## Foundation Engineering

### SECOND EDITION

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#### SYMBOLS

## PART A. PROPERTIES OF SUBSURFACE MATERIALS

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., <u>.</u> 4

· 문화 이상 이 가지 않는 것이 있는	
Chapter 1. Identification and Classification of Soils and	3
Rocks	
1.1 Definition of Soil and Rock	3
1.2 Purpose of Identification and Classification	3
1.3 Description and Identification of Soils	4
1.4 Index Properties of Soils	. 7
1.5. Soil Grain Properties	8
1.6 Weight-Volume Relationships of Soil Aggregate	11
1.7 Structure and Consistency of Soil Aggregate	18
1.8 Soil-Classification Systems	24
1.9 Description and Classification of Rocks	30
Chanter 2 Hudroulie Properties of Soil and Bock	39
Chapter 2. Hydraune Properties of Son and Room	
1. 2.1. Introduction Compared Strangerski by the Anterson descent	39
2.2. Permeability of Soil	39
2.3. Permeability of Rock	44
2.4. Effective and Porewater Pressures	44
2.5. Soil Moisture, Drainage, and Frost Action	-47
2.6. Seepage and Flow Nets	-51
Chapter 3. Consolidation Characteristics of Soils	59
3.1 Significance of Stress-Strain Characteristics of Earth	
Materials	59
3.2. Consolidation Tests on Remolded Clavs	59
3.3. Consolidation Characteristics of Normally Loaded	
Deposits	61
3.4. Computation of Settlement	62
3.5. Consolidation Characteristics of Preloaded Deposits	63
3.6. Consolidation Characteristics of Sensitive Clavs	64
3.7. Consolidation Characteristics of Residual Soils	65
3.8. Consolidation Characteristics of Collapsible Soils	65
3.9. Consolidation Characteristics of Sands	66

TJFA 419 PAGE 002

xi

3.11		
	Swelling Clays and Clay-Shales	67
3.12	. Rate of Consolidation	68
Chapt	er 4. Stress-Deformation-Strength Characteristics	81
-	of Soil and Rock	
4.1.	Behavior of Soils Under Complex States of Stress	81
4.2.	Behavior in Shear of Idealized Granular Mass	81
4.3.	Triaxial Tests and Mohr's Circle of Stress	83
4.4.	Stress-Strain Relations for Dry Sands and Gravels	85
4.5.	Mohr's Rupture Diagram	86
4.6.	Shearing Strength of Dry Sands and Gravels	87
4.7.	Influence of Water in Voids	88
4.8.	Behavior of Fine-Grained Soils	90
4.9.	Shearing Resistance of Unsaturated Soils	94
4.10.	Effects of Repetitive Loads and Time	95
4.11.	Selection of Test Procedures for Determining Shear	
	Strength of Soils in Practice	96
4.12.	Strength and Deformability of Rock	99
Chapt	er 5. Techniques of Subsurface Investigation	103
		109
5.1.	Methods of Exploration	103
5.2.	Exploratory Borings	105
5.3.	Sampling	100
5.4.	Direct Measurements of Consistency and Relative	170
	Density	- 11Z
· · · -		116
5.5.	Miscellaneous Methods of Soil Exploration	116
5.5. 5.6.	Miscellaneous Methods of Soil Exploration Record of Field Exploration	116 120
5.5. 5.6. Chant	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits	116 120 125
5.5. 5.6. Chapt	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits	116 120 125
5.5. 5.6. Chapt 6.1.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits	116 120 125 125
5.5. 5.6. <b>Chapt</b> 6.1. 6.2.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation	116 120 125 125 125
5.5. 5.6. Chapt 6.1. 6.2. 6.3.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits	116 120 125 125 125 129 140
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits	116 120 125 125 129 140 144
5.5. 5.6. Chapt 6.1. 6.2. 6.3. 6.4. 6.5.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits	116 120 125 125 129 140 144 147
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4. 6.5. 6.6.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er.4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock	116 120 125 125 129 140 144 147 149
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Rock and Residual Soil	116 120 125 125 129 140 144 147 149 153
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Rock and Residual Soil	116 120 125 125 129 140 144 147 149 153
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7. <b>Chapt</b>	Miscellaneous Methods of Soil Exploration Record of Field Exploration er.4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Rock and Residual Soil er 7. Program of Subsurface Exploration	116 120 125 125 129 140 144 147 149 153 163
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7. <b>Chapt</b> 7.1.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er.4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Rock and Residual Soil er 7. Program of Subsurface Exploration Development of Exploratory Program	116 120 125 125 129 140 144 147 149 153 163
5.5. 5.6. Chapt 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7. Chapt 7.1. PART	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Bedrock Weathered Rock and Residual Soil er 7. Program of Subsurface Exploration Development of Exploratory Program B. TYPES OF FOUNDATIONS AND METHODS	116 120 125 129 140 144 147 149 153 163 163
5.5. 5.6. Chapt 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7. Chapt 7.1. PART	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Bedrock Weathered Rock and Residual Soil er 7. Program of Subsurface Exploration Development of Exploratory Program B. TYPES OF FOUNDATIONS AND METHODS CONSTRUCTION	116 120 125 129 140 144 147 149 153 163 163 5 OF
5.5. 5.6. Chapt 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 6.7. Chapt 7.1. PART Chapt	Miscellaneous Methods of Soil Exploration Record of Field Exploration er 4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Rock and Residual Soil er 7. Program of Subsurface Exploration Development of Exploratory Program B. TYPES OF FOUNDATIONS AND METHODS CONSTRUCTION er 8. Excavating and Bracing	116 120 125 129 140 144 147 149 153 163 163 5 OF 169
5.5. 5.6. <b>Chapt</b> 6.1. 6.2. 6.3. 6.4. 6.5. 6.6. 7.1. <b>Chapt</b> 7.1. <b>PART</b> <b>Chapt</b> 8.1.	Miscellaneous Methods of Soil Exploration Record of Field Exploration er.4. Character of Natural Deposits Origin of Natural Deposits Deposits Associated with Glaciation Windblown Deposits River and Continental Deposits Organic and Shore Deposits Unweathered Bedrock Weathered Rock and Residual Soil er 7. Program of Subsurface Exploration Development of Exploratory Program B. TYPES OF FOUNDATIONS AND METHODS CONSTRUCTION er 8. Excavating and Bracing Introduction	116 120 125 129 140 144 147 149 153 163 163 5 OF 169

