# CONTENTS

Preface xxxv  
About the Authors xxvii  
List of Abbreviations xxix  

## PART I SUBSEA PRODUCTION SYSTEMS

1. **Overview of Subsea Engineering**  
   1.1. Introduction 3  
   1.2. Subsea Production Systems 6  
      1.2.1. Field Architecture 7  
      1.2.2. Distribution Systems 9  
      1.2.3. Subsea Surveys 10  
      1.2.4. Installation and Vessels 11  
      1.2.5. Cost Estimation 11  
      1.2.6. Subsea Control 12  
      1.2.7. Subsea Power Supply 12  
      1.2.8. Project Execution and Interfaces 13  
   1.3. Flow Assurance and System Engineering 13  
      1.3.1. Subsea Operations 13  
      1.3.2. Commissioning and Start-Up 15  
      1.3.3. Production Processing 16  
      1.3.4. Chemicals Injection 16  
      1.3.5. Well Testing 17  
      1.3.6. Inspection and Maintenance 18  
   1.4. Subsea Structures and Equipment 18  
      1.4.1. Subsea Manifolds 18  
      1.4.2. Pipeline Ends and In-Line Structures 19  
      1.4.3. Jumpers 19  
      1.4.4. Subsea Wellheads 20  
      1.4.5. Subsea Trees 22  
      1.4.6. Umbilical Systems 22  
      1.4.7. Production Risers 24  
   1.5. Subsea Pipelines 24  
   References 25
2. **Subsea Field Development** 27

2.1. Subsea Field Development Overview 27

2.2. Deepwater or Shallow-Water Development 29

2.3. Wet Tree and Dry Tree Systems 29

2.3.1. Wet Tree Systems 31

2.3.2. Dry Tree Systems 33

2.3.3. Systems Selection 34

2.4. Subsea Tie-Back Development 35

2.4.1. Tie-Back Field Design 35

2.4.2. Tie-Back Selection and Challenges 38

2.5. Stand-Alone Development 40

2.5.1. Comparison between the Stand-Alone and Tie-Back Developments 41

2.5.2. Classification of Stand-Alone Facilities 42

2.6. Artificial Lift Methods and Constraints 44

2.6.1. Basic Artificial Lift Methods 44

2.6.2. Gas Lift 44

2.6.3. Subsea Pressure Boosting 46

2.6.4. Electric Submersible Pump (ESP) 47

2.7. Subsea Processing 49

2.8. Template, Clustered Well System, and Daisy Chain 52

2.8.1. Satellite Well System 52

2.8.2. Template and Clustered Well System 53

2.8.3. Daisy Chain 55

2.9. Subsea Field Development Assessment 56

2.9.1. Basic Data 58

2.9.2. Water-Cut Profile 61

2.9.3. Process Simulations 61

References 61

3. **Subsea Distribution System** 63

3.1. Introduction 64

3.1.1. System Architecture 64

3.2. Design Parameters 66

3.2.1. Hydraulic System 66

3.2.2. Electrical Power System and Communication 66

3.3. SDS Component Design Requirements 67

3.3.1. Topside Umbilical Termination Assembly (TUTA) 67

3.3.2. Subsea Umbilical Termination Assembly (SUTA) 68
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.3. Umbilical Termination Head (UTH)</td>
<td>70</td>
</tr>
<tr>
<td>3.3.4. Subsea Distribution Assembly (SDA)</td>
<td>71</td>
</tr>
<tr>
<td>3.3.5. Hydraulic Distribution Manifold/Module (HDM)</td>
<td>74</td>
</tr>
<tr>
<td>3.3.6. Electrical Distribution Manifold/Module (EDM)</td>
<td>76</td>
</tr>
<tr>
<td>3.3.7. Multiple Quick Connects (MQCs)</td>
<td>77</td>
</tr>
<tr>
<td>3.3.8. Hydraulic Flying Leads and Couplers</td>
<td>78</td>
</tr>
<tr>
<td>3.3.9. Electrical Flying Leads and Connectors</td>
<td>84</td>
</tr>
<tr>
<td>3.3.10. Logic Caps</td>
<td>86</td>
</tr>
<tr>
<td>3.3.11. Subsea Accumulator Module (SAM)</td>
<td>88</td>
</tr>
<tr>
<td>References</td>
<td>90</td>
</tr>
</tbody>
</table>

