

# SOIL MECHANICS

---

ALFRED R. JUMIKIS, Dr. Eng. Sc.

*Professor of Civil Engineering  
Rutgers—The State University  
New Brunswick, New Jersey*



D. VAN NOSTRAND COMPANY, INC.

PRINCETON, NEW JERSEY

TORONTO

NEW YORK

LONDON

D. VAN NOSTRAND COMPANY, INC.  
120 Alexander St., Princeton, New Jersey (*Principal office*)  
24 West 40 Street, New York 18, New York

D. VAN NOSTRAND COMPANY, LTD.  
358, Kensington High Street, London, W.14, England

D. VAN NOSTRAND COMPANY (Canada), LTD.  
25 Hollinger Road, Toronto 16, Canada

---

COPYRIGHT © 1962, BY  
D. VAN NOSTRAND COMPANY, INC.

---

Published simultaneously in Canada by  
D. VAN NOSTRAND COMPANY (Canada), LTD.

---

*No reproduction in any form of this book, in whole or in part (except for brief quotation in critical articles or reviews), may be made without written authorization from the publishers.*

# CONTENTS

---

PREFACE v

ACKNOWLEDGMENTS ix

## PART I THE SUBJECT

### CHAPTER

#### 1. INTRODUCTION

1-1. Soil as a Construction Material, 3 1-2. Necessity for Studying Soils, 8

#### 2. HISTORICAL REVIEW

2-1. Soil Problems in Prehistoric Times, 10 2-2. Soil Problems in Ancient Times, 10 2-3. Soil and Foundation Problems in Roman Times, 11 2-4. Earthwork and Foundation Engineering in the Middle Ages, 13 2-5. The Period from the 15th to the 17th Centuries, 15 2-6. Older Concepts on Lateral Earth Pressure, 17 2-7. The Period of the Classical Earth-Pressure Theories, 18 2-8. The Beginning of the Modern Soil Mechanics Era, 21 2-9. Most Recent Development, 24

#### 3. SOIL MECHANICS

3-1. Definition, 27 3-2. Objectives of Soil Mechanics, 28 3-3. Soil Mechanics Problems, 28 3-4. Value of Soil Mechanics, 29

## PART II PHYSICAL PROPERTIES OF SOIL

#### 4. SOIL

4-1. Definition, 33 4-2. Formation of Soil, 34 4-3. Mechanical Weathering, 34 4-4. Chemical Weathering, 35 4-5. Oxidation, 36 4-6. Hydration, 36 4-7. Hydrolysis, 36 4-8. Carbonation, 36 4-9. Leaching, 36 4-10. Chemical Effects on Foundations, 37 4-11. Time, 38 4-12. Soil Types, 38 4-13. Some Soil Designations, 41 4-14. Cohesive and Non-cohesive soils, 42 4-15. Soil as a Disperse System, 43

#### 5. SOME PHYSICAL PROPERTIES OF SOIL

5-1. Color, 44 5-2. Mechanical Composition of Soil, 44 5-3. Soil Phases, 45 5-4. Soil Structure, 46 5-5. Specific Gravity, 47 5-6. Temperature Correction Factor, 49 5-7. Definition of Porosity, 50 5-8. Void Ratio, 51 5-9. Relationship Between Porosity and Void Ratio, 51 5-10. Soil Moisture Content, 53 5-11. Determination of Soil Moisture Content and Soil Density by Means of Radioactive Isotopes, 54 5-12. Degree of Saturation, 56 5-13. Packing, 57 5-14. Soil Texture, 60 5-15. Soil Particle Size Analysis, 60 5-16. Calculations and Representations, 61 5-17. Specific Surface of a Soil Mass, 63 5-18. Colloids, 65 5-19. Properties of the Colloidal Fraction of Soil, 66 5-20. Clay Minerals, 67 5-21. Bentonite, 68

