Contents

Technical Committee on Petroleum and Natural Gas Industry Pipeline Systems and Materials xxi

Executive Committee on Petroleum and Natural Gas Industry Pipeline Systems and Materials xxv

Subcommittee on Aluminum Pipeline Systems xxvi

Subcommittee on Construction xxvii

Subcommittee on Design xxix

Subcommittee on Distribution xxxi

Editorial Subcommittee xxxiii

Subcommittee on Materials xxxiv

Subcommittee on Offshore Pipelines xxxvi

Subcommittee on Operations and Systems Integrity xxxvii

Subcommittee on Production xxxix

Taskforce on Safety and Loss Management Systems xl

Preface xli

1 Scope 1

2 Reference publications 5

3 Definitions 19

4 Design 29

4.1 General 29

4.2 Design conditions 30

4.2.1 General 30

4.2.2 Temperature 30

4.2.3 Sustained force and wind loading 31

4.2.4 Other loading and dynamic effects 31

4.3 Design criteria 31

4.3.1 General 31

4.3.2 Class location assessment areas 32

4.3.3 Class location designations 32

4.3.4 Class location end boundaries 33

4.3.5 Pressure design for steel pipe — General 36

4.3.6 Pressure design for steel pipe — Design factor ($F$) 37

4.3.7 Pressure design for steel pipe — Location factor ($L$) 37

4.3.8 Pressure design for steel pipe — Joint factor ($J$) 39

4.3.9 Pressure design for steel pipe — Temperature factor ($T$) 39

4.3.10 Pressure design for steel pipe — Allowances 39

4.3.11 Pressure design for steel pipe — Wall thickness 40
4.3.12 Pressure design for components — General 42
4.3.13 Pressure design for components — Closures 42
4.3.14 Pressure design for components — Elbows 43
4.3.15 Pressure design for components — Tees and crosses 43
4.3.16 Pressure design for components — Branch connections 43
4.3.17 Pressure design for components — Integrally reinforced extruded outlet headers 43
4.3.18 Pressure design for components — Reinforcement of single openings 48
4.3.19 Pressure design for components — Reinforcement of multiple openings 50
4.4 Valve location and spacing 50
4.5 Selection and limitation of piping joints 51
4.6.1 Applicability 53
4.6.2 Stress design of restrained and unrestrained portions of pipeline systems 53
4.6.3 Discontinuity stresses 53
4.6.4 Supplemental stress design 54
4.6.5 Hoop stress 54
4.6.6 Steel properties 54
4.7 Flexibility and stress analysis — Stress design for restrained portions of pipeline systems 54
4.7.1 Combined hoop and longitudinal stresses 54
4.7.2 Combined stresses for restrained spans 55
4.7.3 Anchors and restraints 55
4.8 Flexibility and stress analysis — Stress design for unrestrained portions of pipeline systems 55
4.9 Flexibility and stress analysis — Loads on pipe-supporting elements 59
4.9.1 General 59
4.9.2 Supports and braces 59
4.10 Flexibility and stress analysis — Design of pipe-supporting elements 59
4.11 Cover and clearance 59
4.12 Crossings 61
4.12.1 General 61
4.12.2 Crossings of utilities 61
4.12.3 Crossings of roads and railways 61
4.12.4 Crossings of water 65
4.13 Requirements for pipelines in proximity to electrical transmission lines and associated facilities 65
4.13.1 General 65
4.13.2 Effects on pipelines in proximity to high-voltage DC lines 66
4.13.3 Safety requirements 66
4.14 Design of compressor stations over 750 kW and pump stations over 375 kW 66
4.14.1 General 66
4.14.2 Design of compressor stations over 750 kW 67
4.14.3 Design of pump stations over 375 kW 70
4.15 Liquid storage in oil pipeline pump stations, tank farms, and terminals 72
4.15.1 Aboveground tanks over 4000 L 72
4.15.2 Aboveground tanks of 4000 L or less 73
4.15.3 Underground tanks 73
4.15.4 Pressure spheres, bullets, and ancillary vessels 73
4.15.5 Pipe-type storage vessels 73
4.16 Gas storage in pipe-type and bottle-type holders 73
4.16.1 General 73
4.16.2 Aboveground installations 73
4.16.3 Underground installations  74
4.17 Vaults  74
4.17.1 Structural design  74
4.17.2 Location  74
4.17.3 Vault ventilation  74
4.17.4 Drainage and waterproofing  75
4.18 Pressure control and overpressure protection of piping  75
4.18.1 General  75
4.18.2 General design requirements for systems for pressure control and overpressure protection  75
4.18.3 Additional design requirements for pressure-relieving installations  76
4.18.4 Additional overpressure-protection requirements for compressor and pump stations  76
4.19 Instrument, control, and sampling piping  77
4.20 Leak detection capability  77
4.21 Odorization  78
4.22 Requirements for pipelines installed by horizontal directional drilling  78