4. **Subsea Surveying, Positioning, and Foundation** | 91 |

4.1. Introduction | 93 |
4.2. Subsea Survey | 93 |
4.2.1. Subsea Survey Requirements | 94 |
4.2.2. Subsea Survey Equipment Requirements | 98 |
4.2.3. Sub-Bottom Profilers | 100 |
4.2.4. Magnetometer | 102 |
4.2.5. Core and Bottom Sampler | 102 |
4.2.6. Positioning Systems | 103 |
4.3. Subsea Metrology and Positioning | 104 |
4.3.1. Transducers | 104 |
4.3.2. Calibration | 104 |
4.3.3. Water Column Parameter | 105 |
4.3.4. Acoustic Long Baseline | 106 |
4.3.5. Acoustic Short Baseline and Ultra-Short Baseline | 108 |
4.4. Subsea Soil Investigation | 110 |
4.4.1. Offshore Soil Investigation Equipment Requirements | 111 |
4.4.2. Subsea Survey Equipment Interfaces | 115 |
4.5. Subsea Foundation | 118 |
4.5.1. Pile- or Skirt-Supported Structures | 118 |
4.5.2. Seabed-Supported Structures | 118 |
4.5.3. Pile and Plate Anchor Design and Installation | 118 |
4.5.4. Geotechnical Capacity of Suction Piles | 119 |
4.5.5. Geotechnical Capacity of Plate Anchors | 121 |
4.5.6. Structural Design of Suction Piles | 123 |
4.5.7. Installation of Suction Piles, Suction Caissons, and Plate Anchors | 128 |
4.5.8. Driven Pile Anchor | 133 |
| References | 137 |
5. Installation and Vessels  

5.1. Introduction 139  
5.2. Typical Installation Vessels 140  
  5.2.1. Transportation Barges and Tug Boats 140  
  5.2.2. Drilling Vessels 141  
  5.2.3. Pipe-Laying Vessels 143  
  5.2.4. Umbilical-Laying Vessels 145  
  5.2.5. Heavy Lift Vessels 146  
  5.2.6. Offshore Support Vessels 146  
5.3. Vessel Requirements and Selection 147  
  5.3.1. Basic Requirements for Vessels and Barges 148  
  5.3.2. Functional Requirements 149  
5.4. Installation Positioning 150  
  5.4.1. Surface Positioning 151  
  5.4.2. Subsea Positioning 151  
5.5. Installation Analysis 152  
  5.5.1. Subsea Structure Installation Analysis 153  
  5.5.2. Pipeline/Riser Installation Analysis 154  
  5.5.3. Umbilical Installation Analysis 155  

References 158

6. Subsea Cost Estimation 159  

6.1. Introduction 159  
6.2. Subsea Capital Expenditures (CAPEX) 161  
6.3. Cost Estimation Methodologies 163  
  6.3.1. Cost-Capacity Estimation 164  
  6.3.2. Factored Estimation 165  
  6.3.3. Work Breakdown Structure 168  
  6.3.4. Cost Estimation Process 169  
6.4. Subsea Equipment Costs 170  
  6.4.1. Overview of Subsea Production System 170  
  6.4.2. Subsea Trees 171  
  6.4.3. Subsea Manifolds 175  
  6.4.4. Flowlines 177  
6.5. Testing and Installation Costs 179  
  6.5.1. Testing Costs 179  
  6.5.2. Installation Costs 180  
6.6. Project Management and Engineering Costs 182
6.7. Subsea Operation Expenditures (OPEX) 183
6.8. Life cycle Cost of Subsea System 183
   6.8.1. RISEX 185
   6.8.2. RAMEX 185
6.9. Case Study: Subsea System CAPEX Estimation 188
References 192

7. Subsea Control 193

7.1. Introduction 193
7.2. Types of Control Systems 195
   7.2.1. Direct Hydraulic Control System 195
   7.2.2. Piloted Hydraulic Control System 197
   7.2.3. Sequenced Hydraulic Control System 197
   7.2.4. Multiplexed Electrohydraulic Control System 199
   7.2.5. All-Electric Control System 200
7.3. Topside Equipment 202
   7.3.1. Master Control Station (MCS) 202
   7.3.2. Electrical Power Unit (EPU) 204
   7.3.3. Hydraulic Power Unit (HPU) 205
7.4. Subsea Control Module Mounting Base (SCMMB) 206
7.5. Subsea Control Module (SCM) 207
   7.5.1. SCM Components 208
   7.5.2. SCM Control Mode Description 209
7.6. Subsea Transducers/Sensors 212
   7.6.1. Pressure Transducer (PT) 213
   7.6.2. Temperature Transducer (TT) 214
   7.6.3. Pressure/Temperature Transducer (PTT) 214
   7.6.4. Sand Detector 215
7.7. High-Integrity Pressure Protection System (HIPPS) 216
7.8. Subsea Production Control System (SPCS) 218
7.9. Installation and Workover Control System (IWOCs) 222
References 224