## CHAPTER

## THIXOTROPY

5-22. Thixotropy, 69 5-23. Thixotropy of Soil, 74 5-24. Thixotropic Fluids in Engineering Operations, 74 5-25. Representation of Particle Size Analyses Data, 75 5-26. Triangular Coordinates, 75 5-27. Histograms, 78 5-28. Integral, or Cumulative, or Granulometric Curves, 79 5-29. Differences Between Sand and Clay, 84 5-30. Unit Weight of Soil, 86

## 6. VOLUMETRY AND GRAVIMETRY

6-1. Functional Relationships Between Various Soil Properties, 88 6-2. Volumetric and Gravimetric Relationships, 88 6-3. Bulking of Sand, 95

## 7. MOISTURE-DENSITY RELATIONS OF SOILS

## SOIL COMPACTION

7-1. Introduction, 101 7-2. Definition, 102 7-3. Maximum Dry Density, 102 7-4. Compaction Fundamentals, 102 7-5. Compaction Phenomenon, 103 7-6. Compaction Test of Soil, 103 7-7. The Moisture Content-Dry Density Curve, 104 7-8. Moisture-Dry Density Relationships of Some Soils, 105 7-9. Saturation Line (or Line of Zero Air Voids), 105 7-10. Derivation of Dry Density Equation at Various Percent Air Voids, 106 7-11. Needle Penetration Test, 113 7-12. Summary, 115

## RELATIVE DENSITY

7-13. The Concept, 117 7-14. Derivation of Equation for Relative Density, 118 7-15. Definition, 118 7-16. Degree of Relative Density, 119

## DETERMINATION OF RELATIVE DENSITY

7-17. Equipment, 120 7-18. Procedure, 120 7-19. Discussion, 123 7-20. Applications, 124

## 8. SOIL CONSISTENCY

8-1. Definition, 125 8-2. Plasticity, 125 8-3. States of Consistency and Their Limits, 126 8-4. Plasticity Index, 127 8-5. Index of Relative Plasticity, 129 8-6. Shrinkage Limit, 132 8-7. Consistency Diagram of Thixotropic Soil, 135

## DETERMINATION OF CONSISTENCY LIMITS OF SOIL

8-8. General Notes, 136 8-9. Liquid Limit Test, 137 8-10. Plastic Limit Test, 141 8-11. Shrinkage Limit Test, 142

THE EFFECT OF PLASTIC SUBGRADE MATERIAL  
UPON THE STABILITY OF FLEXIBLE PAVEMENTS, 144

## 9. CLASSIFICATION OF SOILS

9-1. Classification, 149 9-2. Some Historical Notes, 150 9-3. General Requirements of a Soil Classification System, 150 9-4. Various Soil Classification Systems, 151

## EXTENDED SOIL CLASSIFICATION SYSTEMS

9-5. Highway Subgrade Soil Classification, 157 9-6. Unified Soil Classification System, 168 9-7. The Civil Aeronautics Administration's (CAA) Soil Classification System, 172 9-8. Conclusions, 173

## PART III WATER IN SOIL

## CHAPTER

## 10. THE LIQUID PHASE OF SOIL—WATER

10-1. The "Opponent" Water, 179 10-2. Modes of Occurrence of Water in Soil, 179 10-3. Gravitational Water, 182 10-4. Capillary Moisture, 185 10-5. Chemically Combined Water, 188

## SURFACE TENSION

10-6. Nature and Magnitude of Surface Tension, 188 10-7. Effect of Temperature on Surface Tension, 189 10-8. Capillary Rise, 192

RELATIONSHIP BETWEEN CURVATURE-PRESSURE,  
SURFACE TENSION, AND CURVATURE OF LIQUID SURFACE

10-9. Pressure Due to Surface Tension, 198 10-10. Capillary Stresses, 200 10-11. Surface Tension in Vertically Suspended Capillaries, 204 10-12. Suspended Water in Soil, 205

## SURFACE TENSION IN SOIL

10-13. Capillary Height in Soil, 206 10-14. Determination of Capillary Height, 207 10-15. Effect of Surface Tension on a Soil Mass, 209 10-16. Capillary Siphoning Phenomenon, 210 10-17. Stress Conditions in Soil Caused by Surface Tension Forces, 211

