

Contents

Part I Soil Behavior and Dynamics

| | | |
|----------|---|----|
| 1 | Soil Behavior | 3 |
| 1.1 | Introduction | 3 |
| 1.2 | Soil Classification | 3 |
| 1.3 | Saturation, Water Table, Drainage, and Capillary Effect | 5 |
| 1.3.1 | Saturation | 5 |
| 1.3.2 | Drainage | 6 |
| 1.3.3 | Water Table | 7 |
| 1.3.4 | Capillary Effect | 8 |
| 1.4 | Effective Stress | 8 |
| 1.5 | Mohr's Circle for Describing Stress Condition | 13 |
| 1.6 | Soil Failure | 17 |
| 1.6.1 | Shear Failure for Cohesionless Soils | 18 |
| 1.6.2 | Shear Failure for Cohesive Soils | 18 |
| 1.7 | Total Stress Analysis Versus Effective Stress Analysis | 21 |
| 1.8 | Clay Soil Consistency | 22 |
| 1.9 | Testing Methods to Measure Shear Strength | 24 |
| 1.9.1 | Laboratory and Field Test Methods | 24 |
| 1.9.2 | Direct Shear Test | 24 |
| 1.9.3 | Triaxial Shear Test | 25 |
| 1.9.4 | Vane Shear Test | 29 |
| 1.9.5 | Standard Penetration Test (SPT) | 31 |
| 1.9.6 | Cone Penetration Test (CPT) | 36 |
| 1.9.7 | Other in Situ Testing Methods | 42 |
| 1.10 | Soil Stiffness and Poisson's Ratio | 42 |
| 1.11 | Consolidation | 46 |
| 1.11.1 | Introduction to Consolidation | 46 |
| 1.11.2 | Effects of Consolidation on Soil Stiffness | 47 |
| 1.11.3 | Effects of Consolidation for Shallow Foundations | 48 |

| | | |
|----------|--|------------|
| 1.11.4 | Effects of Consolidation and Aging for Deep Foundations | 50 |
| 1.12 | Obtaining Soil Parameters for Engineering Design | 53 |
| 1.13 | Allowable Stress Design and Load Resistance Factor Design | 56 |
| 1.13.1 | Allowable Stress Design | 56 |
| 1.13.2 | Load Resistance Factor Design | 56 |
| 1.13.3 | Levels of Reliability Method | 69 |
| 1.13.4 | Essential Differences Between LRFD and ASD | 70 |
| 1.13.5 | Applying Partial Safety Factors in Geotechnical Analysis | 71 |
| 1.14 | Incorporating Uncertainties of Soil Parameters | 71 |
| 1.15 | General Soil Conditions at Offshore Sites Worldwide | 73 |
| 2 | Dynamic and Cyclic Properties of Soils | 75 |
| 2.1 | Introduction | 75 |
| 2.2 | Equivalent Linear Soil Models | 78 |
| 2.2.1 | Equivalent Shear Modulus Modeling | 78 |
| 2.2.2 | Determination of G_{\max} | 82 |
| 2.2.3 | Equivalent Damping Modeling | 86 |
| 2.3 | Soil Stiffness and Damping Modeling in an Equivalent Linear Model | 89 |
| 2.3.1 | Trends in Dynamic Soil Properties and Strain Thresholds | 89 |
| 2.3.2 | Stiffness Modeling | 93 |
| 2.3.3 | Damping Modeling | 95 |
| 2.4 | Nonlinear Soil Models | 97 |
| 2.4.1 | General | 97 |
| 2.4.2 | Cyclic Nonlinear Soil Models | 98 |
| 2.4.3 | Small Strain Damping Modeling in Time-Domain Analysis | 100 |
| 2.4.4 | Nonlinear Constitutive Soil Models | 103 |
| 2.5 | Strain Rate Effects Due to Seismic Loading | 106 |
| 2.6 | Differences Between Soil Properties Subjected to Earthquake Loadings and Ocean Wave Loadings | 107 |
| 3 | Site-Response Analysis in Geotechnical Earthquake Engineering | 109 |
| 3.1 | General | 109 |
| 3.2 | Site Period | 115 |
| 3.2.1 | General | 115 |
| 3.2.2 | Influence of Soil Depth on the Site Period | 119 |
| 3.3 | Non-stationary and Peak Ground Motions | 121 |
| 3.3.1 | Peak Ground Motions and Their Relationship with Magnitude and Intensity | 121 |

