 106
- 3-4 Regroutable Anchors / 107
- 3-5 Pressure Bulb Soil Anchors / 112
- 3-6 Anchors For Special Conditions / 115
- 3-7 Caisson-Type Anchors / 117
- 3-8 The Injection Bauer Anchor System / 118
- 3-9 Vertical Anchors / 119

References / 122

4 THE TRANSFER OF LOAD AND MODES OF FAILURE

- 4-1 General Considerations / 123
- 4-2 Steel Tendon; Failure Mechanism And Analysis / 126
- 4-3 Failure Of Grout-Tendon Bond And Safe Bond Length / 130
- 4-4 Failure Of Ground-Grout Bond / 142
- 4-5 Failure Of Anchors In Rock-Straight Shaft / 144
- 4-6 Failure Of Underreamed Anchors In Rock / 150
- 4-7 Failure Of Compressed Tube Anchors In Rock / 155
- 4-8 Failure Of Anchors In Sand / 159
- 4-9 Failure Of Anchors In Clay / 170
- 4-10 Creep And Long-Term Loading / 186
- 4-11 Repetitive Loading / 191

References / 195

5 DESIGN CONSIDERATIONS

- 5-1 Ground And Site Investigations / 201
- 5-2 Legal Considerations / 207

201

240

297

- 5-3 Stability Of A Mass Of Ground / 209
- 5-4 Selection Of Fixed Anchor Location / 218
- 5-5 Selection Of Anchor Spacing And Inclination / 221
- 5-6 Selection Of Anchor Type, Length And Diameter / 224
- 5-7 Design Of Anchor Head / 226
- 5-8 Estimation Of Lockoff Or Transfer Load / 228
- 5-9 Loads Acting On Anchors / 229
- 5-10 Factors Of Safety / 230
- 5-11 Suggested Design Procedure / 235

References / 237

6 CORROSION AND CORROSION PROTECTION

- 6-1 General Requirements / 240
- 6-2 Definition And Mechanism Of Corrosion / 241
- 6-3 Types Of Corrosion / 243
- 6-4 Aggressivity Of Environments / 247
- 6-5 Risk Of Corrosion And Aggressive Circumstances For Anchorages / 253
- 6-6 Objectives Of Corrosion Protection / 256
- 6-7 Requirements Of Corrosion Protection / 258
- 6-8 Protective Systems Of The Free Length / 263
- 6-9 Protective Systems Of The Fixed Length / 269
- 6-10 Protective Systems Of The Anchor Head / 274
- 6-11 Cathodic Protection / 278
- 6-12 Preprotected Bond Length Anchors / 279
- 6-13 A Brief Survey Of Corrosion Incidents / 280

6-14 Documented Performance Of Anchorages / 283 References / 293

7 STRESSING, TESTING, AND ACCEPTANCE CRITERIA

- 7-1 Basic Stressing Techniques / 297
- 7-2 Examples Of Stressing Systems / 305
- 7-3 Load And Extension Measurements / 307
- 7-4 Factors Affecting Interpretation Of Stressing Results / 314
- 7-5 Ideal Mechanism Of Tendon Stressing / 320
- 7-6 Precontract Tests / 321
- 7-7 Acceptance Tests Of Production Anchors / 326
- 7-8 Basic On-Site Suitability Tests / 330

XIV CONTENTS

- 7-9 Typical Example Of Anchor Testing And Stressing / 338
- 7-10 Creep Tests / 343
- 7-11 Long-Term Monitoring Tests / 349
- 7-12 Service Behavior And Acceptance Criteria / 351
- 7-13 Available Remedies For Failed Anchors / 359
- 7-14 Requirements Of Stressing And Monitoring Equipment / 360

References / 362

8 USES AND APPLICATIONS

- 8-1 Anchor-Structure Grouping / 366
- 8-2 Anchored-Wall Characteristics And Applicability / 367
- 8-3 Intermittent Structures / 368
- 8-4 Shotcrete Used With Prestressing / 373
- 8-5 Tall And Massive Structures / 376
- 8-6 Use Of Anchors To Improve Slope Stability / 379
- 8-7 Applications For Dam Strengthening And Restoration / 383
- 8-8 Soil Preconsolidation And Soil Heave Control / 385
- 8-9 Anchorages For Concentrated Forces / 386
- 8-10 Anchorages To Secure Caverns / 390
- 8-11 Anchorages For Tunnels / 393
- 8-12 Anchorages For Underpinning / 399
- 8-13 Anchorages For Deep Excavations / 400
- 8-14 Anchorages For Long Excavations / 403
- 8-15 Anchoring Of Foundation Structures / 404
- 8-16 Waterfront Installations And Offshore Structures / 406