5 Materials  79
5.1 Qualification of materials  79
5.2 Steel materials and gaskets  79
5.2.1 Design temperatures — Steel materials  79
5.2.2 Notch toughness requirements — Steel pipe  79
5.2.3 Notch toughness requirements — Steel components  83
5.2.4 Steel pipe  83
5.2.5 Steel components — General  86
5.2.6 Steel components — Flanges  86
5.2.7 Bolting  87
5.2.8 Gaskets  87
5.2.9 Steel components — Fittings  88
5.3 Other materials  88
5.3.1 Aluminum piping  88
5.3.2 Polyethylene pipe and fittings  88
5.3.3 Cast iron components  89
5.3.4 Copper and copper-based alloys  89
5.3.5 Stainless steels  90
5.3.6 Reinforced composite pipe and fittings  90
5.3.7 Nonferrous flanges  90
5.3.8 Other alloys and composites  90
5.3.9 External protective pipe coatings  90
5.4 Oilfield water service  90
5.5 Cement-mortar linings  90
5.6 Reuse of materials  90
5.7 Records of materials  91

6 Installation  91
6.1 General  91
6.2 Activities on pipeline rights-of-way  92
6.2.1 Clearing, grading, and ground disturbances  92
6.2.2 Pipe and components handling  92
6.2.3 Bends and elbows in steel piping  92
6.2.4 Alignment and welding  93
6.2.5 Protective coatings  93
6.2.6 Ditching and lowering-in  93
6.2.7 Backfilling  93
6.2.8 Internal cleaning  94
6.2.9 Clean-up and restoration  94
6.2.10 Installation of crossings  94
6.2.11 Crossing records  94
6.2.12 Horizontal directional drilling (HDD)  94
6.3 Pipe surface requirements applicable to steel piping  95
6.3.1 Pipe manufacturing defects detected during installation inspection  95
6.3.2 Field repair of gouges and grooves  95
6.3.3 Dents  95
6.3.4 Patching repair  96
6.3.5 Removal of cracks in circumferential butt welds and in fillet welds  96
6.4 Electrical test leads on pipeline systems  96
6.5 Inspection  96
6.6 Precautions to avoid the explosion of gas-air mixtures and uncontrolled fires during installation  97

7 Joining  98
7.1 General  98
7.2 Arc and gas welding — General  98
7.3 Arc and gas welding — Joint configurations  100
7.3.1 Butt welds  100
7.3.2 Fillet welds  100
7.4 Arc and gas welding — Welding equipment  107
7.5 Arc and gas welding — Materials  107
7.5.1 Pipe and components  107
7.5.2 Filler metals and fluxes  107
7.5.3 Shielding gases  108
7.6 Arc and gas welding — Qualification of welding procedure specifications  108
7.6.1 General  108
7.6.2 Company approval  108
7.6.3 Records  108
7.6.4 Welding procedure specifications  108
7.6.5 Essential changes for qualification of welding procedure specifications  111
7.7 Arc and gas welding — Testing for qualification of welding procedure specifications and qualification of welders  113
7.7.1 Welding of test joints  113
7.7.2 Testing of butt welds — General  113
7.7.3 Testing of butt welds — Tension test  118
7.7.4 Testing of butt welds — Nick-break test  118
7.7.5 Testing of butt welds — Root-bend and face-bend tests  119
7.7.6 Testing of butt welds — Side-bend test  120
7.7.7 Testing of fillet welds and branch connection welds — Root-break test  121
7.7.8 Testing of fillet welds and branch connection welds — Macrosection test  124
7.7.9 Testing of fillet welds and branch connection welds — Tension test  124
7.7.10 Additional testing of partial-penetration butt welds  124
7.8 Arc and gas welding — Qualification of welders  124
7.8.1 General  124
7.8.2 Qualification range  125
7.8.3 Special qualification — Butt welds  126
7.8.4 Visual inspection  127
7.8.5 Qualification of welders by visual and nondestructive inspection  127
7.8.6 Retests  127
7.8.7 Records of qualified welders  127
7.9 Arc and gas welding — Production welding  127
7.9.1 General  127
7.9.2 Alignment and root gap 128
7.9.3 Grounding 128
7.9.4 Use of line-up clamps — Butt welds 128
7.9.5 Relative movement 128
7.9.6 Bevelled ends 128
7.9.7 Weather conditions 128
7.9.8 Clearance 129
7.9.9 Cleaning between beads 129
7.9.10 Position welding 129
7.9.11 Roll welding 129
7.9.12 Identification of welds 129
7.9.13 Seal welding 129
7.9.14 Fillet welds 130
7.9.15 Preheating, interpass temperature control, controlled cooling, and stress relieving 130
7.9.16 Stress relieving 130
7.10 Arc and gas welding — Inspection and testing of production welds 132
7.10.1 General 132
7.10.2 Visual inspection 132
7.10.3 Mandatory nondestructive inspection 133
7.10.4 Nondestructive inspection 133
7.10.5 Destructive testing 134
7.10.6 Disposition of defective welds 134
7.11 Arc and gas welding — Standards of acceptability for nondestructive inspection 134
7.11.1 General 134
7.11.2 Weld crown 135
7.11.3 Incomplete penetration of the root bead 135
7.11.4 Incomplete fusion 136
7.11.5 Internal concavity 137
7.11.6 Undercut 137
7.11.7 Incomplete fusion due to cold lap 138
7.11.8 Lack of cross-penetration 139
7.11.9 Elongated slag inclusions 139
7.11.10 Hollow bead 140
7.11.11 Burn-through areas 140
7.11.12 Isolated slag inclusions 141
7.11.13 Spherical porosity 141
7.11.14 Wormhole porosity 142
7.11.15 Cracks and arc burns 142
7.11.16 Unequal leg length — Fillet welds 143
7.11.17 Accumulation of imperfections 143
7.11.18 Weld conditions limiting radiographic interpretation 143
7.12 Arc and gas welding — Repair of welds containing repairable defects 143
7.12.1 Partial-penetration butt welds 143
7.12.2 Authorization for repairs 143
7.12.3 Repair procedures 143
7.12.4 Removal of arc burns in weld areas 144
7.12.5 Removal of cracks in circumferential butt welds and in fillet welds 144
7.12.6 Inspection of repairs 144
7.13 Arc and gas welding — Materials and equipment for radiographic inspection 145
7.13.1 General 145
7.13.2 Radiographic procedure 145
7.13.3 Radiation sources 145
7.13.4 Imaging media 145
7.13.5 Screens 145
7.13.6 Image quality indicators 146
7.13.7 Comparator shims 146
7.14 Arc and gas welding — Production of radiographs 147
7.14.1 Radiation source location 147
7.14.2 Geometric relationship 147
7.14.3 Size of radiation field 148
7.14.4 Location of image quality indicators 148
7.14.5 Radiographic image identification markers 148
7.14.6 Processing of radiographic images 149
7.14.7 Radiation protection 149
7.14.8 Radiographers 149
7.14.9 Retention of radiographic records 149
7.15 Arc and gas welding — Ultrasonic inspection of circumferential butt welds in piping 150
7.15.1 Methods 150
7.15.2 Terminology 150
7.15.3 General 150
7.15.4 Equipment and supplies — General 150
7.15.5 Equipment and supplies — Additional requirements for mechanized inspection systems 150
7.15.6 Qualification of ultrasonic inspectors 151
7.15.7 Calibration 151
7.15.8 Inspection procedure for production welds 152
7.15.9 Inspection procedure for production welds — Additional requirements for mechanized inspection 152
7.15.10 Standards of acceptability for ultrasonic inspection 153
7.15.11 Ultrasonic inspection reports and records 153
7.16 Welding — Explosion 154
7.16.1 General 154
7.16.2 Qualification of welding procedure specifications 154
7.16.3 Qualification of welders 154
7.16.4 Production welding 155
7.17 Mechanical interference fit joints 155
7.17.1 General 155
7.17.2 Qualification of joining procedure specifications 156
7.17.3 Qualification of operators 156
7.17.4 Inspection procedures 157