~

xii

## TJFA 419 PAGE 003

Contents 8.3. Sheeting and Bracing for Shallow Excavations 170 Sheeting and Bracing for Deep Excavations 170 8.4. Movements Associated with Excavation 173 8.5. antes const **Chapter 9. Drainage and Stabilization** 177 9.1. Introduction 177 9.2. **Ditches and Sumps** 177 9.3. Well Points 178 180 9.4. Deep-Well Pumps Sand Drains 180 9.5. Miscellaneous Methods of Drainage and Stabilization 181 9.6. 것 왜 나무지 않는 것을 하나 가 가격하다. Chapter 10. Footing and Raft Foundations 185 and the second statements of the 185 10.1. Types of Footings 10.2. Historical Development 185 and the second second second second General Considerations 10.3. 186 10.4. Allowable Soil Pressures 186 10.5. 187 **Combined Footings** 310.6. Raft Foundations ACCOUNT SO CONTRACT 188 10.7. Drainage, Waterproofing, and Dampproofing 189 **Chapter 11. Foundations on Compacted Fill** 193 医无效性 建合物化 化合物化 计算法 肥富的 化 Historical Development Case, Sure Consult Constants 11.1. 193 11.2. **Design Considerations** .193 11.3. Deep-Seated Settlement 194 11.4. Placement and Compaction of Fill 195 11.5. Control of Compaction 198 11.6. Proportioning and Details of Foundation Elements 199 83 B. 80 800 C. **Chapter 12.** Pile Foundations 203 and the second 12.1. **Function of Piles** 203 12.2. **Types of Piles** 203 Installation of Piles 12.3. 209 12.4. Action of Piles Under Downward Loads 212 12.5. Dynamics of Pile Driving 216 12.6. Choice of Type of Pile 225 12.7. Lateral and Upward Loads on Pile Foundations 225 12.8. Negative Skin Friction 226 All model and the Bart's to Addition a stable stread and the And the second second e gel pe de con Chapter 13. Pier Foundations 229 13.1. Definitions 229 13.2. Methods of Construction 229 13.3. **Drilled Piers** 235 4