| | | |
|----------|--|------------|
| 3.3.2 | Contribution of Body and Surface Wave to Ground Motions | 124 |
| 3.3.3 | Moving Resonance | 125 |
| 3.4 | Measuring Soil Amplification or De-amplification | 126 |
| 3.5 | One-Dimensional Site-Response Analysis | 126 |
| 3.5.1 | One-Dimensional Seismic Wave Propagation Analysis | 126 |
| 3.5.2 | One-Dimensional Frequency-Domain Site-Response Analysis Using Equivalent Linear Soil Model | 133 |
| 3.5.3 | One-Dimensional Site-Response Analysis Using Nonlinear Soil Models | 143 |
| 3.6 | Surface (Topographic) and Subsurface Irregularities | 146 |
| 3.6.1 | General | 146 |
| 3.6.2 | Effects of Irregular Surface Topology | 147 |
| 3.6.3 | Effects of Subsurface Irregularity | 149 |
| 3.7 | Two- and Three-Dimensional Site-Response Analyses | 151 |
| 3.7.1 | Applicability of One-, Two-, and Three-Dimensional Site-Response Analyses | 151 |
| 3.7.2 | Seismic Wave Propagation Effects | 152 |
| 3.7.3 | Site Geometric Effects | 155 |
| 3.8 | Using Site-Response Analysis Results for Seismic Analysis | 159 |
| 3.9 | Characteristics of Site Responses | 159 |
| 3.9.1 | Horizontal Ground Motions | 159 |
| 3.9.2 | Vertical Ground Motions | 161 |
| 3.10 | Vertical Ground Motion Calculations | 162 |
| 3.10.1 | Site-Response Analysis for Calculating Vertical Ground Motions | 162 |
| 3.10.2 | V/H Spectrum | 163 |
| 3.11 | Water Column Effects on Seismic Ground Motions | 165 |
| 4 | Record Selection for Performing Site-Specific Response Analysis | 167 |
| 4.1 | General | 167 |
| 4.2 | Selections of Motion Recordings | 168 |
| 4.3 | Modification of the Recordings to Fit into the Design Rock Spectrum | 169 |
| 4.3.1 | Direct Scaling | 169 |
| 4.3.2 | Spectrum/Spectral Matching | 169 |
| 4.3.3 | Pros and Cons of Direct Scaling and Spectrum Matching | 173 |
| 4.4 | Performing the Site-Response Analysis Using Modified/Matched Recordings | 174 |
| 4.5 | Sources of Ground Motion Recording Data | 175 |

| | | |
|----------|---|-----|
| 5 | Soil–Structure Interaction | 177 |
| 5.1 | Introduction | 177 |
| 5.2 | Direct and Substructure Approach | 178 |
| 5.2.1 | Direct Analysis Approach | 178 |
| 5.2.2 | Substructure Approach | 178 |
| 5.3 | Kinematic Interaction | 180 |
| 5.3.1 | Objective | 180 |
| 5.3.2 | Applications | 181 |
| 5.4 | Subgrade Impedances and Damping | 181 |
| 5.4.1 | Objective | 181 |
| 5.4.2 | Applications for Pile Foundations | 181 |
| 5.4.3 | Applications for Shallow Foundations | 182 |
| 5.5 | Inertial Interaction | 184 |
| 5.5.1 | Objective | 184 |
| 5.5.2 | Applications | 186 |
| 5.6 | Effects of Soil–Structure Interaction | 186 |
| 5.7 | Boundary Modeling in Geotechnical Analysis | 187 |
| 5.8 | Remarks on Substructure Approach | 189 |
| 6 | Seismic Testing | 191 |
| 6.1 | Introduction | 191 |
| 6.2 | Field Testing | 192 |
| 6.2.1 | General | 192 |
| 6.2.2 | Low-Strain Field Test | 192 |
| 6.2.3 | High-Strain Field Test | 210 |
| 6.3 | Laboratory Element Testing | 211 |
| 6.3.1 | Low-Strain Element Test | 211 |
| 6.3.2 | High-Strain Element Test | 217 |
| 6.4 | Model Testing | 218 |
| 6.4.1 | Shaking Table Test | 218 |
| 6.4.2 | Centrifuge Test | 224 |
| 7 | Liquefaction | 227 |
| 7.1 | Introduction to Liquefaction | 227 |
| 7.1.1 | Causes of Liquefactions | 227 |
| 7.1.2 | Liquefaction Damages | 231 |
| 7.2 | Evaluation of Liquefaction Initiation | 236 |
| 7.2.1 | Introduction | 236 |
| 7.2.2 | Cyclic Stress Approach | 237 |
| 7.2.3 | Cyclic Strain Approach | 248 |
| 7.3 | Liquefaction Mitigations | 249 |
| 8 | Slope Stability Due to Seismic Loading | 251 |
| 8.1 | General | 251 |
| 8.2 | Pseudo-Static Analysis Approach | 252 |