8 Pressure testing 157
8.1 General 157
8.2 Strength and leak tests for piping intended to be operated at pressures greater than 700 kPa 158
8.3 Strength and leak tests for piping intended to be operated at pressures of 700 kPa or less 158
8.4 Pressure-test mediums for piping intended to be operated at pressures greater than 700 kPa 158
8.5 Pressure-test mediums for piping intended to be operated at pressures of 700 kPa or less 160
8.6 Minimum strength and leak test pressures for piping intended to be operated at pressures greater than 700 kPa 161
8.7 Minimum strength and leak test pressures for piping intended to be operated at pressures of 700 kPa or less 161
8.8 Maximum strength test pressures 161
8.9 Maximum leak test pressures 161
8.10 Duration of tests 162
8.11 Leaks and ruptures 162
8.11.1 Leaks 162
8.11.2 Ruptures 162
8.11.3 Investigations 162
8.12 Gaseous-medium testing of crossings 162
8.13 Testing of fabricated items 163
8.14 Tie-ins 163
8.14.1 Testing after installation 163
8.14.2 Inspection 163
8.15 Maximum operating pressures 163
8.15.1 Piping intended to be operated at pressures greater than 700 kPa 163
8.15.2 Piping intended to be operated at pressures of 700 kPa or less 164
8.16 Pressure-test measurements and records 164
8.16.1 General 164
8.16.2 Piping intended to be operated at pressures greater than 700 kPa 164
8.16.3 Piping intended to be operated at pressures of 700 kPa or less 164
8.17 Safety during pressure tests 165
8.18 Disposal of pressure-test mediums 165
8.19 Test-head assemblies 165
8.20 Testing procedures and techniques 167

9 Corrosion control 168
9.1 General 168
9.2 Selection of external protective coatings for buried or submerged piping 171
9.3 Application and inspection of external protective coatings for buried or submerged piping 172
9.4 Storage, handling, transportation, and installation of coated pipe and components 173
9.5 Cathodic protection — Design and installation 173
9.6 Electrical isolation 174
9.7 Electrical interference 174
9.7.1 Direct current 174
9.7.2 Alternating current and lightning 174
9.8 Corrosion-control test stations 174
9.9 Operation and maintenance of impressed current and sacrificial cathodic protection systems 175
9.10 Internal corrosion control 176
9.10.1 General 176
9.10.2 Mitigation 177
9.10.3 Monitoring 177
9.11 Corrosion-control records 177