17

**i**8

1

:1

1

3

5

6

7

8

0 4

5

6

9

3

3

3 6

2

6

0

5

5 9

0

4 7

9

3

9

TJFA 419 PAGE 004

xiii

Chapter 14. Pier Shafts, Retaining Walls, and Abutments	245
141 Die Shafte	245
14.9. Potoining Walls	246
14.2. Abutments	247
14.3. Adutments	
Chapter 15. Shoring and Underpinning	251
15.1 Shoring	251
15.9 Underninning	251
13.2. Underprinning	. 14
Chapter 16. Damage Due to Construction Operations	255
16.1 Settlement Due to Excavation	255
16.2 Settlement Due to Vibrations	257
16.3 Settlement Due to Lowering the Water Table	257
16.4 Displacement Due to Pile Driving	258
16.5. Importance of Field Observations for Control of	
Construction Operations	258
16.6 Influence of Construction Procedures on Design	259
	i de s
	SIS
FOR DESIGN	
Chapter 17. Factors Determining Type of Foundation	203
17.1 Store in Choosing Type of Foundation	263
17.2 Bearing Canacity and Settlement	264
17.2. Design Loads An Alexandre 26 Contract	264
set	
Chapter 18. Foundations on Clay and Plastic Silt	269
18.1. Significant Characteristics of Deposits of Clay and	960
Plastic Silt	209
18.2. Footings on Clay	210
18.3. Rafts on Clay	210
18.4. Piers on Clay	281
18.5. Piles on Clay	286
18.6. Settlement of Foundations Underlam by Clay	200
18.7. Excavation in Clay	301
18.8. Lateral Displacements Due to vertical Loads on Siay	1. <b>0.9</b> - 1.
	19.024 19.00
Chapter 19. Foundations on Sand and Nonplastic Silt	
the state of Sand and Silt Denosits	307
19.1. Significant Characteristics of Sand and Ont Deposits	307
19.2. Footings on Sand	318
1945. Raits on Sand Microsoft and Microsoft	321
19.4. Flers on Sand	322
19.6. Fries in Sand	
	325
1970. Excavation in Sand	$\begin{array}{c} 325\\ 327\end{array}$

xiv

## Chapter 20. Foundations on Collapsing and Swelling Soils 333

B

Chapter		
201	General Considerations	333
20.1.	Foundations on Collapsing Soils	334
20.2.	Foundations on Swelling Soils	337
20.5.	Foundations on Shoring a second	5° 4
Chapter	21. Foundations on Nonuniform Soils	349
21.1.	Introduction octown wash	349
21.2.	Soft or Loose Strata Overlying Firm Strata	350
21.3.	Dense or Stiff Laver Overlying Soft Deposit	350
21.4.	Alternating Soft and Stiff Layers	352
21.5.	Irregular Deposits	353
21.6.	Excavation and Stability of Slopes in Nonuniforn	1
	Soils and the second	354
751	·····································	
Chapter	22. Foundations on Rock	361
22.1	Basis for Design	361
22.1.	Foundations on Unweathered Rock	361
223	Treatment of Rock Defects	364
- 22.0. - 7.29 A	Foundations on Weathered Rock	367
3.92.5	Excavation in Rock	369
PART	D. DESIGN OF FOUNDATIONS AND EA RETAINING STRUCTURES	RTH-
PART Chapter	D. DESIGN OF FOUNDATIONS AND EA RETAINING STRUCTURES 23. Individual Column and Wall Footings	ARTH- 375
PART Chapter 23.1,	D. DESIGN OF FOUNDATIONS AND EA RETAINING STRUCTURES 23. Individual Column and Wall Footings Basis for Design Procedures	875 375 375
PART Chapter 23.1. 23.2.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EA RETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> </ul>	875 375 376 376
PART Chapter 23.1 23.2. 23.3.	<ul> <li>DESIGN OF FOUNDATIONS AND EA RETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> </ul>	875 375 375 376 377 279
PART Chapter 23.1 23.2. 23.3. 23.4.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EA RETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> </ul>	875 375 376 376 377 378
PART Chapter 23.1 23.2. 23.3. 23.4. 23.5.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> </ul>	875 375 376 376 377 378 h
PART Chapter 23.1 23.2. 23.3. 23.4. 23.5.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> </ul>	875 375 376 376 377 378 h 378 h
PART Chapter 23.1. 23.2. 23.3. 23.4. 23.5. 23.6.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> </ul>	375 375 375 376 377 378 h 378 378
PART Chapter 23.1	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> </ul>	375 375 375 376 377 378 h 378 378 379 385
PART Chapter 23.1 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> </ul>	RTH- 375 376 377 378 h 378 379 385 385
PART Chapter 23.1 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1. 24.2.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> </ul>	RTH- 375 376 377 378 h 378 378 379 385 385 385
PART Chapter 23.1., 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1. 24.2. 24.3.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> </ul>	RTH- 375 376 377 378 h 378 379 385 385 385 386 387
PART Chapter 23.1.4 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1. 24.2. 24.3. 24.4.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> </ul>	RTH- 375 376 377 378 h 378 379 385 385 385 386 387 391
PART Chapter 23.1, 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1. 24.2. 24.3. 24.4. 24.5.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> <li>Footings Having Unsymmetrical Shapes</li> </ul>	RTH- 375 375 376 377 378 4 379 385 385 385 386 387 391 392
PART Chapter 23.1, 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1. 24.2. 24.3. 24.4. 24.5. 24.6.	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> <li>Footings Having Unsymmetrical Shapes</li> <li>Moment on Pile Footings</li> </ul>	RTH- 375 375 376 377 378 h 379 385 385 386 387 391 392 392
PART Chapter 23.1	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> <li>Footings Having Unsymmetrical Shapes</li> <li>Moment on Pile Footings</li> <li>Piles Subjected to Tension</li> </ul>	RTH- 375 376 377 378 h 378 379 385 386 385 386 387 391 392 392 394
PART Chapter 23.1, 23.2. 23.3. 23.4. 23.5. 23.6. Chapter 24.1. 24.2. 24.3. 24.4. 24.5. 24.6. 24.7. Chapte	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> <li>Footings Having Unsymmetrical Shapes</li> <li>Moment on Pile Footings</li> <li>Piles Subjected to Tension</li> <li>r 25. Combined Footings and Rafts</li> </ul>	RTH- 375 375 376 377 378 4 385 385 385 386 387 391 392 392 394 401
PART Chapter 23.1	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> <li>Footings Having Unsymmetrical Shapes</li> <li>Moment on Pile Footings</li> <li>Piles Subjected to Tension</li> <li>r 25. Combined Footings and Rafts</li> <li>Purpose of Combined Footings</li> </ul>	RTH- 375 375 376 377 378 378 379 385 385 385 385 386 387 391 392 392 394 401 401
PART Chapter 23.1	<ul> <li>D. DESIGN OF FOUNDATIONS AND EARETAINING STRUCTURES</li> <li>23. Individual Column and Wall Footings</li> <li>Basis for Design Procedures</li> <li>Critical Sections</li> <li>Placing of Reinforcement</li> <li>Depth of Spread Footings</li> <li>Procedure for Design and Use of Minimum-Dept</li> <li>Curves</li> <li>Isolated Column Footings on Piles</li> <li>r 24. Footings Subjected to Moment</li> <li>Introduction</li> <li>Resultant Within Middle Third</li> <li>Resultant Outside Middle Third</li> <li>Moment About Both Axes</li> <li>Footings Having Unsymmetrical Shapes</li> <li>Moment on Pile Footings</li> <li>Piles Subjected to Tension</li> <li>r 25. Combined Footings and Rafts</li> <li>Purpose of Combined Footings</li> <li>Combined Footings of Rectangular and Trapezoid</li> </ul>	ARTH- 375 376 377 378 378 379 385 385 385 385 385 386 387 391 392 392 394 401 401 401