GENERAL CONCLUSIONS ABOUT THE  
SURFACE TENSION PHENOMENON IN SOIL

10-18. Summary, 213

ELECTROKINETICS OF SOIL-WATER SYSTEMS  
THE STRUCTURE OF WATER MOLECULE

10-19. Polarity, 213 10-20. Orientation of Water Molecules, 214 10-21. Electrical Charge on Surface of Colloidal Particles, 215 10-22. The Electric Double Layer, 215 10-23. Helmholtz's Electric Double Layer, 216 10-24. Zeta ( $\zeta$ ) Potential, 216 10-25. Gouy Double Layer, 218 10-26. Stern Double Layer, 219 10-27. The Structure of Colloidal Particles, 221

## ELECTRO-OSMOSIS

10-28. Fundamental Principle, 222 10-29. Historical Notes, 223 10-30. Application of Electro-osmosis in Engineering, 224

## STREAMING POTENTIAL

10-31. Induced Electrical Potential, 225

## 11. FROST ACTION IN SOILS

11-1. Frost Problems in Soil, 229

## SOIL FREEZING

11-2. Factors Contributing to Freezing Soils, 232 11-3. Theoretical Considerations on the Freezing Soil System, 237

## EXPERIMENTAL STUDIES OF FREEZING SOIL SYSTEMS

11-4. Purpose of Experiment, 238 11-5. Soil Moisture Transfer as a Function of Porosity and Packing, 240 11-6. Film Transport, 241 11-7. Combination of Various Modes of Moisture Transport, 241 11-8. Sum-

## CHAPTER

mary of the Study of the Possible Mechanism for the Translocation of Soil Moisture in the Film Phase Upon Freezing, 242 11-9. Frost Penetration Depth, 245 11-10. Ice Segregation, 245 11-11. Criteria for Evaluating the Susceptibility of a Soil to Frost, 246 11-12. Some Remedial Measures Against Frost Damage to Roads, 247

## 12. GROUNDWATER

12-1. Permeability of Soil, 249 12-2. Darcy's Law, 249 12-3. Inclined Flow, 255 12-4. Artesian Groundwater Flow, 255 12-5. Seepage Connected to Groundwater, 258 12-6. Permeability Through Stratified Layers of Soil, 259 12-7. Permeability Parallel to Stratification, 261 12-8. Discussion of Darcy's Law, 264

## DETERMINATION OF COEFFICIENT OF PERMEABILITY

12-9. Determination of  $k$  Experimentally in the Laboratory, 265 12-10. Values of Coefficients of Permeability, 271

## 13. THEORY OF WELLS

13-1. Determination of Permeability Experimentally in the Field, 276 13-2. Theory of Ordinary Perfect Wells, 278 13-3. Radius of Influence, 284 13-4. Coefficient of Permeability, 285

## ARTESIAN WELLS

13-5. Description, 289 13-6. Hydraulics of a Perfect Artesian Well, 289

## LOWERING THE GROUNDWATER TABLE

13-7. The Problem, 292 13-8. Wellpoint System, 293 13-9. Comments on the Wellpoint System, 297 13-10. Lowering the Groundwater Table by Means of Horizontal Galleries, 298 13-11. Settlement, 299

## THE SUBSIDENCE OF MEXICO CITY

13-12. Cause of Subsidence, 300 13-13. Soil Profile and Soil Properties, 302 13-14. Nature of Damage, 304 13-15. Recent Development, 305

## 14. SEEPAGE THEORY

14-1. Seepage Through Earth Dams. Assumptions, 307 14-2. Graphical Determination of the Seepage Line, 311 14-3. The Hydrodynamic Flow Net, 319 14-4. Short Description of the Flow Net Theory, 322 14-5. Seepage Analysis by Method of Trial and Error, 325 14-6. Seepage Models, 326

## SEEPAGE PRESSURE

14-7. Derivation of Seepage Pressure Equation, 327 14-8. Effect of Hydrodynamic Pressure Upon the Stability of Soil, 331 14-9. Position of Hydrodynamic Force in a Ruptured Seeping Slope, 332