8. Subsea Power Supply 225

8.1. Introduction 225
8.2. Electrical Power System 227
   8.2.1. Design Codes, Standards, and Specifications 228
   8.2.2. Electrical Load Calculation 228
9. Project Execution and Interfaces

9.1. Introduction

9.2. Project Execution
   9.2.1. Project Execution Plan
   9.2.2. Schedule Versions and Baseline Updates
   9.2.3. Project Organization
   9.2.4. Project Management
   9.2.5. Contracting Strategy
   9.2.6. Quality Assurance
   9.2.7. Systems Integration Manufacturing and Testing
   9.2.8. Installation
   9.2.9. Process Management
   9.2.10. HSE Management

9.3. Interfaces
   9.3.1. General
   9.3.2. Roles and Responsibilities
   9.3.3. Interface Matrix
   9.3.4. Interface Scheduling
   9.3.5. Interface Management Plan
   9.3.6. Interface Management Procedure
   9.3.7. Interface Register
   9.3.8. Internal Interface Management
   9.3.9. External Interface Management
   9.3.10. Interface Resolution
   9.3.11. Interface Deliveries

10. Subsea Risk and Reliability

10.1. Introduction
   10.1.1. Overview of Risk Management
   10.1.2. Risk in Subsea Projects
10.2. Risk Assessment
10.2.1. General
10.2.2. Assessment Parameters
10.2.3. Risk Assessment Methods
10.2.4. Risk Acceptance Criteria
10.2.5. Risk Identification
10.2.6. Risk Management Plan

10.3. Environmental Impact Assessment
10.3.1. Calculate the Volume Released
10.3.2. Estimate Final Liquid Volume
10.3.3. Determine Cleanup Costs
10.3.4. Ecological Impact Assessment

10.4. Project Risk Management
10.4.1. Risk Reduction

10.5. Reliability
10.5.1. Reliability Requirements
10.5.2. Reliability Processes
10.5.3. Proactive Reliability Techniques
10.5.4. Reliability Modeling
10.5.5. Reliability Block Diagrams (RBDs)

10.6. Fault Tree Analysis (FTA)
10.6.1. Concept
10.6.2. Timing
10.6.3. Input Data Requirements
10.6.4. Strengths and Weaknesses
10.6.5. Reliability Capability Maturity Model (RCMM) Levels
10.6.6. Reliability-Centered Design Analysis (RCDA)

10.7. Qualification to Reduce Subsea Failures

References

11. Subsea Equipment RBI
11.1. Introduction
11.2. Objective
11.3. Subsea Equipment RBI Methodology
11.3.1. General
11.3.2. Subsea RBI Inspection Management
11.3.3. Risk Acceptance Criteria
11.3.4. Subsea RBI Workflow
11.3.5. Subsea Equipment Risk Determination

References
PART II  FLOW ASSURANCE AND SYSTEM ENGINEERING

12. Subsea System Engineering  331
   12.1. Introduction  331
       12.1.1. Flow Assurance Challenges  332
       12.1.2. Flow Assurance Concerns  333
   12.2. Typical Flow Assurance Process  334
       12.2.1. Fluid Characterization and Property Assessments  334
       12.2.2. Steady-State Hydraulic and Thermal Performance Analyses  337
       12.2.3. Transient Flow Hydraulic and Thermal Performances Analyses  337
   12.3. System Design and Operability  341
       12.3.1. Well Start-Up and Shut-Down  343
       12.3.2. Flowline Blowdown  345
       References  347