References / 409

9 DESIGN PRINCIPLES OF ANCHORED STRUCTURES

413

- 9-1 Dam Stabilization By Prestressing / 413
- 9-2 Anchorage Reinforcement Of Soil In Soft Ground Tunneling / 420
- 9-3 Soil Preconsolidation By Prestressing / 425
- 9-4 Control Of Swelling In Rock Tunnels / 431
- 9-5 Anchorages For Rock Caverns And Tunnels By Semiempirical Design / 436

- 9-6 Rock Tunnel Reinforcement By Equivalent Support Methods / 457
- 9-7 Effect Of Confining Pressure In Rock Caverns And Tunnels / 461
- 9-8 The Exponential Formulation Theory For Rock Openings / 461
- 9-9 Spiling Reinforcement In Rock Tunnels / 472
- 9-10 Elastic And Plastic Behavior Of Rock Tunnels / 474
- 9-11 Rock Tunnel Reinforcement By The Convergence-Confinement Method / 480
- 9-12 Underground Opening In Blocky Rock—The "Block Theory" / 492
- 9-13 Principles Of Rock Slope Engineering / 492
- 9-14 Analysis Of Plane Slides In Rock Slopes / 496
- 9-15 Wedge Failure In Rock Slopes / 498
- 9-16 Other Methods Of Analysis And Support Of Rock Slopes / 501
- 9-17 Structures Resisting Concentrated Forces / 510
- 9-18 Analysis Of Anchored Foundation Mats And Rafts / 519
- 9-19 Consideration Of Dynamic Loads / 521
- 9-20 Fundamentals Of Anchored Walls / 533
- 9-21 Procedures For Estimating Lateral Stresses And Deformations / 534
- 9-22 Empirical Guidelines For Control Of Movement / 543
- 9-23 General Stability Of The Ground-Anchored Wall System / 545
- 9-24 Estimation Of Anchor Loads / 551
- 9-25 Analysis Of Anchored Walls By Finite-Element Methods / 557
- 9-26 Miscellaneous Topics Relevant To Anchored Wall Design / 563
- 9-27 Numerical Procedures / 576
- 9-28 Underpinning Considerations / 580

9-29 Limit States In The Design Of Anchored Walls / 582 References / 585

10 DESIGN EXAMPLES

- 10-1 Anchorages At Devonport Nuclear Complex / 599
- 10-2 Rock Slope Stabilization By Prestressing / 602

- 10-3 Development Of A Design And Testing Program / 606
- 10-4 Example Of NATM—The Arlberg Tunnel / 609
- 10-5 Stabilizing Effect Of Anchoring In A Circular Tunnel / 613
- 10-6 Estimation Of Anchor Capacity By Equivalent Support Method / 615
- 10-7 Design Of An Anchored Wall By Limiting Equilibrium Methods / 617
- 10-8 Design Of An Anchored Slurry Wall / 619
- 10-9 Procedure Of Anchored Wall Design By Elastic-Plastic Method / 623
- 10-10 Example Of Limit State Design For Anchored Wall / 626

References / 629

11 OBSERVED PERFORMANCE OF ANCHORED STRUCTURES

630

- 11-1 Monitoring Guidelines / 630
- 11-2 Effects Of Single Anchor Failure In A Group / 632
- 11-3 Long-Term Performance Of Anchorage At Devonport / 633
- 11-4 Surveillance Program To Check Rock Slope Stability / 639
- 11-5 Field Study Of Spiling Reinforcement For Rock Tunnel / 641
- 11-6 Field Studies On Freezing And Thawing Effects / 647
- 11-7 The Kops Powerhouse, Austria / 650
- 11-8 Behavior Of Anchored Walls In London Clay / 652
- 11-9 Field Studies Of Special Anchorages / 662
- 11-10 Analysis Of Ground Movement In London Clay By Finite-Element Methods / 669
- 11-11 Observed Performance Of Rigid Wall At World Trade Center / 671
- 11-12 Inclined Wall For The Munich Subway / 672

11-13 Observed Performance Of Hybrid Construction / 674 References / 677

INDEX