| | | |
|-------|--|-----|
| 8.3 | Dynamic Stress-Deformation Analysis Approach | 255 |
| 8.4 | Newmark Sliding-Block Approach | 256 |
| 8.4.1 | Rigid-Block Analysis | 257 |
| 8.4.2 | Decoupled Analysis | 259 |
| 8.4.3 | Coupled Analysis | 260 |
| 8.4.4 | Selection of Analysis Methods | 260 |
| 8.4.5 | Potential of Landslides Based on the Predicted Displacement | 261 |
| 8.5 | Testing Method | 262 |
| 8.6 | Post-Earthquake Slope Instability Assessment | 262 |
| 8.7 | Landslides | 263 |
| 8.7.1 | General | 263 |
| 8.7.2 | Assessment of Regional Landslide Potential by Arias Intensity | 264 |

Part II Offshore Structures and Earthquake Engineering

| | | |
|-----------|--|------------|
| 9 | Offshore Structures and Hydrodynamic Modeling | 269 |
| 9.1 | Introduction to Offshore Structures | 269 |
| 9.1.1 | Offshore Platforms | 269 |
| 9.1.2 | Offshore Wind Turbine Substructures and Foundations | 277 |
| 9.2 | Dynamic Design of Structures | 283 |
| 9.2.1 | Dynamics Versus Statics | 283 |
| 9.2.2 | Characteristics of Dynamic Responses | 288 |
| 9.2.3 | Frequency Range of Dynamic Loading | 294 |
| 9.3 | Difference Between Offshore and Land-Based Structures | 299 |
| 9.4 | Hydrodynamic Modeling of Offshore Structures | 302 |
| 9.4.1 | Introduction to Hydrodynamic Force Calculation | 302 |
| 9.4.2 | Effects of Drag Forces | 308 |
| 9.4.3 | Effects and Determination of Added Mass | 308 |
| 9.4.4 | Effects of Buoyancy | 310 |
| 9.4.5 | Effects and Modeling of Marine Growth | 311 |
| 10 | Representation of Seismic Ground Motions | 315 |
| 10.1 | General | 315 |
| 10.2 | Earthquake Excitations Versus Dynamic Ocean Wave, Wind, and Ice Loading | 316 |
| 10.3 | Power Spectrum of Seismic Ground Motions | 319 |
| 10.3.1 | Introduction to Fourier and Power Spectrum | 319 |
| 10.3.2 | Power Spectrum of Seismic Ground Motions | 328 |
| 10.4 | Response Spectrum | 330 |
| 10.4.1 | Background | 330 |
| 10.4.2 | Elastic Response and Design Spectrum | 332 |

