Contents

Preface xi
Definitions xiii

1 Introduction to Ageing of Structures 1
1.1 Structural Engineering and Ageing Structures 1
1.2 History of Offshore Structures Worldwide 4
1.3 Failure Statistics for Ageing Offshore Structures 8
1.3.1 Introduction 8
1.3.2 Failure Statistics of Offshore Structures 8
1.3.3 Experience from Land Based Structures 9
1.3.4 Experience from Offshore Fixed Steel Structures 10
1.3.5 Experience from the Shipping and Mobile Offshore Unit Industries 14
1.4 The Terms ‘Design Life’ and ‘Life Extension’ and the Bathtub Curve 15
1.5 Life Extension Assessment Process 18
References 20

2 Historic and Present Principles for Design, Assessment and Maintenance of Offshore Structures 23
2.1 Historic Development of Codes and Recommended Practices 23
2.1.1 US Recommended Practices and Codes 23
2.1.2 UK Department of Energy and HSE Guidance Notes 24
2.1.3 Norwegian Standards 26
2.1.4 ISO Standards 27
2.2 Current Safety Principles Applicable to Structural Integrity 28
2.2.1 Introduction 28
2.2.2 Application of Safety Principles to Structures 29
2.2.2.1 General 29
2.2.2.2 Partial Factor and Limit State Design Method 30
2.2.2.3 Robustness 32
2.2.2.4 Design Analysis Methods 34
2.2.2.5 Management of Structures in Operation 35
2.2.3 Managing Safety 35
2.2.4 Change Management 38
### Contents

3.4.5  Concrete Structures  75  
3.4.5.1  Corrosion of Steel Reinforcement  75  
3.4.5.2  Corrosion of Prestressing Tendons  77  
3.5  Fatigue  77  
3.5.1  Introduction  77  
3.5.2  Factors Influencing Fatigue  80  
3.5.3  Implications of Fatigue Damage  81  
3.5.4  Fatigue Issues with High Strength Steels  83  
3.5.5  Fatigue Research  84  
3.6  Load Changes  85  
3.6.1  Marine Growth  85  
3.6.2  Subsidence and Wave in Deck  86  
3.7  Dents, Damages, and Other Geometrical Changes  86  
3.8  Non-physical Ageing Changes  88  
3.8.1  Technological Changes (Obsolescence)  88  
3.8.2  Structural Information Changes  89  
3.8.3  Knowledge and Safety Requirement Changes  90  
References  91  

4  Assessment of Ageing and Life Extension  95  
4.1  Introduction  95  
4.1.1  Assessment Versus Design Analysis  96  
4.2  Assessment Procedures  97  
4.2.1  Introduction  97  
4.2.2  Brief Overview of ISO 19902  99  
4.2.3  Brief Overview of NORSOK N-006  101  
4.2.4  Brief Overview of API RP 2A-WSD  102  
4.2.5  Brief Overview of ISO 13822  102  
4.2.6  Discussion of These Standards  103  
4.3  Assessment of Ageing Materials  104  
4.4  Strength Analysis  107  
4.4.1  Introduction  107  
4.4.2  Strength and Capacity of Damaged Steel Structural Members  108  
4.4.2.1  Effect of Metal Loss and Wall Thinning  109  
4.4.2.2  Effect of Cracking and Removal of Part of Section  110  
4.4.2.3  Effect of Changes to Material Properties  110  
4.4.2.4  Effect of Geometric Changes  110  
4.4.2.5  Methods for Calculating the Capacity of Degraded Steel Members  110  
4.4.3  Strength and Capacity of Damaged Concrete Structural Members  111  
4.4.4  Non-Linear Analysis of Jacket of Structures (Push-Over Analysis)  113  
4.5  Fatigue Analysis and the $S$–$N$ Approach  115  
4.5.1  Introduction  115  
4.5.2  Methods for Fatigue Analysis  116  
4.5.3  $S$–$N$ Fatigue Analysis  117  
4.5.3.1  Fatigue Loads and Stresses to be Considered  117  
4.5.3.2  Fatigue Capacity Based on $S$–$N$ Curves  119
Contents

4.5.3.3 Damage Calculation  121
4.5.3.4 Safety consideration by Design Fatigue Factors  122
4.5.4 Assessment of Fatigue for Life Extension  122
4.5.4.1 Introduction  122
4.5.4.2 High Cycle/Low Stress Fatigue  123
4.5.4.3 Low Cycle/High Stress Fatigue  124
4.6 Fracture Mechanics Assessment  126
4.6.1 Introduction  126
4.6.2 Fatigue Crack Growth Analysis  128
4.6.3 Fracture Assessment  131
4.6.4 Fracture Toughness Data  132
4.6.5 Residual Stress Distribution  132
4.6.6 Application of Fracture Mechanics to Life Extension  132
4.7 Probabilistic Strength, Fatigue, and Fracture Mechanics  134
4.7.1 Introduction  134
4.7.2 Structural Reliability Analysis – Overview  135
4.7.3 Decision Making Based on Structural Reliability Analysis  136
4.7.4 Assessment of Existing Structures by Structural Reliability Analysis  138
References  139

5 Inspection and Mitigation of Ageing Structures  143
5.1 Introduction  143
5.2 Inspection  144
5.2.1 Introduction  144
5.2.2 The Inspection Process  145
5.2.3 Inspection Philosophies  147
5.2.4 Risk and Probabilistic Based Inspection Planning  148
5.2.5 Inspection of Fixed Jacket Structures  150
5.2.6 Inspection of Floating Structures  154
5.2.7 Inspection of Topside Structures  155
5.2.8 Structural Monitoring  158
5.3 Evaluation of Inspection Findings  160
5.4 Mitigation of Damaged Structures  161
5.4.1 Introduction  161
5.4.2 Mitigation of Corrosion Damage  163
5.4.3 Mitigation of the Corrosion Protection System  163
5.4.4 Mitigation of Fatigue and Other Damage  166
5.5 Performance of Repaired Structures  168
5.5.1 Introduction  168
5.5.2 Fatigue Performance of Repaired Tubular Joints  168
5.5.3 Fatigue Performance of Repaired Plated Structures  170
References  171

6 Summary and Further Thoughts  173
6.1 Ageing Structures and Life Extension  173
6.2 Further Work and Research Needs Related to Ageing Structures  174
6.3 Final Thoughts  176
A Types of Structures 177
A.1 Fixed Platforms 177
A.2 Floating Structures 177
Reference 179

B Inspection Methods 181
B.1 General Visual Inspection 181
B.2 Close Visual Inspection 181
B.3 Flooded Member Detection 181
B.4 Ultrasonic Testing 182
B.5 Eddy Current Inspection 182
B.6 Magnetic Particle Inspection 182
B.7 Alternating Current Potential Drop 182
B.8 Alternating Current Field Measurement 182
B.9 Acoustic Emission Monitoring 183
B.10 Leak Detection 183
B.11 Air Gap Monitoring 183
B.12 Strain Monitoring 183
B.13 Structural Monitoring 184

C Calculation Examples 185
C.1 Example of Closed Form Fatigue Calculation 185
C.2 Example of Application of Fracture Mechanics to Life Extension 186

Index 191