13. Hydraulics  349
    13.1. Introduction  350
    13.2. Composition and Properties of Hydrocarbons  351
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.2.1.</td>
<td>Hydrocarbon Composition</td>
<td>351</td>
</tr>
<tr>
<td>13.2.2.</td>
<td>Equation of State</td>
<td>352</td>
</tr>
<tr>
<td>13.2.3.</td>
<td>Hydrocarbon Properties</td>
<td>354</td>
</tr>
<tr>
<td>13.3.</td>
<td>Emulsion</td>
<td>357</td>
</tr>
<tr>
<td>13.3.1.</td>
<td>General</td>
<td>357</td>
</tr>
<tr>
<td>13.3.2.</td>
<td>Effect of Emulsion on Viscosity</td>
<td>358</td>
</tr>
<tr>
<td>13.3.3.</td>
<td>Prevention of Emulsion</td>
<td>359</td>
</tr>
<tr>
<td>13.4.</td>
<td>Phase Behavior</td>
<td>360</td>
</tr>
<tr>
<td>13.4.1.</td>
<td>Black Oils</td>
<td>361</td>
</tr>
<tr>
<td>13.4.2.</td>
<td>Volatile Oils</td>
<td>361</td>
</tr>
<tr>
<td>13.4.3.</td>
<td>Condensate</td>
<td>361</td>
</tr>
<tr>
<td>13.4.4.</td>
<td>Wet Gases</td>
<td>362</td>
</tr>
<tr>
<td>13.4.5.</td>
<td>Dry Gases</td>
<td>362</td>
</tr>
<tr>
<td>13.4.6.</td>
<td>Computer Models</td>
<td>363</td>
</tr>
<tr>
<td>13.5.</td>
<td>Hydrocarbon Flow</td>
<td>364</td>
</tr>
<tr>
<td>13.5.1.</td>
<td>General</td>
<td>364</td>
</tr>
<tr>
<td>13.5.2.</td>
<td>Single-Phase Flow</td>
<td>365</td>
</tr>
<tr>
<td>13.5.3.</td>
<td>Multiphase Flow</td>
<td>371</td>
</tr>
<tr>
<td>13.5.4.</td>
<td>Comparison of Two-Phase Flow Correlations</td>
<td>375</td>
</tr>
<tr>
<td>13.6.</td>
<td>Slugging and Liquid Handling</td>
<td>379</td>
</tr>
<tr>
<td>13.6.1.</td>
<td>General</td>
<td>379</td>
</tr>
<tr>
<td>13.6.2.</td>
<td>Hydrodynamic Slugging</td>
<td>381</td>
</tr>
<tr>
<td>13.6.3.</td>
<td>Terrain Slugging</td>
<td>383</td>
</tr>
<tr>
<td>13.6.4.</td>
<td>Start-up and Blowdown Slugging</td>
<td>384</td>
</tr>
<tr>
<td>13.6.5.</td>
<td>Rate Change Slugging</td>
<td>384</td>
</tr>
<tr>
<td>13.6.6.</td>
<td>Pigging</td>
<td>384</td>
</tr>
<tr>
<td>13.6.7.</td>
<td>Slugging Prediction</td>
<td>385</td>
</tr>
<tr>
<td>13.6.8.</td>
<td>Parameters for Slug Characteristics</td>
<td>386</td>
</tr>
<tr>
<td>13.6.9.</td>
<td>Slug Detection and Control Systems</td>
<td>386</td>
</tr>
<tr>
<td>13.6.10.</td>
<td>Equipment Design for Slug Flow</td>
<td>387</td>
</tr>
<tr>
<td>13.6.11.</td>
<td>Slug Catcher Sizing</td>
<td>387</td>
</tr>
<tr>
<td>13.7.</td>
<td>Slug Catcher Design</td>
<td>388</td>
</tr>
<tr>
<td>13.7.1.</td>
<td>Slug Catcher Design Process</td>
<td>389</td>
</tr>
<tr>
<td>13.7.2.</td>
<td>Slug Catcher Functions</td>
<td>389</td>
</tr>
<tr>
<td>13.8.</td>
<td>Pressure Surge</td>
<td>390</td>
</tr>
<tr>
<td>13.8.1.</td>
<td>Fundamentals of Pressure Surge</td>
<td>390</td>
</tr>
<tr>
<td>13.8.2.</td>
<td>Pressure Surge Analysis</td>
<td>392</td>
</tr>
<tr>
<td>13.9.</td>
<td>Line Sizing</td>
<td>392</td>
</tr>
<tr>
<td>13.9.1.</td>
<td>Hydraulic Calculations</td>
<td>392</td>
</tr>
</tbody>
</table>
## 14. Heat Transfer and Thermal Insulation