XV

	Choice of Column Loads	
25.5.	Structural Design of Combined Footings	
25.6.	Basis for Design of Raft Foundations	
Chapte	r 26. Retaining Walls and Abutments	
26.1.	Introduction	
26.2.	Proportions of a Cantilever Retaining Wall	
26.3.	Summary of Forces Acting on Retaining Walls	
26.4.	Earth Pressure	
26.5.	Vertical Pressure Against Base	
26.6.	Forces Resisting Sliding	
26.7.	Summary of Procedure for Design of Cantilever R	le-
	taining Wall	
26.8.	Pile-Supported Retaining Walls	;
26.9.	Abutments	
	the state of the s	÷
Chapte	r 27. Flexible Earth-Retaining Structures	+
27.1.	Behavior of Flexible Earth-Retaining Structures	
27.2.	Anchored Bulkheads	
27.3.	Braced Cuts	
27.4.	Tieback Bracing System	
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xvi

#### Behavior of Fine-Grained Soils

tendency exceeds the tendency to consolidate as a result of positive pore pressures induced by the shearing stresses, the water content of the clay may eventually increase and the shear strength correspondingly decrease. These conditions are not likely to occur beneath excavations one or two stories deep in normally loaded or slightly overconsolidated clays. If they do, however, the shear strengths derived from Q-tests no longer err on the side of safety.

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The  $\phi = 0$  concept and the use of Q-tests would also be valid for overconsolidated clays if in the field no opportunity existed for change in water content. However, the strong negative pore pressures associated with high overconsolidation ratios create a tendency for the soil to swell, whereupon the strength is reduced. Thus, in most practical problems the  $\phi = 0$  concept for an overconsolidated clay leads to results on the unsafe side. Hence, except for overconsolidation ratios as low as possibly 2 to  $4_{3}^{cr}$ the  $\phi = 0$  concept should not be used for preloaded clays.