10 Operating, maintenance, and upgrading 177
10.1 General 177
10.2 Safety and loss management system 177
10.3 Operating and maintenance procedures 178
10.3.1 General 178
10.3.2 Pipeline emergencies 179
10.3.3 Failure investigations 179
10.3.4 Communication facilities 179
10.3.5 Environmental effects 179
10.3.6 Leak detection for liquid hydrocarbon pipeline systems 180
10.3.7 Leak detection for gas pipeline systems 180
10.3.8 Leak detection for oilfield water pipeline systems 181
10.3.9 Pipeline identification 181
10.3.10 Signs at stations and other facilities 182
10.3.11 Ground disturbance 183
10.4 Records 183
10.4.1 General 183
10.4.2 Pipeline systems 183
10.4.3 Pipeline emergency records 184
10.4.4 Leaks and breaks 184
10.4.5 Pressure-test records 184
10.5 Safety 184
10.5.1 Training programs 184
10.5.2 Employee information 184
10.5.3 Supervisor responsibility 185
10.5.4 Hazards 185
10.5.5 Security 185
10.5.6 Work sites 185
10.5.7 Firefighting and special equipment 185
10.5.8 In-service pipelines 185
10.5.9 Smoking and open flames 185
10.5.10 Additional precautions for pipeline systems transporting high-vapour-pressure hydrocarbons 186
10.5.11 Fluids containing H₂S 186
10.5.12 Carbon dioxide pipelines 186
10.6 Right-of-way inspection and maintenance 187
10.6.1 Pipeline patrolling 187
10.6.2 Vegetation control 187
10.6.3 Exposed facilities 187
10.6.4 Crossings 187
10.7 Operation and maintenance of facilities and equipment 188
10.7.1 Compressor and pump stations 188
10.7.2 Aboveground tanks and pressure vessels 188
10.7.3 Underground storage 189
10.7.4 Pipe-type and bottle-type gas holders and pipe-type storage vessels 190
10.7.5 Pressure-control, pressure-limiting, and pressure-relieving systems 190
10.7.6 Valves 191
10.7.7 Vaults 191
10.8 Change of class location and crossings of existing pipelines 192
10.8.1 Change of class location 192
10.8.2 Crossings of existing pipelines 192
10.9 Evaluation of imperfections 193
10.9.1 General 193
10.9.2 Corrosion imperfections in pipe 193
10.9.3 Gouges, grooves, and arc burns in pipe 196
10.9.4 Dents in pipe 196
10.9.5 Pipe body surface cracks 196
10.9.6 Weld imperfections in field circumferential welds 197
10.9.7 Weld imperfections in mill seam welds and mill circumferential welds 197
10.10 Permanent repair methods 197
10.10.1 General 197
10.10.2 Grinding repairs 198
10.10.3 Piping replacements 199
10.10.4 Repair sleeves 199
10.10.5 Defect removal by hot tapping 202
10.10.6 Direct deposition welding 202
10.11 Temporary repair methods 202
10.11.1 General 202
10.11.2 Fibreglass sleeves 206
10.12 Maintenance welding 206
10.12.1 General 206
10.12.2 In-service piping 206
10.12.3 In-service piping — Fillet welding and branch connection welding on liquid-filled piping or flowing-gas piping and direct deposition welds on flowing-gas piping 207
10.12.4 In-service piping — Face-bend testing of fillet welds and branch connection welds 208
10.12.5 In-service piping — Macroexamination and hardness testing of fillet welds and branch connection welds 208
10.12.6 In-service piping — Qualification of welding procedure specifications and welders for direct deposition welds 210
10.12.7 In-service piping — Nondestructive inspection of fillet welds and direct deposition welds 212
10.13 Pipeline hot taps 214
10.13.1 General 214
10.13.2 Pipe preparation 214
10.13.3 Welding and hot tapping considerations 214
10.14 Integrity of pipeline systems 215
10.14.1 General 215
10.14.2 Integrity of existing pipeline systems 215
10.14.3 Change in service fluid 216
10.14.4 Upgrading to a higher maximum operating pressure 216
10.14.5 Pressure testing existing piping 217
10.14.6 Engineering assessments 217
10.15 Odorization 218
10.16 Deactivation and reactivation of piping 219
10.16.1 Deactivation of piping 219
10.16.2 Reactivation of piping 219
10.17 Abandonment of piping 219