| | | |
|---|--|------------|
| 10.4.3 | Ductility-Modified (Inelastic) Design Spectrum Method | 351 |
| 10.5 | Time History Method | 357 |
| 10.5.1 | General Method | 357 |
| 10.5.2 | Drift Phenomenon and Its Correction | 358 |
| 11 | Seismic Hazard Assessment | 363 |
| 11.1 | Seismic Hazard Analysis | 363 |
| 11.1.1 | Introduction | 363 |
| 11.1.2 | Deterministic Seismic Hazard Analysis (DSHA) | 365 |
| 11.1.3 | Probabilistic Seismic Hazard Analysis (PSHA) | 367 |
| 11.1.4 | Deaggregation (Disaggregation) in PSHA for Multiple Sources | 385 |
| 11.1.5 | Logic Tree Method | 390 |
| 11.2 | Seismic Hazard Map | 392 |
| 11.3 | Apply PSHA for Engineering Design | 395 |
| 11.4 | Conditional Mean Spectrum | 399 |
| 11.5 | The Neo-deterministic Approach | 405 |
| 11.6 | Forecasting “Unpredictable” Extremes | 409 |
| Part III Shallow Foundations | | |
| 12 | Bearing Capacity of Shallow Foundations | 413 |
| 12.1 | Introduction | 413 |
| 12.2 | Failure of Shallow Foundations | 415 |
| 12.3 | Bearing Capacity of Drained Soil | 421 |
| 12.3.1 | Bearing Capacity Due to General Shear Failure | 421 |
| 12.3.2 | Bearing Capacity Due to Local and Punching Shear Failure | 425 |
| 12.3.3 | Bearing Capacity for Layered Soil | 426 |
| 12.4 | Bearing Capacity for Undrained Clay | 426 |
| 12.5 | Bearing Capacity of Unliquefiable Soil Subjected to Seismic Loading | 427 |
| 12.6 | Bearing Capacity Control of Soils with Liquefaction Potential Subjected to Seismic Loading | 428 |
| 12.7 | Sliding Stability of Shallow Foundations | 430 |
| 12.8 | Effects of Cyclic Loading on Shallow Foundations | 430 |
| 12.9 | Piping Actions and Scour for Shallow Foundations | 432 |
| 13 | Modeling of Shallow Foundation Dynamics | 435 |
| 13.1 | Foundation Impedance | 435 |
| 13.2 | Combination of Damping for Foundations and Superstructures | 450 |

Part IV Pile Foundations

| | | |
|-----------|---|-----|
| 14 | Introduction to Deep Foundations | 455 |
| 15 | Capacity Control, Modeling of Pile Head Stiffness, and Mitigation Measures to Increase Pile Capacity | 465 |
| 15.1 | Capacity Control of Pile Foundations | 465 |
| 15.2 | Representation of Piles, Surrounding Soils, and Soil–Pile Interactions | 467 |
| 15.3 | Winkler Foundation Modeling | 472 |
| 15.4 | Simplified Calculation of Pile Stiffness and Natural Frequency for Pile–Structure System | 475 |
| 15.4.1 | Stiffness of Pile–Structure System | 475 |
| 15.4.2 | Pile Head Stiffness | 477 |
| 15.4.3 | Natural Frequency of Non-uniform Beams | 477 |
| 15.5 | Increasing Existing Pile Foundation Capacity for Offshore Structures | 480 |
| 16 | Lateral Force–Displacement of Piles—p-y Curve | 481 |
| 16.1 | Introduction to p - y Curve | 481 |
| 16.2 | Calculation of p_u for Clays | 486 |
| 16.3 | Calculation of p_u for Sands | 490 |
| 16.4 | Constructing p - y Curves for Clays | 491 |
| 16.5 | Constructing p - y Curves for Sands | 495 |
| 16.6 | Effects of Cyclic Loading on p - y Curves and Structural Dynamic Response | 498 |
| 16.7 | Effects of Dynamic Loading on p - y Curves | 503 |
| 16.8 | Effects of Pile Diameter on Lateral Load–Displacement Behavior | 505 |
| 16.8.1 | Introduction | 505 |
| 16.8.2 | Effects of Pile Diameter Under Sand Soil Conditions | 508 |
| 16.8.3 | Effects of Pile Diameter Under Clay Soil Conditions | 512 |
| 16.9 | Hybrid Spring Model for Modeling Piles' Lateral Force–Displacement Relationship | 518 |
| 17 | Axial Force–Displacement of Piles: t-z and Q-z Curve | 521 |
| 17.1 | Pile–Soil Modeling Under Axial Pile Loading | 521 |
| 17.2 | Axial Compression Capacity | 522 |
| 17.3 | Axial Tension Capacity | 529 |
| 17.4 | Determining Unit Friction Capacity for Cohesive Soils | 531 |
| 17.4.1 | Friction Capacity for Highly Plastic Clays by API | 531 |
| 17.4.2 | Friction Capacity for Other Types of Clays by API | 532 |