Many stiff saturated clays contain networks of hair cracks or slickensides. The shearing strength of deposits of this kind depends on the influence of such defects. Triaxial Q-tests on large specimens that include a representative number of defects have in some instances been found useful in determining the shearing strength of the mass. The cell pressure is usually taken as the overburden pressure on the sample as it existed in the ground. More reliable data can be obtained by means of large-scale loading tests or test excavations in the field.

c/p Ratio. The  $\phi = 0$  concept leads to a useful corollary. According to eq. 4.5 the strengths of normally consolidated samples are defined by the rupture line

$$s = \bar{p} \tan \phi_d \qquad (4.5)$$

An effective-stress rupture circle for one of a series of undrained tests is shown in Fig. 4.10*a*. The cell pressure under which all the samples in the series were consolidated is  $\bar{p}_{3.}$ . The value of *s* corresponding to the  $\phi = 0$ , concept is the radius *c* of the circle. It is ap<sup>2b</sup>





FIGURE 4.10. (a) Rupture diagram illustrating constancy of ratio  $c/p_3$  for normally loaded samples of clay consolidated under different cell pressures. (b) Relation between ratio  $c/\tilde{p}_n$  and plasticity index.

parent that, for samples of a given material consolidated under different confining pressures, the ratio  $c/\bar{p}_3$  is a constant.

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In a natural deposit of normally loaded sedimented soil the consolidation stresses differ in horizontal and vertical directions. This condition introduces a complication into the interpretation, but it has nevertheless been found that a constant ratio exists between values of c determined by Q-tests and the effective vertical overburden pressure on horizontal planes. This ratio is designated as  $c/\bar{p}_n$  or, for short, as the c/pratio, Furthermore, a broadly valid statistical relation has been found between  $c/\bar{p}_n$ and the plasticity index for normally loaded sedimentary clays (Skempton, 1948; Bjerrum and Simons, 1960). The relation is shown in Fig. 4.10b. It may be approximated by the equation so administration and action tive income detrate of standarding incomences

 $\vec{p}_n = 0.10 + 0.004I_P$ where  $I_P$  is expressed in per cent.

> TJFA 419 PAGE 008

4/Stress-Deformation-Strength Characteristics of Soil and Rock

This relation is useful in at least two ways. If a deposit is known to be normally loaded, values of c for the various layers in the deposit can be estimated roughly on the basis of the Atterberg-limit tests on disturbed samples. On the other hand, if values of c and  $I_P$  have been determined by test, the relation can be used to judge whether the deposit is preloaded and, in a qualitative way, what the degree of overconsolidation may be.

#### 4.9. Shearing Resistance of Unsaturated Soils

The relations between effective normal stress and shear strength for unsaturated materials are not significantly different from those for saturated soils. However, evaluation of the shear strength on the basis of these relations requires a knowledge of the pore pressure not only in the water contained in the voids but also in the air that occupies the remainder of the voids. The pore-air pressure and the porewater pressure may have quite different values on account of the surface tension at the airwater interfaces. Because of the difficulties in evaluating these pressures, it is current practice to investigate the strength of partly saturated soils by means of triaxial tests in which only total stresses are measured and in which the laboratory test conditions are made to duplicate, as closely as possible, those anticipated in the field. In many instances Q-tests are appropriate. The water content of each sample is kept constant. Volume changes occur, nevertheless, because of the compression of the air in the voids.

Typical results of several series of Q-tests on samples of an inorganic clay (CL) are shown in Fig. 4.11 (Casagrande and Hirshfeld, 1960). All samples were compacted to the same dry density. The rupture line for samples having a relatively low initial degree of saturation is markedly curved. For increasingly greater initial degrees of saturation, the strengths decrease. Moreover, for a given initial degree of saturation, increases in pressure cause compression of the air in the voids and, in addition, increase the solubility of air in water. Consequently, the



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TJFA 419 PAGE 009

FIGURE 4.11. Results of Q-tests on partially saturated samples of an inorganic clay compacted to equal dry densities.

degree of saturation increases. For those samples with high initial degrees of saturation,  $S_\tau$  may reach 100 per cent at a comparatively low pressure, whereupon the  $\phi = 0$  conditions are satisfied and the rupture line with respect to total stresses becomes horizontal.

A compacted fill is ordinarily placed at a moisture content close to the optimum value; this value corresponds to a partially saturated condition. The strength at the



Frome 4.12: (a) Results of Q-tests on samples of a compacted silty clay tested as compacted and after soaking (b) Standard Proctor moisturedensity curve for material.

94