14.1. Introduction 402
14.2. Heat Transfer Fundamentals
   14.2.1. Heat Conduction 403
   14.2.2. Convection 405
   14.2.3. Buried Pipeline Heat Transfer 409
   14.2.4. Soil Thermal Conductivity 411
14.3. U-Value
   14.3.1. Overall Heat Transfer Coefficient 412
   14.3.2. Achievable U-Values 417
   14.3.3. U-Value for Buried Pipe 417
14.4. Steady-State Heat Transfer
   14.4.1. Temperature Prediction along a Pipeline 418
   14.4.2. Steady-State Insulation Performance 420
14.5. Transient Heat Transfer
   14.5.1. Cooldown 421
   14.5.2. Transient Insulation Performance 427
14.6. Thermal Management Strategy and Insulation
   14.6.1. External Insulation Coating System 428
   14.6.2. Pipe-in-Pipe System 436
   14.6.3. Bundling 437
   14.6.4. Burial 439
   14.6.5. Direct Heating 439
   References 443
   Appendix: U-Value and Cooldown Time Calculation Sheet 445
   Properties of Ambient Surroundings 446

## 15. Hydrates

15.1. Introduction 451
15.2. Physics and Phase Behavior
   15.2.1. General 454
   15.2.2. Hydrate Formation and Dissociation 456
15.2.3. Effects of Salt, MeOH, and Gas Composition 459
15.2.4. Mechanism of Hydrate Inhibition 461

15.3. Hydrate Prevention 464
  15.3.1. Thermodynamic Inhibitors 464
  15.3.2. Low-Dosage Hydrate Inhibitors 466
  15.3.3. Low-Pressure Operation 466
  15.3.4. Water Removal 466
  15.3.5. Thermal Insulation 467
  15.3.6. Active Heating 467

15.4. Hydrate Remediation 468
  15.4.1. Depressurization 470
  15.4.2. Thermodynamic Inhibitors 471
  15.4.3. Active Heating 471
  15.4.4. Mechanical Methods 471
  15.4.5. Safety Considerations 472

15.5. Hydrate Control Design Philosophies 472
  15.5.1. Selection of Hydrate Control 472
  15.5.2. Cold Flow Technology 476
  15.5.3. Hydrate Control Design Process 477
  15.5.4. Hydrate Control Design and Operating Guidelines 477

15.6. Recovery of Thermodynamic Hydrate Inhibitors 478

16. Wax and Asphaltenes 483
16.1. Introduction 483
16.2. Wax 484
  16.2.1. General 484
  16.2.2. Pour Point Temperature 485
  16.2.3. Wax Formation 487
  16.2.4. Gel Strength 490
  16.2.5. Wax Deposition 490
  16.2.6. Wax Deposition Prediction 491
16.3. Wax Management 492
  16.3.1. General 492
  16.3.2. Thermal Insulation 493
  16.3.3. Pigging 493
  16.3.4. Inhibitor Injection 494
16.4. Wax Remediation 494
  16.4.1. Wax Remediation Methods 495
16.4.2. Assessment of Wax Problem 496
16.4.3. Wax Control Design Philosophies 496

16.5. Asphaltenes 497
16.5.1. General 497
16.5.2. Assessment of Asphaltenes Problem 498
16.5.3. Asphaltenes Formation 501
16.5.4. Asphaltenes Deposition 502

16.6. Asphaltenes Control Design Philosophies 502
References 504

17. Subsea Corrosion and Scale 505
17.1. Introduction 506
17.2. Pipeline Internal Corrosion 507
17.2.1. Sweet Corrosion: Carbon Dioxide 507
17.2.2. Sour Corrosion: Hydrogen Sulfide 518
17.2.3. Internal Coatings 519
17.2.4. Internal Corrosion Inhibitors 520
17.3. Pipeline External Corrosion 520
17.3.1. Fundamentals of Cathodic Protection 521
17.3.2. External Coatings 523
17.3.3. Cathodic Protection 524
17.3.4. Galvanic Anode System Design 528
17.4. Scales 532
17.4.1. Oil Field Scales 532
17.4.2. Operational Problems Due to Scales 536
17.4.3. Scale Management Options 537
17.4.4. Scale Inhibitors 537
17.4.5. Scale Control in Subsea Field 539
References 546

18. Erosion and Sand Management 541
18.1. Introduction 542
18.2. Erosion Mechanisms 543
18.2.1. Sand Erosion 544
18.2.2. Erosion-Corrosion 547
18.2.3. Droplet Erosion 547
18.2.4. Cavitation Erosion 548
18.3. Prediction of Sand Erosion Rate 549
PART III  SUBSEA STRUCTURES AND EQUIPMENTS

19.  Subsea Manifolds  

19.1.  Introduction  
19.1.1.  Applications of Manifolds in Subsea Production Systems  
19.1.2.  Trends in Subsea Manifold Design  