## THEORY OF QUICKSAND CONDITION

14-10. Quick Condition, 333

## THE STUDY OF THE QUICKSAND PHENOMENON IN THE LABORATORY

14-11. Quicksand Apparatus, 335 14-12. Hydrodynamics of Flow Conditions in the Quicksand Apparatus, 337 14-13. Other Uses of Quicksand Apparatus, 339 14-14. Remedial Measures Against a Quick Condition, 341

## PART IV CONSOLIDATION OF SOIL AND SETTLEMENT OF STRUCTURES

## CHAPTER

## 15. PERFORMANCE OF SOIL UNDER COMPRESSIVE LOAD

15-1. Introduction, 353 15-2. Effect of Settlement of Support on a Structure, 354 15-3. Causes of Settlements, 355

## THE MECHANICS OF CONSOLIDATION OF A LAYER OF CLAY

15-4. Two Important Questions of Interest, 358 15-5. The Mechanical Spring and Water Analogy, 359 15-6. Consolidometer, 362 15-7. Consolidation Test, 363

## STRESS-STRAIN RELATIONSHIP IN A CONSOLIDATION PROCESS

15-8. Stress-Strain Diagrams, 364 15-9. Preconsolidation, 371 15-10. Change in Void Ratio, 374 15-11. Pressure-Void Ratio Equations, 376 15-12. Simplified Pressure-Void Ratio Equation, 380 15-13. The Pressure-Void Ratio Curve, 384 15-14. Settlement of Several Thin Layers of Soil, 386 15-15. Settlement of a Thick Layer of Soil, 386 15-16. Time-Settlement Diagrams, 386 15-17. Determination of Zero and 100% Consolidation, 388

## 16. ONE-DIMENSIONAL CONSOLIDATION THEORY; THE CONSOLIDATION PROCESS

16-1. The Consolidation Process-Hydraulic Problem, 398 16-2. Assumptions Underlying the Consolidation Theory, 398 16-3. The Clay System for Analysis, 398 16-4. Drainage and Pressure Conditions in Clay During Consolidation, 400 16-5. The Rate of the Pore Water Flow, 405 16-6. Derivation of Equation, 407

## SOLUTION OF THE CONSOLIDATION EQUATION

16-7. Outset, 409 16-8. The General Isochrone Equation, 413 16-9. Solution of General Differential Equation, 414

## PRESSURE DISTRIBUTION DIAGRAMS

16-10. Shapes of Pressure Diagrams, 415 16-11. Description of Diagrams, 416

## SETTLEMENT CALCULATIONS BY THE USE OF PRESSURE DISTRIBUTION AREAS

16-12. Settlement, 418 16-13. Degree of Consolidation, 421 16-14. Trapezoidal Pressure Distribution Area, 423 16-15. The General Isochrone Equation for  $A_0 = (\Delta p)(2H)$ , 424 16-16. Derivation of General Degree of Consolidation Equation, 428 16-17. Time Factor, 429 16-18. Model Law, 430 16-19. The Theoretical Time Factor-Percent Consolidation Curve, 432 16-20. Theoretical Time Factor-Consolidation Tables, 433 16-21. Illustrative Example, 435 16-22. Illustrative Example, 439 16-23. Consolidation of Sludge, 440 16-24. Conclusion, 440

## 17. VERTICAL SAND DRAINS

17-1. Principle of Function of Sand Drains, 451 17-2. Purpose of Sand Drain, 453 17-3. Diameter of Drains, 453 17-4. Spacing of Sand Drains, 453 17-5. Depth of Sand Drains, 453 17-6. Installation of Sand Drains, 453 17-7. Sand for Drains, 454 17-8. Blanket, 454 17-9. Rate of Loading, 455 17-10. Applications of Sand Drains, 456 17-11. Theory of

## CHAPTER

Vertical Sand Drains, 456 17-12. Summary on Vertical Sand Drains, 456  
17-13. Sand Drain Model, 458

## 18. SETTLEMENT

## SETTLEMENT BY CONSOLIDATION

18-1. The Washington Monument, Washington, D.C., 461 18-2. The  
Leaning Tower of Pisa, 462