11 Offshore steel pipelines 220
11.1 Applicability 220
11.2 Design — General 220
11.3 Design information 221
11.3.1 Pipeline route 221
11.3.2 Route survey and data acquisition 224
11.3.3 Pipeline operating conditions 225
11.4 Design and load conditions 225
11.5 Functional loads 226
11.6 Environmental loads 227
11.6.1 General 227
11.6.2 Wind forces 227
11.6.3 Hydrodynamic loads — General 227
11.6.4 Wave-induced and current-induced hydrodynamic loads 227
11.6.5 Loads due to ice conditions and regional ice features 228
11.6.6 Seismic activity 229
11.6.7 Loads arising from marine growth 229
11.6.8 Indirect environmental loads 229
11.6.9 Accidental loads 229
11.7 Design analysis 230
11.8 Design for mechanical strength 230
11.8.1 Design criteria for installation 230
11.8.2 Design criteria for pressure testing 231
11.8.3 Design criteria for operation 231
11.8.4 Determination of stresses 232
11.8.5 Pipe wall thickness specification 233
11.8.6 Strain-based design 233
11.8.7 Strain-based design criteria 234
11.9 Design for thermal expansion 235
11.10 Design for on-bottom stability 235
11.11 Design for fatigue life 236
11.12 Design for free spans, anchoring, and supports 236
11.13 Design for shore approaches 236
11.14 Design for components 236
11.15 Design for crossings 237
11.16 Pipeline components and fabrication details 237
11.16.1 General 237
11.16.2 Supports, braces, anchors, and buckle arresters 237
11.16.3 Mechanical connectors 237
11.16.4 Welded branch connections and reinforcements 237
11.16.5 Reducers 238
11.16.6 Weight-coating 238
11.16.7 Thermal insulation 239
11.17 Pipeline pressure control 239
11.18 Leak detection 239
11.19 Emergency shutdown valve 239
11.20 Materials 240
11.20.1 General 240
11.20.2 Pipe 240
11.20.3 Fittings, flanges, and valves 240
11.21 Installation 241
11.21.1 General 241
11.21.2 Transportation, handling, and storage of materials 241
11.21.3 Ancillary equipment and specialty items 241
11.21.4 Installation procedures 241
11.21.5 Installation inspection 242
11.21.6 Repair of pipe and components prior to installation 242
11.21.7 Repair of pipelines after installation 243
11.21.8 As-built surveys 243
11.21.9 Commissioning 243
11.22 Welding 243
11.22.1 General 243
11.22.2 Qualification of welding procedures 243
11.22.3 Testing of welded joints — Pipe butt welds 244
11.22.4 Production welding 244
11.22.5 Underwater welding 244
11.23 Mechanical connectors 245
11.24 Pressure testing 245
11.24.1 General 245
11.24.2 Testing of mechanical connector assemblies 245
11.24.3 Test pressure 245
11.24.4 Pressure-test medium 246
11.24.5 Safety during pressure tests 246
11.24.6 Pressure-test records 246
11.25 Corrosion-control 246
11.25.1 General 246
11.25.2 External corrosion-control — Protective coatings 246
11.25.3 External corrosion-control — Cathodic protection systems 247
11.25.4 Internal corrosion-control 247
11.25.5 Maintenance of cathodic protection systems 247
11.25.6 Records 248
11.26 Operating and maintenance 248
11.26.1 General 248
11.26.2 Manual of operating procedures 248
11.26.3 Contingency manual 249
11.26.4 Communication systems 249
11.26.5 Inspection and patrolling of pipelines 249
11.26.6 Leak detection 250
11.26.7 Valves 250
11.26.8 Control and safety devices 250
11.26.9 Safety 250
11.26.10 Repair of pipelines 251
11.26.11 Records 251
11.26.12 Pipeline deactivation and reactivation 251

12 Gas distribution systems 251
12.1 General 251
12.2 Applicability 251
12.3 Gas containing hydrogen sulphide 251
12.4 Design 252
12.4.1 Steel piping 252
12.4.2 Polyethylene piping — Design pressure 254
12.4.3 Polyethylene piping — Design limitations 254
12.4.4 Polyethylene piping — Design pressure of components 255
12.4.5 Other metallic piping materials 255
12.4.6 Other nonmetallic piping and tubing 255
12.4.7 Cover and clearance 256
12.4.8 Pipelines within road and railway rights-of-way 256
12.4.9 Limitations on operating pressure — General 257
12.4.10 Limitations on operating pressure — Piping within customers’ buildings 257
12.4.11 Pressure control and overpressure protection 258
12.4.12 Distribution system valves — General 259
12.4.13 Distribution system valves — Valve location and spacing 259
12.4.14 Distribution system valves — Service shutoffs 260
12.4.15 Customers’ meters and service regulators 261
12.4.16 Distribution systems within buildings 262
12.4.17 Liquefied petroleum gas (LPG) pipeline systems 262
12.5 Materials 263
12.5.1 Steel pipe, tubing, and components 263
12.5.2 Polyethylene pipe, tubing, and components 263
12.5.3 Cast iron pipe and valves 263
12.5.4 Continuous length reinforced thermoplastic pipe and fittings 263
12.6 Installation 263
12.6.1 General 263
12.6.2 Steel piping 264
12.6.3 Polyethylene piping — General 264
12.6.4 Polyethylene piping — Inspection and handling 264
12.6.5 Polyethylene piping — Direct burial 265
12.6.6 Polyethylene piping — Insertion in casing 265
12.6.7 Polyethylene piping — Bends and branches 265
12.6.8 Cast iron piping 266
12.6.9 Copper piping 266
12.6.10 Installation of service lines — Drainage 266
12.6.11 Installation of service lines into or under buildings 266
12.6.12 Installation of service lines — Additional installation requirements for polyethylene service lines 267
12.6.13 Trenchless installations 267
12.7 Joining 268
12.7.1 General 268
12.7.2 Steel pipe joints and connections — Essential changes for qualification of welding procedure specifications 268
12.7.3 Steel pipe joints and connections — Qualification of welders 268
12.7.4 Steel pipe joints and connections — Inspection of field welds 271
12.7.5 Steel pipe joints and connections — Inspection of tie-in welds 271
12.7.6 Steel pipe joints and connections — Steel pipe joints within buildings 271
12.7.7 Polyethylene pipe joints and connections — General 272
12.7.8 Polyethylene pipe joints and connections — Joining by heat fusion 272
12.7.9 Polyethylene pipe joints and connections — Joining by electrofusion 272
12.7.10 Polyethylene pipe joints and connections — Joining by mechanical methods 273
12.7.11 Cast iron pipe joints 273
12.7.12 Joints in copper pipe and tubing 273
12.7.13 Service line connections 274
12.8 Pressure testing 275
12.8.1 Piping in distribution systems intended to be operated at pressures in excess of 700 kPa 275
12.8.2 Piping within customers’ buildings 275
12.8.3 Polyethylene piping 276
12.8.4 Test-head assemblies 276
12.9 Corrosion-control 276
12.9.1 Steel piping 276
12.9.2 Cast iron piping 276
12.9.3 Copper piping 277
12.9.4 Visual inspection 277
12.10 Operating, maintenance, and upgrading 277
12.10.1 Marking of piping 277
12.10.2 Distribution system maintenance 277
12.10.3 Pressure recording for distribution systems 278
12.10.4 Valve maintenance 278
12.10.5 Pressure-control, pressure-limiting, and pressure-relieving devices 278
12.10.6 Repair procedures for steel distribution pipeline systems 278
12.10.7 Maintenance welding 279
12.10.8 Additional maintenance and repair requirements for polyethylene piping — Squeezing of polyethylene pipe for pressure-control purposes 279
12.10.9 Maintenance and repair requirements for polyethylene piping and polyvinyl chloride piping and tubing 279
12.10.10 Static electricity dissipation 280
12.10.11 Pressure upgrading of distribution piping 280
12.10.12 Operating and maintenance procedures for cast iron piping 281
12.10.13 Integrity of pipeline systems 281
12.10.14 Pipeline emergencies 281
12.10.15 Ground disturbances 281