19.2.  Manifold Components  
19.2.1.  Subsea Valves  
19.2.2.  Chokes  
19.2.3.  Control System  
19.2.4.  Subsea Modules  
19.2.5.  Piping System  
19.2.6.  Templates  

References
19.3. Manifold Design and Analysis 588
  19.3.1. Steel Frame Structures Design 589
  19.3.2. Manifold Piping Design 592
  19.3.3. Pigging Loop 596
  19.3.4. Padeyes 597
  19.3.5. Control Systems 598
  19.3.6. CP Design 598
  19.3.7. Materials for HP/HT and Corrosion Coating 600
  19.3.8. Hydrate Prevention and Remediation 601
19.4. Pile and Foundation Design 604
  19.4.1. Design Methodology 607
  19.4.2. Design Loads 608
  19.4.3. Geotechnical Design Parameters 609
  19.4.4. Suction Pile Sizing—Geotechnical Design 612
  19.4.5. Suction Structural Design 615
19.5. Installation of Subsea Manifold 618
  19.5.1. Installation Capability 619
  19.5.2. Installation Equipment and Installation Methods 622
  19.5.3. Installation Analysis 628
  References 630

20. Pipeline Ends and In-Line Structures 633
  20.1. Introduction 633
    20.1.1. PLEM General Layout 635
    20.1.2. Components of PLEMs 636
  20.2. PLEM Design and Analysis 638
    20.2.1. Design Codes and Regulations 638
    20.2.2. Design Steps 638
    20.2.3. Input Data Required 639
  20.3. Design Methodology 640
    20.3.1. Structure 640
    20.3.2. Mudmat 642
    20.3.3. PLEM Installation 643
  20.4. Foundation (Mudmat) Sizing and Design 644
    20.4.1. Load Conditions 645
    20.4.2. Mudmat Analysis 645
  20.5. PLEM Installation Analysis 649
    20.5.1. Second-End PLEM 650
    20.5.2. First-End PLEMs 657
21. **Subsea Connections and Jumpers**

21.1. Introduction 664
   21.1.1. Tie-In Systems 664
   21.1.2. Jumper Configurations 668
21.2. Jumper Components and Functions 671
   21.2.1. Flexible Jumper Components 671
   21.2.2. Rigid Jumper Components 673
   21.2.3. Connector Assembly 674
   21.2.4. Jumper Pipe Spool 677
   21.2.5. Hub End Closure 678
   21.2.6. Fabrication/Testing Stands 679
21.3. Subsea Connections 682
   21.3.1. Bolted Flange 683
   21.3.2. Clamp Hub 684
   21.3.3. Collet Connector 685
   21.3.4. Dog and Window Connector 687
   21.3.5. Connector Design 687
21.4. Design and Analysis of Rigid Jumpers 689
   21.4.1. Design Loads 689
   21.4.2. Analysis Requirements 689
   21.4.3. Materials and Corrosion Protection 690
   21.4.4. Subsea Equipment Installation Tolerances 690
21.5. Design and Analysis of a Flexible Jumper 691
   21.5.1. Flexible Jumper In-Place Analysis 692
   21.5.2. Flexible Jumper Installation 697
   References 701

22. **Subsea Wellheads and Trees**

22.1. Introduction 704
22.2. Subsea Completions Overview 705
22.3. Subsea Wellhead System 705
   22.3.1. Function Requirements 706
   22.3.2. Operation Requirements 708
   22.3.3. Casing Design Program 709
22.3.4. Wellhead Components 712
22.3.5. Wellhead System Analysis 717
22.3.6. Guidance System 725

22.4. Subsea Xmas Trees 728
22.4.1. Function Requirements 728
22.4.2. Types and Configurations of Trees 728
22.4.3. Design Process 732
22.4.4. Service Conditions 734
22.4.5. Main Components of Tree 735
22.4.6. Tree-Mounted Controls 750
22.4.7. Tree Running Tools 753
22.4.8. Subsea Xmas Tree Design and Analysis 753
22.4.9. Subsea Xmas Tree Installation 757

References 761

23. ROV Intervention and Interface 763

23.1. Introduction 764
23.2. ROV Intervention 764
23.2.1. Site Survey 764
23.2.2. Drilling Assistance 765
23.2.3. Installation Assistance 766
23.2.4. Operation Assistance 767
23.2.5. Inspection 767
23.2.6. Maintenance and Repair 769