## SETTLEMENT BY LATERAL EXPULSION OF SOIL

18-3. Laterally Unconfined Settlement, 465 18-4. Amount of Settlement  
by Lateral Expulsion of Soil, 465 18-5. Loading Radius, 467

## REMEDIAL MEASURES AGAINST HARMFUL SETTLEMENTS

18-6. Remedy, 469

## PART V STRENGTH PROPERTIES OF SOIL

## 19. SHEAR STRENGTH OF SOIL

19-1. Definition, 475 19-2. Determination of Shear Strength of Soil, 475  
19-3. Direct Shear Test, 475 19-4. Types of Shear Tests, 477 19-5.  
Controlled Strain Shear Testing of Soil, 479 19-6. Shear Strength of Sand,  
479 19-7. Shear Strength of Clay, 482 19-8. Unconsolidated Quick Shear  
Test of Clay, 483 19-9. Consolidated Quick Shear Test of Clay, 484  
19-10. Consolidated Slow Shear Test of Clay, 486 19-11. Comments on  
Direct Shear Tests, 486

## TRIAxIAL COMPRESSION OF SOIL

19-12. Stress Conditions on the Shear Plane, 488 19-13. Discussion, 489  
19-14. Variation of Normal and Shear Stresses, 493 19-15. Purpose of  
Triaxial Compression Test, 495 19-16. Types of Tests, 495 19-17. Ap-  
paratus, 496 19-18. Effect of Lateral Stress on Shear ("Beam") Strength  
of Sand, 498 19-19. Types of Failure, 498 19-20. Graphs, 498 19-21.  
Pore Water Pressure, 498 19-22. Example, 502

## UNCONFINED COMPRESSION TEST

19-23. General Notes, 503 19-24. Purpose and Application of Unconfined  
Compression Test, 504 19-25. Analysis, 505 19-26. Preparation of Test  
Samples, 506 19-27. Apparatus, 507 19-28. The Vane Shear Test, 507

## 20. STRESS DISTRIBUTION IN SOIL

20-1. Principal Problem, 516 20-2. Contact Stresses, 516 20-3. Bou-  
sinesq's Theory. Assumptions, 516 20-4. System, 517 20-5. Designation  
of Stresses, 519 20-6. Derivation of  $\sigma_z$ -stress, 520 20-7. Pressure Dis-  
tribution Diagrams, 528 20-8. Summary of Boussinesq's Theory, 531  
20-9. Stress Underneath Any Point Outside the Loaded Area, 532 20-10.  
Steinbrenner's Influence Values, 533 20-11. Newmark's Influence Chart,  
535 20-12. Active Zone in Soil, 539

## 21. EARTH PRESSURE THEORY

21-1. Retaining Walls, 549 21-2. Some Possible Forces Acting on Earth  
Retaining Structures, 549 21-3. Lateral Earth Pressures, 550



## CHAPTER

## COULOMB'S EARTH PRESSURE THEORY

- 21-4. Assumptions, 552 21-5. Deficiencies in Coulomb's Theory, 554  
 21-6. Principles, 555 21-7. Method of Force Projections, 556 21-8.  
 Derivation of the Active Earth Pressure Function,  $E_a$  When  $\alpha = \delta = 0$ , 557  
 21-9. Lateral Earth Pressure Stress Distribution Diagram, 558 21-10.  
 Passive Earth Pressure, 558

## SURCHARGE

- 21-11. Various Kinds of Surcharge, 559

## PONCELET GRAPHICAL METHOD

- 21-12. Active Earth Pressure, 561 21-13. Steps for Graphical Method,  
 563 21-14. Surcharge, 564 21-15. Passive Earth Pressure (Earth Re-  
 sistance), 564 21-16. Steps for Construction for Passive Earth Pressure,  
 564