| | | |
|-----------|---|------------|
| 17.4.3 | Friction Capacity by Revised API Method (α -Method) | 533 |
| 17.4.4 | Friction Capacity for Long Piles in Clay | 533 |
| 17.4.5 | β -Method | 534 |
| 17.4.6 | λ -Method | 535 |
| 17.5 | Determining Unit Friction Capacity for Cohesionless Soils . . . | 535 |
| 17.5.1 | Unit Friction Capacity by API 1993 Method | 536 |
| 17.5.2 | Unit Friction Capacity by API 2000 Method | 537 |
| 17.6 | Modeling of Pile–Soil Friction Behavior by FEM | 538 |
| 17.7 | Modeling of t - z Curves | 539 |
| 17.8 | Determining Unit End-Bearing Capacity for Cohesive Soils . . . | 540 |
| 17.9 | Determining Unit End-Bearing Capacity for Cohesionless Soils | 541 |
| 17.10 | Modeling of Q - z Curves | 541 |
| 17.11 | Effects of Soil Layer Boundaries on End-Bearing Capacity . . . | 542 |
| 17.12 | Soil Plugging | 543 |
| 17.13 | Recently Developed CPT-Based Methods to Assess the Axial Pile–Soil Interaction Capacity | 545 |
| 17.13.1 | Skin Friction Calculation for CPT-Based Method . . . | 546 |
| 17.13.2 | End-Bearing Capacity Calculation for CPT-Based Method | 548 |
| 17.13.3 | Comments on the CPT-Based Methods | 552 |
| 17.14 | Ultimate End-Bearing Capacity from Tests | 554 |
| 17.15 | Effects of Cyclic Loading on Axial Capacity of Piles | 554 |
| 18 | Torsional Moment–Rotation Relationship | 559 |
| 18.1 | General | 559 |
| 18.2 | Behavior of Single Piles Under Torsion | 560 |
| 18.3 | Behavior of Pile Groups Under Torsion | 564 |
| 19 | Modeling, Response Calculation, and Design of Piles Under Seismic Loading | 565 |
| 19.1 | Loading of Piles During Earthquakes | 565 |
| 19.2 | Pseudo-static Approach | 568 |
| 19.2.1 | Inertia Loading on Piles | 568 |
| 19.2.2 | Kinematic Loading and Pile Response | 569 |
| 19.3 | The Location for Transferring the Earthquake Input Energy from Soils to Piles or Shallow Foundations | 576 |
| 19.4 | Simple Modeling of Pile Impedance | 577 |
| 19.5 | Determination of Pile Impedance | 579 |
| 19.6 | Kinematic and Inertia Loading Modeling in the Direct Analysis Approach | 584 |