13 Reinforced composite, thermoplastic-lined, and polyethylene pipelines 282
13.1 Reinforced composite pipelines 282
13.1.1 General 282
13.1.2 Design 282
13.1.3 Materials 285
13.1.4 Installation 285
13.1.5 Joining 286
13.1.6 Pressure testing 287
13.1.7 Operation 288
13.1.8 Pipeline repairs 289
13.2 Thermoplastic-lined pipelines 289
13.2.1 General 289
13.2.2 Design 289
13.2.3 Materials 291
13.2.4 Installation 292
13.2.5 Joining liners 292
13.2.6 Flange connections 292
13.2.7 Pressure testing 293
13.2.8 Operation and maintenance 293
13.3 Polyethylene pipelines for gas gathering, multiphase, LVP, and oilfield water services 294
13.3.1 General 294
13.3.2 Design 294
13.3.3 Materials 298
13.3.4 Installation 298
13.3.5 Joining 299
13.3.6 Heat fusion joining inspection and test plan 300
13.3.7 Pressure testing 301
13.3.8 Operation and maintenance 302

14 Oilfield steam distribution pipelines 302
14.1 General 302
14.2 Design 303
14.2.1 General 303
14.2.2 Straight pipe under internal pressure 303
14.2.3 Pipe bends 304
14.2.4 Limits of calculated stresses due to sustained loads and displacement strains 304
14.2.5 Expansion, flexibility, and support 304
14.2.6 Corrosion and erosion allowances 305
14.2.7 Wall thickness tolerance 305
14.3 Materials 305
14.3.1 General 305
14.3.2 Material testing 306
14.3.3 Pipe 306
14.3.4 Fittings other than bends 306
14.3.5 Flanges 307
14.3.6 Valves 307
14.3.7 Transition pieces 307
14.3.8 Pipe bends — General 308
14.3.9 Pipe bends — Qualification and production 308
14.3.10 Piping supports 308
14.4 Joining 309
14.5 Pressure testing 309
14.5.1 General 309
14.5.2 Aboveground pipelines 309
14.5.3 Underground pipelines 310
14.6 Corrosion-control 310
14.7 Commissioning and operation 311