## CULMANN'S METHOD

- 21-17. Active Earth Pressure, 566 21-18. Passive Earth Pressure, 569

## GENERAL EARTH PRESSURE COEFFICIENT EQUATIONS

- 21-19. Basis for Establishment of Equations, 570 21-20. Key Figure to  
 $K_a$ - and  $K_p$ -Equations, 570 21-21. Derivation of  $K_a$ - and  $K_p$ -Coefficients,  
 571

DISCUSSION ON FACTORS ENTERING INTO  $E_a$ - AND  $E_p$ -EQUATIONS

- 21-22. Factors, 577 21-23. Unit Weight of Soil,  $\gamma$ , 577 21-24. Angle  
 of Internal Friction, 585 21-25. Cohesion, 585 21-26. Angle of Friction  
 Between Wall and Backfill Material, 587 21-27. Effect of Wall Friction  
 Angle  $\phi_1$  on  $K_a$  and  $K_p$ , 588 21-28. Effect of  $\alpha$  and  $\delta$  on  $K_a$  and  $K_p$ , 589  
 21-29. Points of Application of  $E$ , 591

## ACTIVE AND PASSIVE EARTH PRESSURE COEFFICIENT TABLES

- 21-30. Tables, 591

## 22. BEARING CAPACITY OF SOIL; DEPTH OF FOUNDATION

- 22-1. Stability Requirements of a Foundation, 597 22-2. Rating of Soil,  
 597 22-3. Sources of Obtaining Values of Soil Bearing Capacity, 598  
 22-4. Building Codes, 598 22-5. Summary on Bearing Capacity of Soils  
 as Tabulated by Building Codes, 600 22-6. Soil Loading Tests, 601 22-7.  
 Summary on Field Loading Tests of Soil Bearing Materials, 605 22-8.  
 Housel's Bearing Capacity Method, 606 22-9. Summary on Housel's  
 Perimeter-Area Ratio Method, 608 22-10. Laboratory Testing of Soils, 608

## ANALYTICAL METHODS FOR CALCULATING SOIL BEARING CAPACITY

- 22-11. Soil Bearing Capacity Calculations by Means of the Theory of  
 Elasticity, 609 22-12. Soil Bearing Capacity Calculations by Means of the  
 Classical Earth Pressure Theory, 612 22-13. Pauker's Method, 612 22-14.  
 Rankine's Formula, 616 22-15. Bell's Equations, 616 22-16. A. Casa-  
 grande-Fadum Illustration, 617

SOIL BEARING CAPACITY CALCULATIONS BY MEANS OF THEORY OF PLASTIC  
EQUILIBRIUM

- 22-17. Prandtl's Theory, 618 22-18. Terzaghi's Correction, 624 22-19.  
 Taylor's Correction, 625 22-20. Discussion of Prandtl's Theory, 626

## CHAPTER

- 22-21. Terzaghi's Contribution, 629 22-22. Krey's Method, 633 22-23. Fröhlich's Critical Edge Pressure Theory, 640

## SOIL BEARING CAPACITY DETERMINATIONS FROM EXPERIMENTAL RESULTS

- 22-24. General Notes, 642 22-25. Shapes of Rupture Surfaces, 643

## STATIC MOMENTS

- 22-26. Resisting Moments, 646 22-27. Calculation of the Resisting Moment,  $M'_R$ , 647 22-28. The Surcharge Moment, 647 22-29. The Resisting Moment from Shear Resistance, 648 22-30. The Total Resisting Moment, 648 22-31. Calculation of Driving Moments, 648 22-32. Comparison of Resisting and Driving Moments, 648 22-33. Conclusions, 649

## 23. PILES

- 23-1. Introduction, 656 23-2. Types of Piles, 656 23-3. Negative Mantle Friction, 656 23-4. Bearing Capacity of Piles, 659

## DYNAMIC PILE-DRIVING FORMULAS

- 23-5. Formulas, 659 23-6. Principle of Pile Driving, 659 23-7. Work-Energy Relationships, 661 23-8. Rational Pile-Driving Formula, 662 23-9. *Engineering News* Formulas, 662 23-10. The Pure, Classical, Complete Pile-Driving Formula, 663 23-11. Stern's Formula, 664 23-12. Weisbach's Formula (~1850), 664 23-13. Other Formulas, 665 23-14. Brix Equation, 665 23-15. Discussion, 665