23.3. ROV System 769
23.3.1. ROV Intervention System 769
23.3.2. ROV Machine 774

23.4. ROV Interface Requirements 778
23.4.1. Stabilization Tool 779
23.4.2. Handles 780
23.4.3. Torque Tool 781
23.4.4. Hydraulic Connection Tool 783
23.4.5. Linear Override Tool 784
23.4.6. Component Change-Out Tool (CCO) 787
23.4.7. Electrical and Hydraulic Jumper Handling Tool 788

23.5. Remote-Operated Tool (ROT) 789
23.5.1. ROT Configuration 789
23.5.2. Pull-In and Connection Tool 790
## PART IV SUBSEA UMBILICAL, RISERS & FLOWLINES

### 24. Subsea Umbilical Systems

#### 24.1. Introduction

#### 24.2. Umbilical Components

- **24.2.1. General**
- **24.2.2. Electrical Cable**
- **24.2.3. Fiber Optic Cable**
- **24.2.4. Steel Tube**
- **24.2.5. Thermoplastic Hose**

#### 24.3. Umbilical Design

- **24.3.1. Static and Dynamic Umbilicals**
- **24.3.2. Design**
- **24.3.3. Manufacture**
- **24.3.4. Verification Tests**
- **24.3.5. Factory Acceptance Tests**
- **24.3.6. Power and Control Umbilicals**
- **24.3.7. IPU Umbilicals**

#### 24.4. Ancillary Equipment

- **24.4.1. General**
- **24.4.2. Umbilical Termination Assembly**
- **24.4.3. Bend Restrictor/Limiter**
- **24.4.4. Pull-In Head**
- **24.4.5. Hang-Off Device**
- **24.4.6. Bend Stiffer**
- **24.4.7. Electrical Distribution Unit (EDU)**
- **24.4.8. Weak Link**
- **24.4.9. Splice/Repair Kit**
- **24.4.10. Carousel and Reel**
- **24.4.11. Joint Box**
- **24.4.12. Buoyancy Attachments**

#### 24.5. System Integration Test

#### 24.6. Installation

- **24.6.1. Requirements for Installation Interface**
- **24.6.2. Installation Procedures**
- **24.6.3. Fatigue Damage during Installation**
24.7. Technological Challenges and Analysis 817
  24.7.1. Umbilical Technological Challenges and Solutions 817
  24.7.2. Extreme Wave Analysis 819
  24.7.3. Manufacturing Fatigue Analysis 820
  24.7.4. In-Place Fatigue Analysis 821
24.8. Umbilical Industry Experience 824
References 824

25. Drilling Risers 827
  25.1. Introduction 827
  25.2. Floating Drilling Equipment 828
    25.2.1. Completion and Workover (C/WO) Risers 828
    25.2.2. Diverter and Motion-Compensating Equipment 833
    25.2.3. Choke and Kill Lines and Drill String 834
  25.3. Key Components of Subsea Production Systems 834
    25.3.1. Subsea Wellhead Systems 834
    25.3.2. BOP 835
    25.3.3. Tree and Tubing Hanger System 836
  25.4. Riser Design Criteria 836
    25.4.1. Operability Limits 836
    25.4.2. Component Capacities 837
  25.5. Drilling Riser Analysis Model 837
    25.5.1. Drilling Riser Stack-Up Model 837
    25.5.2. Vessel Motion Data 838
    25.5.3. Environmental Conditions 838
    25.5.4. Cyclic p-y Curves for Soil 839
  25.6. Drilling Riser Analysis Methodology 839
    25.6.1. Running and Retrieve Analysis 840
    25.6.2. Operability Analysis 842
    25.6.3. Weak Point Analysis 843
    25.6.4. Drift-Off Analysis 844
    25.6.5. VIV Analysis 845
    25.6.6. Wave Fatigue Analysis 846
    25.6.7. Hang-Off Analysis 846
    25.6.8. Dual Operation Interference Analysis 847
    25.6.9. Contact Wear Analysis 848
    25.6.10. Recoil Analysis 850
References 851
26. **Subsea Production Risers** 853

26.1. **Introduction** 854
   26.1.1. Steel Catenary Risers (SCRs) 855
   26.1.2. Top Tensioned Risers (TTRs) 857
   26.1.3. Flexible Risers 858
   26.1.4. Hybrid Riser 858