| | | |
|-----------|---|-----|
| 20 | Scour for Pile Foundations | 589 |
| 20.1 | Introduction to Scour | 589 |
| 20.2 | Influence of Scours | 592 |
| 20.3 | Scour Modeling | 595 |
| 20.4 | Determination of Scour Depth for Single Piles and Bridge Piers | 595 |
| 20.5 | Scour Depth Influenced by Pile Groups | 597 |
| 20.6 | Influence of Scour on Pile's Capacity | 599 |
| 20.6.1 | Influence of Scour on Axial Pile Capacity | 599 |
| 20.6.2 | Influence of Scour on Lateral Pile Capacity | 600 |
| 20.6.3 | The Consideration of Scour in Pile Designs by DNV-OS-J101 | 600 |
| 21 | Effects of Pile Group, Adjacent Structures, and Construction Activities | 601 |
| 21.1 | Introduction to Pile Group | 601 |
| 21.2 | Pile Group Effects Under Axial Loading | 605 |
| 21.2.1 | General | 605 |
| 21.2.2 | Modifying Friction Resistance | 608 |
| 21.2.3 | Modifying Tip Resistance | 609 |
| 21.3 | Pile Group Effects Under Lateral Loading | 609 |
| 21.3.1 | General | 609 |
| 21.3.2 | Modifying Soil Resistance | 612 |
| 21.4 | Effects of Cyclic Loading on Pile Group Behavior | 615 |
| 21.5 | Effects of Dynamic Loading on Pile Group Behavior | 615 |
| 21.5.1 | General | 615 |
| 21.5.2 | Modifying Pile Resistance Due to Dynamic Loading | 615 |
| 21.6 | Modifying Pile Displacement to Account for Both Pile Group and Dynamic Loading Effects | 616 |
| 21.7 | Pile Cap | 618 |
| 21.8 | Influence of Adjacent Structures and Construction Activities on the Existing Piled Foundations | 619 |
| 21.8.1 | Problem Description | 619 |
| 21.8.2 | Pile–Soil Interaction Influenced by the Presence of Spudcan | 620 |
| 21.8.3 | Influence of Pile–Soil Interaction Due to Construction Activities | 622 |
| 22 | Grout Connections | 625 |
| 22.1 | Introduction | 625 |
| 22.2 | Grout Connection Capacity Control | 627 |
| 22.3 | Typical Mechanical Properties of Grout | 627 |

| | | |
|-----------|---|-----|
| 23 | Vertical Piles Versus Inclined/Battered/Raked Piles | 629 |
| 23.1 | Introduction to Inclined/Battered Piles | 629 |
| 23.2 | Seismic Performance of Pile Groups with Battered Piles | 629 |
| 23.3 | Wave- and Wind-Induced Response of Pile Group with Battered Piles | 632 |
| 24 | Negative (Downward) Friction and Upward Movement | 637 |
| 24.1 | Negative Friction | 637 |
| 24.2 | Upward Movement | 640 |
| 25 | Anchor Piles | 641 |
| 25.1 | Introduction | 641 |
| 25.2 | Behavior of Anchor Lines | 643 |
| 25.2.1 | Behavior of Anchor Lines on Seabed | 643 |
| 25.2.2 | Behavior of Buried Anchor Lines | 644 |
| 25.3 | Anchor Pile Padeye(s) | 646 |
| 25.4 | Seismic Response of Anchor Pile | 648 |
| 25.5 | Required Safety Factors for Offshore Anchor Pile Design | 648 |
| 25.6 | Fatigue Capacity Control of Anchor Line–Pile Connection | 649 |
| 25.6.1 | Method | 649 |
| 25.6.2 | Derivation of Hot-Spot Stress | 652 |
| 26 | Suction Piles/Caissons | 655 |
| 26.1 | Introduction | 655 |
| 26.2 | Suction Pile Installations | 656 |
| 26.3 | Modeling and In-place Capacity Control for Suction Piles | 658 |
| 26.4 | Modeling of Suction Piles Subjected to Seismic Loading | 661 |
| 26.5 | Advantages of Suction Piles/Caissons | 664 |
| 26.6 | Engineering Applications | 665 |
| 26.6.1 | Application for Offshore Structures | 665 |
| 26.6.2 | Application as Deep-Water Anchors | 667 |
| 26.6.3 | Application for Subsea Production Facility Foundations | 668 |
| 27 | General Design Issues for Offshore Foundations and Relevant International Codes and Guidelines | 669 |
| | Appendix | 673 |
| | References | 675 |
| | Index | 727 |

<http://www.springer.com/978-3-319-40357-1>

Soil Dynamics and Foundation Modeling
Offshore and Earthquake Engineering

Jia, J.

2018, XXIII, 740 p. 412 illus., 258 illus. in color.,
Hardcover

ISBN: 978-3-319-40357-1