15 Aluminum piping 311
15.1 General 311
15.2 Applicability 311
15.3 Design 312
15.3.1 Pressure design for aluminum pipe 312
15.3.2 Pressure design for components 314
15.3.3 Piping joints 314
15.3.4 Aluminum properties 314
15.3.5 Uncased railway crossings 315
15.3.6 Effects on pipelines in proximity to low-voltage alternating current lines and associated facilities 315
15.4 Materials 315
15.4.1 Design temperatures 315
15.4.2 Notch toughness 316
15.4.3 Aluminum pipe and components 316
15.5 Installation of aluminum piping 316
15.5.1 Bends and elbows 316
15.5.2 Attachment of test leads 316
15.5.3 Storage and handling of aluminum pipe and fittings during installation 316
15.5.4 Ambient temperature 317
15.5.5 Burial of coiled aluminum pipe by ploughing 317
15.5.6 Plain dents 317
15.6 Joining 318
15.6.1 General 318
15.6.2 Arc welding 318
15.6.3 High energy joining — General 318
15.6.4 High energy joining — Qualification of joining procedure specifications 318
15.6.5 High energy joining — Qualification of personnel 319
15.6.6 High energy joining — Inspection and testing of high energy joints for qualification of joining procedure specifications and personnel 319
15.6.7 High energy joining — Production welding 319
15.6.8 High energy joining — Inspection and testing of high energy joints 320
15.6.9 Mechanical interference fit joints 320
15.7 Pressure testing 320
15.8 Corrosion control 321
15.8.1 Test lead attachment 321
15.8.2 Installation of cathodic protection systems 321
15.8.3 Corrosive medium 321
15.9 Operating, maintenance, and upgrading 321
15.9.1 Evaluation of imperfections and repair of piping containing defects 321
15.9.2 Maintenance welding 322
15.9.3 Pipeline hot taps 322
15.10 Sour service 323
15.10.1 General 323
15.10.2 Material properties 323
15.10.3 Exposure to iron sulphides 323
15.10.4 Location factor 323
15.10.5 Sectionalizing valves 323
15.10.6 Nondestructive inspection 323
15.10.7 Integrity management 323
15.10.8 Construction 323
15.10.9 Operating and maintenance 323
15.10.10 Records 323

16 Sour service pipelines 324
16.1 General 324
16.2 Sour service — Specific definition 324
16.3 Design 324
16.3.1 Location factor for steel pipe 324
16.3.2 Design parameters 324
16.3.3 Design information 324
16.3.4 Design considerations 325
16.3.5 Stress design 325
16.3.6 Anchors and restraints 325
16.3.7 Sectionalizing valves 325
16.3.8 Partial-penetration welds 325
16.3.9 Threaded joints 325
16.3.10 Mechanical interference fit joints 325
16.3.11 Pipe-type and bottle-type holders and pipe-type storage vessels 325
16.4 Materials 326
16.4.1 Environmental cracking 326
16.4.2 Material provisions 326
16.4.3 Marking 326
16.4.4 Nonferrous materials 326
16.5 Construction 327
16.5.1 Deviations 327
16.5.2 Records 327
16.5.3 Inspection plan 327
16.6 Joining 327
16.6.1 Carbon equivalent 327
16.6.2 Change in carbon equivalent 327
16.6.3 Butt welds of unequal thickness 327
16.6.4 Weld hardness requirements 327
16.6.5 Deposited weld metal composition limitations 328
16.6.6 Alignment 328
16.6.7 Preheat 328
16.6.8 Mandatory nondestructive inspection 328
16.6.9 Standards of acceptability for nondestructive inspection 328
16.6.10 Backwelding 328
16.6.11 Welding — Explosion 329
16.7 Corrosion and corrosion-control 329
16.7.1 Supplemental mitigation requirements 329
16.7.2 Mitigation and monitoring program 329
16.7.3 Start-up corrosion mitigation 329
16.7.4 Design and sizing of pigs 329
16.8 Operation and maintenance 329
16.8.1 Procedures 329
16.8.2 Records 329
16.8.3 Repair methods 329
16.8.4 Hydrogen charging 330
16.8.5 Direct deposition welding 330
16.8.6 Change management process 330
16.8.7 Changes in service conditions 330
16.8.8 Pipeline integrity management program 330

17 Composite-reinforced non-sour service steel pipelines 330
17.1 General 330
17.2 Applicability 330
17.3 Specific definitions 330
17.4 Design 331
17.4.1 Stress distribution 331
17.4.2 Maximum operating pressure 331
17.4.3 Design pressure 331
17.4.4 External pressures and loadings 332
17.4.5 Stress limits 332
17.4.6 Design temperature 332
17.4.7 Engineering assessment 333
17.5 Materials and manufacture 333
17.5.1 Steel pipe 333
17.5.2 Fibre-reinforced composite 333
17.5.3 Composite-reinforced steel pipe manufacture 334
17.6 Installation 335
17.6.1 Field bending 335
17.6.2 Damage 335
17.6.3 Crossings 335
17.7 Joining 336
17.7.1 General 336
17.7.2 Joint reinforcement 336
17.7.3 Transitions to steel pipe 336
17.7.4 Qualification of joining procedure specifications 336
17.8 Pressure testing 336
17.9 Corrosion control 336
17.10 Operation and maintenance 337

Annexes
A (informative) — Safety and loss management system 340
B (informative) — Guidelines for risk assessment of pipelines 348
C (informative) — Limit states design 356
D (informative) — Guidelines for in-line inspection of piping for corrosion imperfections 385
E (informative) — Recommended practice for liquid hydrocarbon pipeline system leak detection 388
F (informative) — Slurry pipeline systems 393
G (informative) — Precautions to avoid explosions of gas-air mixtures 396
H (informative) — Pipeline risk dictionary 398
I (informative) — Oilfield steam distribution pipelines — Alternate provisions 428
J (informative) — Recommended practice for determining the acceptability of imperfections in fusion
welds using engineering critical assessment 432
K (informative) — Standards of acceptability for circumferential pipe butt welds based upon fracture
mechanics principles 434
L (informative) — Alternate or supplementary test methods for coating property and characteristics
evaluation 448
M (informative) — Gas distribution system integrity management guidelines 450
N (informative) — Guidelines for pipeline integrity management programs 458
O (informative) — Reliability-based design and assessment of onshore non-sour natural gas transmission
pipelines 468