26.2. **Steel Catenary Riser Systems** 860
   26.2.1. Design Data 861
   26.2.2. Steel Catenary Riser Design Analysis 864
   26.2.3. Strength and Fatigue Analysis 864
   26.2.4. Construction, Installation, and Hook-Up Considerations 865
   26.2.5. Pipe-in-Pipe (PIP) System 866
   26.2.6. Line-End Attachments 868

26.3. **Top Tensioned Riser Systems** 870
   26.3.1. Top Tensioned Riser Configurations 871
   26.3.2. Top Tensioned Riser Components 872
   26.3.3. Design Phase Analysis 873

26.4. **Flexible Risers** 874
   26.4.1. Flexible Pipe Cross Section 875
   26.4.2. Flexible Riser Design Analysis 878
   26.4.3. End Fitting and Annulus Venting Design 878
   26.4.4. Integrity Management 879

26.5. **Hybrid Risers** 882
   26.5.1. General Description 882
   26.5.2. Sizing of Hybrid Risers 885
   26.5.3. Sizing of Flexible Jumpers 886
   26.5.4. Preliminary Analysis 887
   26.5.5. Strength Analysis 887
   26.5.6. Fatigue Analysis 887
   26.5.7. Riser Hydrostatic Pressure Test 887

27. **Subsea Pipelines** 891

27.1. **Introduction** 892
27.2. **Design Stages and Process** 893
   27.2.1. Design Stages 893
   27.2.2. Design Process 894

27.3. **Subsea Pipeline FEED Design** 897
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>27.3.1</td>
<td>Subsea Pipeline Design Basis Development</td>
<td>897</td>
</tr>
<tr>
<td>27.3.2</td>
<td>Subsea Pipeline Route Selection</td>
<td>897</td>
</tr>
<tr>
<td>27.3.3</td>
<td>Steady-State Hydraulic Analysis</td>
<td>898</td>
</tr>
<tr>
<td>27.3.4</td>
<td>Pipeline Strength Analysis</td>
<td>899</td>
</tr>
<tr>
<td>27.3.5</td>
<td>Pipeline Vertical and Lateral On-Bottom Stability Assessment</td>
<td>899</td>
</tr>
<tr>
<td>27.3.6</td>
<td>Installation Method Selection and Feasibility Demonstration</td>
<td>899</td>
</tr>
<tr>
<td>27.3.7</td>
<td>Material Take-Off (MTO)</td>
<td>900</td>
</tr>
<tr>
<td>27.3.8</td>
<td>Cost Estimation</td>
<td>900</td>
</tr>
<tr>
<td>27.4</td>
<td>Subsea Pipeline Detailed Design</td>
<td>900</td>
</tr>
<tr>
<td>27.4.1</td>
<td>Pipeline Spanning Assessment</td>
<td>900</td>
</tr>
<tr>
<td>27.4.2</td>
<td>Pipeline Global Buckling Analysis</td>
<td>900</td>
</tr>
<tr>
<td>27.4.3</td>
<td>Installation Methods Selection and Feasibility Demonstration</td>
<td>901</td>
</tr>
<tr>
<td>27.4.4</td>
<td>Pipeline Quantitative Risk Assessment</td>
<td>901</td>
</tr>
<tr>
<td>27.4.5</td>
<td>Pipeline Engineering Drawings</td>
<td>901</td>
</tr>
<tr>
<td>27.5</td>
<td>Pipeline Design Analysis</td>
<td>901</td>
</tr>
<tr>
<td>27.5.1</td>
<td>Wall-Thickness Sizing</td>
<td>901</td>
</tr>
<tr>
<td>27.5.2</td>
<td>On-Bottom Stability Analysis</td>
<td>905</td>
</tr>
<tr>
<td>27.5.3</td>
<td>Free-Span Analysis</td>
<td>907</td>
</tr>
<tr>
<td>27.5.4</td>
<td>Global Buckling Analysis</td>
<td>909</td>
</tr>
<tr>
<td>27.5.5</td>
<td>Pipeline Installation</td>
<td>909</td>
</tr>
<tr>
<td>27.6</td>
<td>Challenges of HP/HT Pipelines in Deep Water</td>
<td>910</td>
</tr>
<tr>
<td>27.6.1</td>
<td>Flow Assurance</td>
<td>912</td>
</tr>
<tr>
<td>27.6.2</td>
<td>Global Buckling</td>
<td>912</td>
</tr>
<tr>
<td>27.6.3</td>
<td>Installation in Deep Water</td>
<td>913</td>
</tr>
</tbody>
</table>

**References** | | 914  |

**Index** | | 915  |