## STATIC LOAD TESTS OF PILES

- 23-16. Description of Test, 666 23-17. Pulling Tests, 669

## PILE STATIC BEARING CAPACITY FORMULAS

- 23-18. Assumptions, 669 23-19. Vierendeel's Formula, 669 23-20. Benecncq's Static Formula, 671 23-21. Dörr's Formula, 671 23-22. Krey's Pile Static Bearing Capacity Formula, 672 23-23. Summary, 672

## 24. SHEETING AND BRACING OF TRENCHES

- 24-1. Application of Coulomb's Theory, 676 24-2. Earth Pressure Distribution in Reality, 677

## 25. STABILITY ANALYSIS OF SLOPES

- 25-1. Definitions, 681 25-2. Factors Contributing to Slope Failures, 682 25-3. Slides in the Panama Canal, 682 25-4. Classification, 683 25-5. Mode of Rupture, 684 25-6. Plane Rupture Surfaces, 684 25-7. Stability of Mass of Soil on an Inclined Plane, 684 25-8. Stability of Slopes With a Plane Rupture Surface, 686

## STABILITY OF SLOPES CONSIDERING CURVED RUPTURE SURFACES

- 25-9. General Notes, 689 25-10. Collin's Work on Landslides in Clays, 689 25-11. Circular Sliding Surface, 689 25-12. Pure Cohesive Soils. Stability En Masse—Slope Failure, 690 25-13. Tension Cracks, 693 25-14. Pure Cohesive Soils—Stability En Masse—Base Failure, 693 25-15. Stability Number, 694 25-16. Frictional-Cohesive Soils, ( $\phi$ - $c$ )-Soils—Stability En Masse—Slope Failure, 695 25-17. Pure Cohesive Soils—( $\phi$ - $c$ )-Soils—Stability Calculations by Method of Slices, 696 25-18. Example, 699 25-19. Seepage Force, 703 25-20. Seismic Forces, 705 25-21.

## CHAPTER

Friction-Circle Method, 706 25-22. Remedial Work Against Failures of Slopes, 709 25-23. Rupture of Slope Made of Frictional Soil, 710 25-24. Summary of the Circular Rupture Surface Method, 710

## PART VI SOIL EXPLORATION

## 26. SOIL EXPLORATION

26-1. Introduction, 719 26-2. Purpose of Soil Exploration, 720

## SOIL EXPLORATION METHODS

26-3. Groups, 720 26-4. Probings, 721 26-5. Auger Borings, 721 26-6. Test Trenches, Pits, Shafts, Tunnels, 722 26-7. Soil Borings, 723 26-8. Wash Borings, 723 26-9. Dry-Sample Boring, 725 26-10. Mechanical Rotary Soil Drilling Unit, 725 26-11. Soil Samplers, 726

## SOIL SAMPLES

26-12. Disturbed Soil Samples, 727 26-13. Undisturbed Soil Samples, 729 26-14. Shallow Sampling, 729 26-15. Deep Sampling, 730 26-16. Boring Log, 730 26-17. Boring Report, 731

## NEED AND IMPORTANCE OF BORINGS

26-18. Examples of the Importance of Borings, 731

## AMOUNT OF SOIL EXPLORATION

26-19. Spacing of Borings, 735 26-20. Depth of Borings, 738 26-21. Effect of the Spacing and Depth of Borings on Disclosing Soil Conditions, 740 26-22. Cost of Soil Exploration and Soil Testing, 741

## ENGINEERING SOIL SURVEY

26-23. Purpose, 742 26-24. Soil Maps, 742 26-25. Aerial Photographs, 744

## APPENDIX I

Greek Alphabet, 749  
Key to Signs and Notations, 749

## APPENDICES II and III, 759

Dynamic Viscosity Tables for Water, 760  
Dynamic Viscosity Correction Factor Tables for Water, 763

## SUBJECT INDEX, 767

## AUTHOR INDEX, 789