Tables
4.1 — Class location designations 33
4.2 — Location factor for steel pipe 38
4.3 — Joint factor for steel pipe 39
4.4 — Temperature factor for steel pipe 39
4.5 — Least nominal wall thickness for steel carrier pipe 41
4.6 — Design of welded branch connections 45
4.7 — Valve spacing, km 51
4.8 — Flexibility and stress intensification factors 57
4.9 — Cover and clearance 60
4.10 — Least nominal wall thickness for steel casing pipe in cased crossings and carrier pipe in uncased
crossings 62
4.11 — Maximum pipe diameter to wall thickness (D/t) ratio for uncased railway crossings 64
5.1 — Pipe body notch toughness for steel pipe 80
5.2 — Pipe threshold stress values 82
5.3 — Limitations for pipe and components 84
5.4 — Cement-mortar lining thickness tolerances 90
7.1 — Equivalent ASME S-1 group numbers for welding procedures for piping materials 99
7.2 — Compliance factor (F) — Carbon equivalent formula 109
7.3 — Essential changes for qualification of welding procedure specifications 111
7.4 — Type and number of test specimens for butt welds 114
7.5 — Number of root-break or macrosection test specimens for fillet welds and branch connection welds 121
7.6 — Outside crown height 135
7.7 — Maximum acceptable amount of spherical porosity 141
7.8 — Image quality indicator selection criteria for X-ray radiography 146
7.9 — Image quality indicator selection criteria for gamma radiography 147
8.1 — Test requirements for steel piping intended to be operated at pressures greater than 700 kPa 160
9.1 — Selection of external coating systems 169
10.1 — Limitations on acceptable permanent repair methods 203
10.2 — Number of face-bend test specimens 208
10.3 — Number of test specimens for qualification of procedures and welders for direct deposition welding 211
11.1 — Design factors 234
12.1 — Temperature factor for polyethylene pipe and tubing 254
12.2 — Cover and clearance 257
12.3 — Essential changes for qualification of welding procedure specifications 269
12.4 — Leak test pressure within buildings 275
13.1 — Reinforced composite pipes 284
13.2 — Material classification and minimum property values 296
13.3 — Service fluid factor (F) 297
13.4 — Design temperature factor (T) 297
14.1 — Minimum nominal wall thickness of threaded pipe nipples 307
15.1 — Circumferential joint factor 313
15.2 — Temperature factor 313
15.3 — Alloy factor 314
15.4 — Linear coefficient of thermal expansion and modulus of elasticity 315
15.5 — Limitations for acceptable pipe and components 316
15.6 — Minimum bend radius 317
17.1 — Visual acceptance criteria for fibre-reinforced composite 337
17.2 — Damage severity and repair guidelines for fibre-reinforced composite 339

**Figures**

1.1 — Scope diagram — Oil industry pipeline systems 3
1.2 — Scope diagram — Gas industry pipeline systems 4
4.1 — Class location end boundaries, determined by dwelling-unit density 35
4.2 — Integrally reinforced extruded outlet headers 46
4.3 — Details for openings with complete encirclement types of reinforcement 47
4.4 — Reinforcement of branch connections 49
7.1 — End preparations and acceptable combinations of end preparations 101
7.2 — Buttwelding details between items having unequal thickness 102
7.3 — Fillet weld details 104
7.4 — Welding details of opening with localized type of reinforcement 105
7.5 — Welding details for branch-to-run pipe connection 106
7.6 — Location of test specimens for butt welds 115
7.7 — Tension test specimen 116
7.8 — Nick-break test specimen 116
7.9 — Root-bend or face-bend test specimen 117
7.10 — Side-bend test specimen 117
7.11 — Permissible dimensions for slag inclusions in the fracture surfaces of nick-break test specimens
7.12 — Jig for guided-bend tests
7.13 — Location of root-break or macrosection test specimens for fillet welds and branch connection welds
7.14 — Root-break or macrosection test specimens
7.15 — Incomplete penetration of the root bead
7.16 — Incomplete fusion
7.17 — Internal concavity
7.18 — Comparator shim
7.19 — Incomplete fusion due to cold lap
7.20 — Lack of cross-penetration
7.21 — Hollow bead
7.22 — Spherical porosity
10.1 — Method of deriving the longitudinal length of corrosion
10.2 — Location of test specimens
10.3 — Face-bend test specimen
10.4 — Test specimens for direct deposition welding
11.1 — Scope diagram
11.2 — Subsea completion to platform and platform to shore (typical arrangement)
11.3 — Landward jetty system and offshore loading/unloading system (typical arrangement)
11.4 — Artificial island (typical arrangement)
11.5 — Single-point mooring system (typical arrangement)
12.1 — Scope diagram
13.1 — Typical reinforced composite to steel transition
13.2 — Typical flange configuration for pipe liner